Quality timber products of

TEAK from sustainable forest management

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The Kerala Forest Research Institute (KFRI) is one of the six institutions under the Kerala State Council for Science, Technology and Environment (KSCSTE) of the Government of Kerala, established in 1975. By conducting time-bound multidisciplinary applied research in thrust areas of tropical forestry, KFRI has created a niche among the leading forest research organizations in the tropics. The Institute undertakes multidisciplinary research on all aspects of tropical forestry including wood science and technology, wildlife biology and socio-economics under the Programme Divisions. KFRI has a Sub-Centre at Nilambur and a Field Station at Veluppadam for carrying out nursery and plantation trials, germplasm collection, etc. KFRI has the largest collection of bamboo and rattn species in India for research and conservation purpose. Also at Nilambur, there is a Teak Museum, the only one of its kind, devoted to a single tree species in the world; it is open to public, researchers, forest officials and others interested in teak.

International Tropical Timber Organization

The International Tropical Timber Organization (ITTO) is an intergovernmental organization which brings together countries that produce and consume tropical timber to discuss and exchange information and develop policies on all aspects of the world tropical timber economy. The ITTO is headquartered in Yokohama, Japan and in July 2001 had 57 members, including the European Community, which together represent 95 per cent of world trade in tropical timber and 75 per cent of the world's tropical forests. The ITTO recognizes that a continuing supply of tropical timber on the world market depends on quality information about the trade and market place, on efficient timber production and processing methods and on sustainable forest management practices

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Report on the Conference

FOREWORD

Teak has been recognized for centuries as a king among timbers due to its durability, workability, attractiveness and strength. It is not surprising, therefore, that teak plantations are being established in many countries in the tropics. Yet sometimes these plantations are being established with insufficient information about how to achieve best results on particular sites, and about the markets into which their products will ultimately be sold. The risk is that some teak-growers will not receive an adequate return on their investment, to the detriment of economic development and sustainable forest management.

International Tropical Timber Organization (ITTO) is committed to promoting the conservation and sustainable management, use and trade of tropical forest resources. Sustainable timber production depends on good forest management, efficient timber processing and quality information about the trade and market place. In December 2003 ITTO teamed up with the Kerala Forest Research Institute to organise a very important international conference – *Quality timber products of teak from sustainable forest management* – in Peechi, India. This conference stimulated considerable interest; it was attended by 175 delegates representing the world's most important teak growers, users and consumers. It is certain that the outcome of the conference, as laid out in this book, will pave the way for a more coordinated and ultimately a more successful approach to the production and marketing of teak. It presents some of the best available scientific information on teak silviculture and utilization and proposing strategies for promoting quality teak products in the global market. It is to be hoped that the *Kerala Call for Action*, a statement issued by the conference, will help to ensure the sustainable development of the global teak sector.

Yokohama
18 March 2005

Manoel Sobral Filho
Executive Director
International Tropical Timber Organization
(ITTO)

PREFACE

Teak is widely planted throughout the tropics although its natural distribution is limited to India, Mynmar, Lalos and Thailand. Kerala State in India has the unique distinction of establishing the world's first teak plantation in 1842 in Nilambur. Though quite a few conferences on teak have been organized in the past, considering the changed scenario in tropical forestry due to imbalance in supply and demand of timber, there is an increasing awareness on quality of timber and sustainability. With the financial support of International Tropical Timber Organization (ITTO), the Kerala Forest Research Institute (KFRI), hosted an international conference on - *Quality Timber Products of Teak from Sustainable Forest Management (SFM)* in Peechi, Kerala, India, during 2-5 December, 2003. The conference was organized in collaboration with the International Union of Forest Research Organizations (IUFRO 5.06.02 Working Party) to address the following critical issues:

- Does teak maintain superiority in timber quality when grown in high input short rotation plantations with silviculturally and genetically modified trees?
- What is the potential of teak for sustainable forest management (SFM) to meet the environmental, economic and cultural criteria in the tropics?
- What is the role of teak plantations in the livelihood of rural communities and poverty alleviation in promoting the tropical timber trade?
- Is teak amenable, under socially acceptable conditions, to advanced technology of production and further processing for better marketability with certification and labelled products?

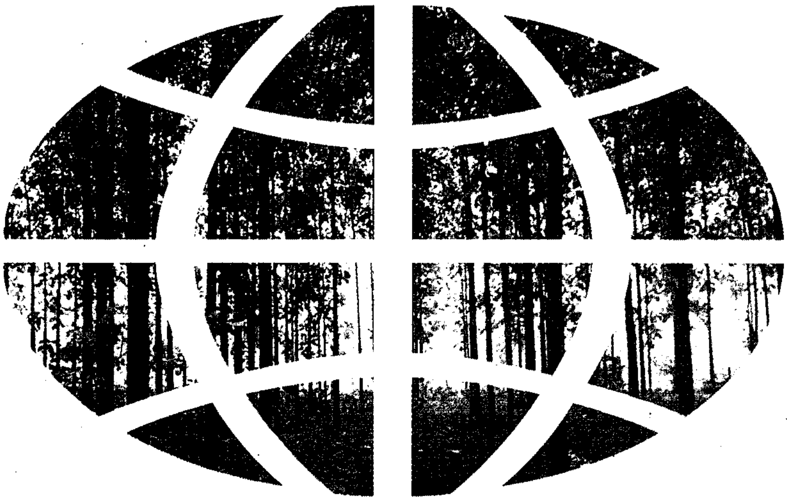
The Conference, attended by 175 participants from 24 countries, provided an excellent global forum for researchers, foresters, industrialists, farmers and NGOs to deliberate on various issues to address their needs. This Proceedings consists of 68 oral and 31 poster papers presented during the conference. The subject matter is organised under ten headings, viz. *Status of Teak in Producer Countries, Sustainable Forest Management with Reference to Teak, Quality Timber Products of Teak from Sustainable Forest Management, Genetic Aspects of Teak Wood Production, Clonal Propagation and Genetic Improvement, Health of Cultivated Teak, Growth, Wood Formation and Productivity, Economics of Teak Plantations and Policy Issues, Teak Timber Trade and Wood Industry and Investment, Institutions and Networking.* Some of the specific aspects of SFM dealt with in this volume include : wood forming, further processing, value-added products, recycling, carbon balancing, land degradation, biodiversity, certification and labelled products, poverty alleviation, community participation and networking.

I gratefully acknowledge the untiring efforts of Drs. K. M. Bhat, K. K. N. Nair, K.V. Bhat and E. M. Muralidharan in bringing out this proceedings. I am hopeful that this publication will serve as an invaluable reference document for plantation teak under SFM in the context of tropical timber development programme as well as in soliciting response to the KERALA CALL FOR ACTION. I take this opportunity to express my sincere thanks to all participants, contributors and sponsors for extending full cooperation and support without which, it would not have been possible to bring out this proceedings.

3 March 2005

Dr. J. K. Sharma
Director, KFRI

Status of Teak in Producer Countries



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Teak in India: Status, Prospects and Perspectives

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ABSTRACT

Teak is a celebrated timber of the tropics and India is one of the major teak growing and utilizing countries in the world. Domestication through plantations for one and a half centuries has made teak the most widely planted and researched tropical hardwood species. Significant developments have taken place in standardizing plantation techniques, perfecting harvesting and post-harvest utilization methods and tree improvement. In spite of these efforts, teak resources of the world need immediate attention for their sustainable management. The ecological and economic aspects of raising teak in monoculture have to be considered for long-term management of supply of timber and the soils in which they are grown. Whilst bottlenecks in tree improvement and seed production have to be removed through increased basic research, the potential of frontier areas like biotechnology must also be used for rapid improvement of this plantation species.

Keywords: Teak, sustainable management, improvement, productivity, conservation.

INTRODUCTION

Teak (*Tectona grandis* L.f.) is one of the most favoured timber all over the world, since it has been used for many centuries for a range of products and services. It is known for its strength, durability and main-taining attractive appearance. Obviously, it constitutes highclass furniture and is one of the most sought after hardwoods in the international market. The ever increasing need for teak timber has resulted in large scale plantations, both within and outside its range of natural distribution. Teak is a species of significant ecological and socio-economic importance throughout the tropics.

Teak occurs in natural forests between 9° to 26° N latitude and 73° to 104° E longitude, which includes southern and central India, Myanmar, Laos People's Democratic Republic and northern Thailand (White, 1991). Teak has been introduced in South-East Asia, Indonesia, Sri Lanka, Vietnam, Malaysia and the Soloman Islands as well as in Africa and Latin America. Teak was introduced to Java (Indonesia) 400-600 years ago and in Sri Lanka in 1680. Teak planting in India began during the 1840s. In 1902, teak was first introduced outside Asia, in Nigeria (Horne, 1966). Teak introductions in other countries of Africa included Ivory Coast, Nigeria, and Ghana. Teak plantations in tropical America were first established in Trinidad and Tobago in 1913 (Keogh, 1979). It was also introduced in Costa Rica and Brazil. Globally, area under teak plantations in 1990 was 2.2 million hectares (FAO, 1995), with 94 per cent in Tropical Asia, major area being in India and Indonesia. Other countries of the region which plant teak are Thailand, Myanmar, Bangladesh, and Sri Lanka. About 4.5 per cent of teak plantations are in tropical Africa (Ivory Coast, Nigeria, Sierra Leone, Tanzania and Togo) and the rest are in tropical America.

TEAK: GLOBAL SCENARIO

Growth and productivity

Teak grows well in regions having deep, flat and well-drained alluvial soils rich in calcium, a mean annual temperature of 22-27°C and annual precipitation of 1,200-2,500 mm, with a marked dry season of three to five months and a maximum of 50 mm of rain during the period. Dry site conditions are usually associated with stunted growth. Highly moist condition may be conducive for faster growth, but with more sapwood, lower average density, yellowish colour, poor texture and inadequate strength.

In Asia, teak is grown in rotations of 60 years or more while in tropical America plantations are harvested at 20 to 30 years. Teak trees grown in plantations on good soils may reach an average of 60 cm diameter at breast height (dbh), and 30 m in height in about 50 years. The largest standing teak tree is in the Baw Forest Reserve of Myanmar measuring 2.4 m in diameter, and 46 m tall. The earliest yield table for teak was prepared by von Wulfing (1932) for plantations in Java (Indonesia). Laurie and Ram (1940) constructed a yield table for teak plantations in India. Teak yield tables indicate the early peak of mean annual volume increments between 6 and 20 years. High mean annual increments of above 20 m^3 ha^{-1} $year^{-1}$ is reported from Indonesia, Trinidad and Tobago (Pandey and Brown, 2000). In Indonesia, the average actual MAI at harvest age, with rotation varying between 40 and 90 years, was 2.91 m^3 per hectare per year (FAO, 1986). Konni forest in Kerala, India, averaged 172 m^3 ha^{-1} with a 70- years rotation, giving an MAI of about 2.46 m^3 ha^{-1} year-1 (FAO, 1985). The mean annual increment of teak plantations in rotations of 40 to 50 years, in Benin and Ivory Coast, was between 8 and 11 m^3 ha^{-1} $year^{-1}$ (Pandey and Brown, 2000).

GLOBAL DEMAND AND SUPPLY SITUATION

The estimated global production of tropical hardwood logs in 1998 was around 123 million m^3 (ITTO, 1998). Indonesia is the largest round wood producer in the world, followed by Myanmar. Myanmar and Ivory Coast dominate the export trade in teak logs, while China and Thailand are the largest importers. The largest manufacturers of teak products are Indonesia, Thailand and India. Most of the sawn timber produced in India is consumed in the domestic market. India also imports teak wood. The worldwide demand for teak is much greater than the available resources (Dupuy, 1990).

Teak plantations are being established because supplies from natural forests have dwindled. Teak constituted 90 per cent of area under quality tropical hardwood plantations in 1980 (Granger, 1988). The total area under teak plantations in 1995 was about 2.2 million ha which rose to 3 million ha in 1997 (Centeno, 1997). The net increase in the plantation area since 1990 has been marginal and most plantings are believed to be replantings, following harvesting (Ball *et al.*, 1999). The demand for high quality wood will continue to grow, despite gains made in engineered timber and other low cost substitutes (Earhart, 1999), thus making it increasingly difficult to supply teak wood on a sustainable basis, either from natural forests or from plantations. The International Tropical Timber Organization defines Sustainable Forest Management (SFM) as the process of managing forest to achieve specified objectives of management with regard to the production of a continuous flow of desired forest products and services without undue reduction of its inherent values, future productivity and without undesirable effects on the physical and social environment. Restrictions on logging trees in one area can have adverse effects elsewhere (Binkley, 1997). To meet the global timber requirements in the context of reduced output from natural forests due to the practice of sustainable forest management, establishement of large areas of quality tropical hardwood plantations is essential.

INTERNATIONAL NETWORKING INITIATIVES

The long rotation period of teak has made commercial investments for large scale plantations unattractive. In order to promote plantations of teak in the context of sustainable forest management, new strategies have to be devised (Keogh, 2000).

Carbon credits for teak plantations

It has been estimated that an area of 2.4 million ha under a species like teak would have the potential to accumulate 240 million tonnes of carbon. Hardcastle (1999) reports that the payments for carbon would be significant in terms of costs of establishment, if annual payments were capitalized in return for dedicating land to timber plantation in addition to providing sustainable material for high-energy substitutes like steel and aluminium. Thus, environmental benefits of growing teak must be factored into costing and provision made for annual cash flow. Other strategies suggested include, incorporation of teak in agroforestry systems, enabling conditions for capital investments, provision of soft loans and subsidies, and allocating proportions of tax revenues for growing quality hardwoods.

Teaknet

This network was established in 1995 with the objective of strengthening interaction among all those concerned with conservation and sustainable management of teak-bearing forests and plantations through sharing of information and promoting collaborative efforts to deal with common problems. TEAKNET comprises of institutes, both in private and public sectors, and individuals involved in managing natural teak forests and plantations, undertaking research and studies on teak and/or involved in processing and trade of teak products.

Teak 2000

The Consortium Support Model (CSM) developed under the title TEAK 2000 is a system which supports (in the areas of finance, management, information, communications, genetics, processing, marketing and quality control) groups (consortia) of growers to enable them to produce more and better quality timber, using best practices. The CSM provides a 'seed-to-sawdust' approach. TEAK 2000 was launched in October 1996, in the Royal Tropical Institute, Amsterdam. The aim is to develop sufficient areas of quality tropical hardwood plantations to supply a substantial level of high grade timber on a sustained basis while, offsetting pressure on natural forests. To ensure this both plantation and natural forest undertakings are developed in a balanced manner, alliances between the CSM and entities working in natural forests must be strengthened.

IUFRO Unit 5.06.02 formed in 1997, aims to promote all teak research programmes, with special emphasis on identification of superior planting stock/ reproductive material from different provenances and genetically improved strains, developing models for intensive silvicultural and genetic improvement techniques and characterization of market standardization of juvenile wood produced in intensively managed plantations. Utilization of juvenile or sap wood available from thinning of teak plantations and establishment of grading or quality standards for improved market-value of small dimensional teak timber is considered to be of immediate priority for formulation and co-ordination of the international cooperative projects.

TEAK IN INDIA

Extent and diversity of natural teak forests

Teak has a wide but discontinuous distribution in India. It grows in the dry and moist deciduous forests below 24° N latitude in the States of Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Chattisgarh, Madhya Pradesh, Rajasthan, Uttar Pradesh, Manipur and Orissa. There are nearly 8.9 million hectares of teak-bearing forests in India (Tewari, 1992), within the precipitation range of 800 to 2500 mm. It grows well from sea level to an elevation of 1200 metres. Five subtypes of teak are recognized viz. very dry, dry, semi-moist, moist and very moist (Seth and Khan, 1958). It shows poor growth in dry localities and thrives best in moist, warm, tropical climate. The growth rate is high in deep alluvial soil with optimum calcium and phosphorus and a pH 6.5 (Kulkarni, 1951). Clay and laterite soils are unsuitable and it does not tolerate water logging.

In India, traders and timber users recognise several varieties of teak suitable for different end uses. Teak varies greatly in timber characteristics such as colour, grain and texture. Teak from the Western Ghats region in Kerala and Karnataka States is preferred for structural needs like shipbuilding and construction. In this region of high rainfall (2000-3000 mm), teak attains huge sizes suitable for the above uses. On the other hand, teak from Central Indian region, known for colour, texture and grains is preferred for furmiture and other aesthetic needs. In Seoni, Kanker and parts of Bastar in Madhya Pradesh/Chattisgarh, the timber is golden yellow in colour with the heartwood blending into the sapwood. In Khariar Division of the same State, teak timber is known to have good decorative grains. Teak timber of Chandrapur is well known in Indian market for its colour and texture. Teak wood of Godavari valley in Andhra Pradesh is highly priced for furniture and cabinet making due to its ornamental figuring. Teak timber from Rajulmadugu of Adilabad Division of Andhra Pradesh has pink coloured heartwood, making it highly valuable. Teak timber and poles are classified differently in various States depending upon their utilization. In Kerala, timber as poles are classified based on length and girth relationships, which also determines the market value.

Teak plantations: Extent, practices and productivity

The first teak plantation in India was established in 1846 at Nilambur, Kerala. Presently, 1.5 million ha of teak plantations exist in India and around 50,000 ha of teak plantations are raised annually (Subramanian *et al.*, 2000). Silvicultural practices like site matching, spacing, thinning methods, rotation age and harvesting have been refined, yet the productivity of plantations is low and is declining steadily in successive rotations. The first attempt to identify the most appropriate seed source for a given planting region was the All India Teak Seed Origin Sample Plots experiment conducted during 1934-36. Systematic teak improvement programmes started with the submission of a report by Mathews (1961) to the Government of India. Kedharnath and Mathews (1962) formulated a programme for the genetic improvement of teak. Following this, teak improvement activities gained momentum in all the teak growing States. During the past four decades, considerable progress has been made in improving the planting stock of teak (Table 2).

The rotation period of teak plantations in India differs according to the site conditions, environmental factors and management. The dry teak plantations of Madhya Pradesh have 80 years rotation, 50 to 60 years in Kerala and 40 years for plantations of Maharashtra Forest Development Corporation. In Kerala, teak plantations cover about 50 per cent of the total man made forests, of which 32 per cent are of site quality II and above, while the rest are of quality III and IV (George, 1961). Teak plantations are raised in Nilambur, Wynad, Ranni, Konni, Chalakudy, Trichur and Palghat areas. The MAI of the Nilambur teak plantations ranges from 0.97 to 5.64 m3 ha^{-1} $year^{-1.}$ The average productivity is 2.85 m^3 ha^{-1} $year^{-1}$ in 53 years rotation period. The thinning schedule is practiced at ages 6,8,13,19,28 and 41. Recent studies conducted on teak growing in farmlands with irrigation, fertilizer application and management revealed the possibility of

Table 1. Total yield and MAI for specific ages and different site quality classes

Age	Item	Yield in different site quality classes (m^3 ha^{-1})						
		I	I/II	II	II/III	III	III/IV	IV
20	Total yield	229.6	212.37	184.73	151.14	119.65	78.019	55.63
	MAI	11.27	10.64	9.24	7.56	6.02	3.92	2.80
50	Total yield	499.95	427.88	354.41	280.24	220.41	156.74	107.76
	MAI	10.01	8.54	7.07	5.60	4.41	3.15	2.17
51	Total yield	506.67	434.04	359.73	284.65	223.56	158.70	109.30
	MAI	9.95	8.49	7.04	5.58	4.38	3.12	2.16
53	Total yield	520.10	446.35	370.36	293.46	229.86	162.62	112.38
	MAI	9.84	8.41	6.98	5.56	4.32	3.06	2.13
55	Total yield	533.54	458.67	381.00	302.28	236.16	166.53	115.45
	MAI	9.73	8.33	6.93	5.53	4.27	3.01	2.10
56	Total yield	539.23	464.20	386.18	306.90	239.66	168.98	116.92
	MAI	9.66	8.28	6.90	5.51	4.25	3.01	2.09
58	Total yield	550.75	475.25	396.53	316.14	246.65	173.88	119.86
	MAI	9.52	8.20	6.84	5.49	4.23	3.01	2.06
60	Total yield	562.23	486.31	406.89	325.37	253.65	178.78	122.80
	MAI	9.38	8.12	6.79	5.46	4.20	3.01	2.03
65	Total yield	588.47	510.80	429.28	347.41	273.24	191.02	131.90
	MAI	9.03	7.84	6.58	5.32	4.20	2.94	2.03

Table 2. Plus trees, SPAs and CSOs in India

States	Number of plus trees	SPA (ha)	CSO (ha)	Extent of area 000s(ha)
Andamans	—	—	—	10
Andhra Pradesh	40	811	92	105
Arunachal Pradesh	3	—	25	—
Assam	—	64	—	37
Gujrat	4	100	—	122
Karnataka	45	464	120	137
Kerala	10	1337	35	75
Madhya Pradesh	7	1360	240	148
Maharashtra	29	749	450	276
Mizoram	—	20	—	—
Orissa	73	217	30	73
Tamil Nadu	19	53	30	20
Tripura	—	—	—	75
Uttar Pradesh	14	10	—	—
West Bengal	2	—	—	—
Total	**246**	**5185**	**1022**	**1078**

reducing the rotation period to 25 years with increase in productivity. Laurie and Sant Ram (1940) prepared the All India Teak Tables using sample plots of India and Myanmar, and later Sowani and Gadkari (1977) prepared a revised version of these tables for Indian teak. The productivity of teak in different site qualitites reported in All India Yield and Standard Volume Table and the total yields and MAI for different age and site quality classes are given in Table 1.

Planting and thinning

Stump planting is the common practice in India and it is planted at 2 x 2 m spacing. Two mechanical and three silvicultural thinnings are performed by the Forest Departments and Forest Development Corporations. The interval of thinning cycle is at ages of 5,10,15, 20, 30 for 60 year rotation in Kerala and at ages 5, 8, 16, 20 for 40 year rotation in Maharastra. After final thinning, 150 to170 trees per hectare are maintained. Pruning of side branches is a common practice in young plantations to improve the value of the basel timber.

Irrigation

Irrigation in teak plantations is followed in farmlands. The irrigated canal bank plantations in Tanjore,Tamil Nadu (Kondas, 1998) and protected irrigation in Maharastra (Gogate *et al.*, 1995) increased growth rate. It is necessary to standardize the irrigation frequencies in teak plantations to enhance productivity and to reduce rotation period without affecting the quality of the wood.

Wood quality as influenced by age and site

Farmers and commercial organisations are increasingly raising teak in high input plantations. There is concern on the quality of wood produced from such fast grown short rotation plantations. Bhat and Indira (1997) and Bhat (1999) observed that faster growth obtained in 5-year-old teak trees with application of fertilizers resulted in 8 per cent increase in wood specific gravity. Teak responds to fertilizer application and cultural operations only in the initial years (Balagopalan *et al.*, 1998), and not in older plantations. Thus much of the growth related changes in wood traits in early age might be absent in later years when juvenile wood gives way to the comparatively stable mature wood. There is only 5 per cent increase in wood density in 50-year-old trees compared to 8-year-old trees of the same location (Bhat *et al.*, 1995). Physical and chemical properties of soil influence to a great extent tree growth and cell characteristics (Bhat *et al.*, 1995). Edaphic and climatic factors may impact wood quality more than cultural operations. High positive correlation exists between girth and heartwood content. Faster growth in plantations may increase the heartwood content though with a lighter colour. Wood density and heartwood content are seen to be higher in lower latitudes of Peninsular India (Varghese *et al.*, 2000). Site factors influence the wood properties and the radial growth. Teak wood is stable across different populations and locations, as wood density and cell dimensions are not altered. The coefficient of variation for wood density in samples tested across nine populations from Peninsular India was only 6.2 per cent. In contrast there was a high coefficient of variation of 18.1 per cent for tree girth, which resulted in a high variation of 27.3 per cent in heartwood content. Better growth seen in moist climates in southern latitudes associated with wood characteristics. Latitude influences on wood density considerably. Differences in radial growth within a population are the main factor that causes variability in wood traits. Proper selections based on ecotype and family information leading to selection of high yielding clones would be an answer to quality wood production with uniform heartwood content. Density variation may be low in a population (Bhat, 1995). But selection when focussed on radial growth would serve to enhance the heartwood content.

Teak in corporate forestry

In India, forest development corporations have taken up planting and sale of teak as a commercial activity. During the last decade, many private companies ventured to raise teak plantations with investments raised from public. A staggering number of (around 3600) companies offered schemes for investing in teak plantations (Aiyar, 1998). The investors were promised huge returns from teak trees with gestation period of 20 years and returns ranging from Rs.50000 to Rs. 100000 for an investment of Rs.500 to Rs. 2500 (Kinhal, 1995). There is no reliable estimate of total investments made in such programmes or the area covered under the planting programmes. The claims of investment companies have been questioned by several reports (Krishnamurthi, 1991; Chaturvedi, 1995; Kinhal, 1995; Parameswarappa, 1995; Rawat, 1995; Gangopadhyay, 1997). Many companies could not withstand the scrutiny and folded in the late nineties. Economic offences wing have initiated proceedings to retrieve the investments. However, there are favourable reports for some programmes that are capable of paying the promised returns (Mehta, 1995). Productivity of plantations has to be enhanced to meet the growing demand and to reduce imports. India also has large areas as degraded forests/wastelands part of which can profitably be used for teak cultivation. Teak planting activity also provides employment opportunities. Unsuccessful early attempts have created negative impact on commercial tree cultivation in India. Nevertheless, there is tremendous opportunity to commercialize teak cultivation through forest development corporations with guidance of research institutions using combination of quality seeds, nursery techniques and selecting good sites.

The major technical reasons that affected the commercial teak plantations are choice of unsuitable sites for teak cultivation and unrealistic projection of timber production. Troup (1921) observed, "the importance of careful selection of sites for teak plantations has not always been fully realized" which is still common. Most of plantations by private enterprises were located in unsuitable sites for teak, especially for the high productivity promised from such plantations. Teak needs deep, well-drained and fertile soils with an optimum pH of 6.5 to 7.5. Soils can be ameliorated with appropriate cultural practices to improve teak growth (Krishnapillay, 2000). Although India has vast areas of degraded forest-lands, making them available to private enterprises may not be possible with the existing Government regulations on forest areas and their utilization. But there are large tracts of fallow lands not used for agriculture due to shortage of water. With good monsoon and efficient management of rain and ground water, such areas can profitably be put to teak cultivation. Cost of land and initial infrastructure must be subsidized through carbon credits.

The returns from teak plantations in terms of timber production and its value were subjected to severe criticisms in the past. An unrealistic MAI of more than 1 to 3 m/tree^{-1} was claimed at a stocking of around 1000 trees ha^{-1}. This works out to be an MAI of 50 m^3 ha^{-1} year^{-1}, which is several times higher than the current rates ranging from 2-10 m^3 ha^{-1} year^{-1} in 50 year rotation. Assuming an average of 5 m^3 ha^{-1} year^{-1} in a 20 year rotation, the production would be 100 m^3 in a hectare (with a stocking of 200 stems ha^{-1}). In other words 0.5 m^3 per tree in 20 years, which is realistic and comparable to yield obtained from high input plantations of Malaysia in 15 years (Krishnapillay, 2000). The price of teak logs increased by 970 per cent from 1975 to 1990 (Balooni, 2000). With a conservative estimate of doubling of current prices (around Rs.30,000) by 2020, the returns from one hectare would be around Rs. 6 million. Commercial teak cultivation is profitable provided all necessary inputs are properly taken care of and the programmes monitored effectively.

Plantation targets and planting stock requirements

The annual planting target in India is 50,000 hectares Teak seeds collected from clonal seed orchards (CSO) and seed production areas (SPA) are used for raising plantations. Several clonal seed orchards of teak have been established in Maharastra, Madhya Pradesh, Tamil Nadu, Andhra Pradesh, Kerala and Karnataka. Seed production in CSO is low indicating that the existing CSO and SPA can not meet the demand of planting target. In India, most of the teak plantations are raised through seeds from unselected source, which leads to low productivity.

The recommendations of Kedharnath and Mathews (1962) have been the basis for teak improvement in the country. This has paved way for developing of seed production areas and clonal seed orchards. More than 5000 ha of seed production areas, 1000 ha of clonal seed orchards have been established in addition to identifying 250 plus trees in teak growing States (Table 2). The results of the progeny trials established in different States revealed high variations within and between families. At five years of age, traits like height, girth and collar diameter show high heritability values with good correlations (Nagarajan *et al.*, 1996).

STATUS OF RESEARCH AND DEVELOPMENT

Teak is one of the most researched tropical hardwoods. Almost the entire century that followed the first planting of teak was spent on perfecting the technique of raising teak as plantations. The thrust was to make them successful in terms of silviculture and profitability. Choice of site, nursery, spacing, weeding, thinning schedules and fixing rotation ages were dominating the research agenda during the early years. As a result, teak is one of the most easily raised trees in plantations of the tropics. The cultural practices have been developed in such a way that the cost of raising plantations is usually obtained through the many thinnings carried out during the rotation time. Apart from silvicultural aspects considerable research was done on standardizing germination of teak seeds and to obtain uniform planting stock. Although some of these areas are researched, the foundation was firmly laid in the early years.

EARLY DOMESTICATION EFFORTS

Selection of seed source

The 'All India Coordinated Seed Source Trials' were a pioneering effort in understanding provenance variation in teak for improving productivity of teak plantations through deploying the most suitable provenance (Mathauda, 1954). However the inadequate number of provenances represented in these trials made it inconclusive. The initiative from IUFRO/Danish Seed Centre developed into international coordinated provenance trials in 1972.

Recognition of subtypes

Notable efforts in recognizing the natural variation in Indian teak was the classification of teak bearing forests into five subtypes viz. very moist, moist, semi-moist, dry and very dry (Seth and Khan, 1958). The classification was based on rainfall and edaphic factors, in agreement with geographic distribution of different types of teak. This classification was used while organizing seed collections for the IUFRO international teak provenance trials. Results from these trials indicate that the classification can be used for genecological zonation of Indian teak forests. There are other reported varieties of teak which local people recognised based on morphological traits. Certain populations and individuals of teak in southern Tamil Nadu, Kerala and Karnataka were reported to escape from defoliator (*Hyblea puera*) attack by flushing earlier than normal growing season (Nair *et al.*, 1989). Some patches in Karnataka were known as *'teli'* variety of teak, purported to be resistant to the defoliator attack. Similar teak was observed in the Kalakkad region in Tamil Nadu (Kaushik, 1956; Rajasingh, 1960).

ORGANIZED TEAK IMPROVEMENT

Seed Production Area (SPA)

The first step towards improving the genetic quality of the seed is setting apart a few excellent plots as Seed Stands (SS) or Seed Production Areas (SPA) which are in broad sense interim seed orchards. Such SPAs are highly relevant for long rotation crops like teak since they assure immediate availability of adequate quantities of seeds at modest cost. Over 5000 ha of SPAs are established in the country (Mandal *et al.*, 1997; Emmanuel and Misra, 1998; Sekaran *et al.*, 1999). SPAs have been developed by converting plantations with higher percentage of trees with desirable characteristics and culling the trees with undesirable traits. The extent of yield increase through such approach may not be more than 5-8 per cent.

International provenance trials

India took part in the IUFRO-DANIDA Forest Seed Centre (DFSC) coordinated international series of teak provenance trials (Keiding *et al.*, 1986). India supplied 30 provenance seedlots of teak from different recogni-sed subtypes. DFSC classified these provenances as moist West coast (Tamil nadu, Kerala and Karnataka), semi-moist East coast (Andhra Pradesh and Orissa) and dry interior (Andhra Pradesh, Maharashtra and Madhya Pradesh). Forty-eight trials were established in both natural and exotic regions of teak. Of these, 21 trials were assessed at the age of 7-9 years and 8 at 17 years of age.

The lone trial in India was established at Maredumilli (Lat. 17.36 N; Long. 81.43 E; Elev. 500 m; Annual rainfall: 1470 mm) in Andhra Pradesh with 11 seedlots from two regions in teak's natural range and one introduced region. This trial was assessed at the age of 9 years for health (survival and disease/pest incidence), growth (height and diameter) and quality (stem straightness, axis persistence, and branch size). The local seed source was the best in terms of health and growth followed by the seedlot from Konni (Kerala) with better quality characteristics than local seedlot. Provenances from Thailand showed poor survival and growth. The African land race seedlot from Ivory Coast showed good growth (Keiding *et al.*, 1986). Field trials with representative of Indian teak subtypes established in different soil and climatic conditions showed high adaptability. The Indian moist provenances were found to be the best for moist regions of West Africa and Brazil. The Indian provenances have a tendency to lose persistence of the main axis earlier than the Indonesian provenances, but stem form and branch characteristics are better for the moist Indian provenances than for the Indonesian provenances. Indian moist provenances were also found to be better than rest in dry and semi-moist West Africa. Provenances from Indonesia and moist India grow relatively fast and are of good quality. The moist and dry Indian provenances developed less epicormics and protuberant buds than the Indonesian provenances. Moist Indian provenances are also recommended for Central American region (Keiding *et al.*, 1986; Kjaer *et al.*, 1995).

Plus Trees and Seed Orchards

Selection criteria are highly rigorous for plus trees and often only a few trees are selected from several hundred hectares of forest or plantation (Gogate, 1993). Total number of plus trees identified from all teak growing States is around 250 (Table 2). Vegetative buds are collected from plus trees, grafted on to stumps of seedlings and maintained in germplasm banks/multiplication garden for further propagation. Grafted ramets of plus trees are planted, usually in a randomised design, to establish clonal seed orchards (CSO). Total number of clones planted in a CSO rarely exceeds fifty and they usually come from many regions within the country. More than 1000 ha of CSOs have been established in India with 450 ha in Maharashtra and 240 ha in Madhya Pradesh (Table 2).

Although CSOs are the main focus of genetic improvement of teak in India, the output from these orchards has been far from satisfactory. Poor flowering, asynchrony in flowering phenology, low fruit and seed set were the major problems faced. It has been estimated that one ha of CSO (with roughly 100 trees) produces seed sufficient to plant only 16 ha following standard plantation methods (Wellendorf and Kaosa-ard, 1988). It is also the case in other natural teak regions like Thailand. However, flowering and seed production were high in the exotic regions like Africa and Central America (Kjaer *et al.*, 1999). It is suggested that a CSO should have plus trees from the same provenance or ecotype with as many trees as possible to avoid non-overlapping of flowering and to maintain a broad genetic base (Kedharnath, 1984; Subramanian *et al.*, 1994). This approach is further supported by the recent investi-gations in teak using isozyme and DNA markers indicating that major portion of variability in teak must be exploited from within the zonal population (Kertadikara and Prat, 1995; Nicodemus *et al.*, 2003).

Seed production and germination

The fruiting season of teak in India is between November and March/April. Collection of fruits during later part of the season gives better results (Hedegart, 1976). Teak starts yielding fruits from10-12 years of planting. On an average a 40-year tree produces about 3 kg fruits. The size of the tree has influence on fruiting. Teak fruits vary in size from 5-20mm. On an average 1kg has about 2200 fruits. Seeds sown immediately after collection give poor germination, whereas seeds stored for 3 months germinate better. Grading of fruits according to size help in improving germination. Teak seed germination increases with increase in size of fruits. Teak fruits of less than 14 mm may not be used in nurseries (Banik, 1977). In general, moist teak possesses larger-sized fruits, higher seed filling and better germination than dry teak (Jayasankar *et al.*, 1999; Mackenzie and Jones, 1998; Rajput and Tiwari, 2001; Dabral, 1976). Dry teak is characterized by high proportion of empty fruits (i.e. fruits without a single fully developed seed) ranging from 13-86 per cent (Gupta and Kumar, 1976). The main factors that affect germination are moisture, temperature and light. Teak germination is not favoured by either too wet or too dry medium (Suangtho, 1980). Optimum moisture content for effective germination is dependent upon soil type and characteristics. They require relatively high humidity and high temperature for germination (Masilamani *et al.*, 2002).

Though teak seed research is being carried out for over a century, nurserymen still find it difficult getting adequate quantities of plantable seedlings. The problems of teak germination are multifarious like physiological block due to presence of germination inhibitors in the mesocarp and physical barrier of stony endocarp. Several procedures for pretreatment of teak seeds have been prescribed for both laboratory and nursery, none of these treatments have given consistent results. The various treatments for impro-ving the germination are treating the seeds with water (Moss, 1892; Muttiah, 1975; Ngulube, 1988; Bedell, 1989; Yadav, 1992; Chacko *et al.*, 1997), heat (Chen and Yang, 1969; Suangtho, 1980), and chemicals (Kaewkannerd, 1962; Kulpracheep, 1963; Gupta and Pattanath, 1975; Unnikrishnan and Rajeeva, 1990; Vijaya *et al.*, 1996; Masilamani, 1996), Removal of the mesocarp and mechanical treatment to fruits (Bryndum, 1968; Keiding and Knudsen, 1974; Suangtho, 1980; Bapat and Phulari, 1995) improved per cent germination.

Insect pest management

Teak is one of the most extensively studied timber species for its insect pests problems. Over 300 species of insects have so far been reported to be associated with teak in India. They include flower and seed feeders, defoliators, sap suckers root and bark feeders, borers of living and dry wood, gall formers and leaf minors but only a few species cause serious damage. This includes two species of *Hyblaea puera* and *Eutectona machaeralis* besides the live tree borer *Alcterogystia cadambae*. These insects cause extensive damage to plantations, resulting in reduced productivity. Biology and ecology of the important insect pests have been dealt by many researchers (Beeson, 1941; Mathur and Singh, 1960; Roonwal, 1954; Browne, 1968; Khan *et al.*, 1985; Mani, 1959).

The teak defoliator *H. puera* and *E. machaeralis* commonly known as the teak skelotonizer are the major pests of teak in India. Out-break of both are common in teak plantations throughout the country. *H. puera* feeds on tender foliage during the early part of the growth season and *E. machaeralis* feeds on older foliage towards the end of the season. The effect of such defoliations on volume increment of teak and the resultant economic loss has been a subject of much speculation as well as a few serious studies. Beeson (1941) estimated 13 per cent loss of normal current annual increment. When younger plantations are infested, defoliation by this pest can cause 44 per cent loss of the potential volume increment. (Nair *et al.*, 1985). Distinct morphological, physiological and biochemical differences are found in association with different levels of susceptibility, tolerance and resistance. These variations have been documented and methods to breed for resistance are programmed.

Mass migrating behaviour of defoliators limits the use of natural enemies or pesticides against them. An ecological approach to make the environment unfavourable to pests and less harmful to the natural enemies is needed. Selection of pest resistant trees from wild populations is another choice for dealing with pest problem. Investigation in this direction is already initiated by the Institute of Forest Genetics and Tree Breeding, Coimbatore (Jacob *et al.*, 2002). Identification of a resistant crop/ tree variety, which forms the basic foundation for an integrated pest management programme, hold promise for effective suppression of defoliators in teak. Field level assessment on the incidence and intensity of attack of two important defoliators, viz. *Hyblaea puera* and *Eutectona machaeralis* were carried out for 4 years. A number of germplasm were found to be highly susceptible and a few resistant though resistance mechanism needs to be elaborated.

RECENT DEVELOPMENTS IN TEAK RESEARCH

Genetic diversity

Population structure and patterns of diversity of teak populations have been studied using molecular (isozymes and RAPDs) markers in recent years (Kertadikara and Prat, 1995; Kjaer and Suangtho, 1995; Changtragoon and Szmidt, 2000; Nicodemus *et al.*, 2003). All these studies showed that teak is an outcrossing species with major portion of diversity present within the populations. A recent study on genetic variation within and among ten populations of teak from Western Ghats and Central Indian regions showed that 78 per cent of variation existing within the population and the rest between populations (Nicodemus *et al.*, 2003). In general, populations from the Western Ghats region possessed more diversity compared to those from Central India. Genetic distance among populations tended to be low between populations from the same geographic region. This study demonstrates presence of moderate levels of diversity in Indian teak, most of which is distributed within the population. The current selection strategy of selecting a few outstanding trees from different populations needs to be revised and many superior trees should be selected to capture the within-population diversity. Western Ghats and Central Indian regions may be designated as separate breeding zones since these populations are genetically distant. Conservation strategies should aim at preserving both within and across population variation in teak.

Reproductive dynamics

In teak, low seed production is a bottleneck to meet demand for planting stock and to move breeding programmes to advanced generations. This is also a common problem throughout teak's natural distribution and one of priority areas of research. Generally, most of the teak populations in India flower once during May-July coinciding with the South-West monsoon. In certain places (e.g. Kalakkad in Tamil nadu), which receive both South-West and North-East monsoons, teak has two distinct leaf flushing and flowering seasons. Teak populations in the moist regions of Western Ghats and those from dry and semi-moist regions of central and eastern India differ in phenology, flowering duration and fruit set characteristics. In general, dry populations (e.g. in the States of Maharashtra and Madhya Pradesh) show very poor flowering, fruiting and seed filling (Dabral and Amin, 1975). Clones of one region, when moved to another region, flowering and fruiting were significantly affected (Nagarajan *et al.*, 1996). For example, out of 235 clones assembled in the National Germplasm Bank at Lohara in Maharashtra, 123 have not flowered. Out of these, 90 clones are from moist and semi-moist populations in the States of Tamil Nadu, Kerala, Karnataka, Orissa and Andhra Pradesh. Only 28 clones have been recorded to be flowering continuously for the last five years, out of which, 21 are from local populations in Maharashtra and nearby States of Madhya Pradesh and Andhra Pradesh (Kumar, 1997). Similar trends of flowering have been reported from different CSOs established with clones of varying numbers and origin (Gogate, 1993; Varghese *et al.*, 2000).

All these observations indicate the advantages of having clones from local populations in the seed orchards and locating them in sites suitable for flowering and fruiting. By selecting as many clones as possible from the provenance, a broad genetic base can be ensured. Such orchards from a well-defined base population are expected to produce seeds of improved genetic quality in adequate quantities (Nicodemus *et al.*, 2003; Varghese *et al.*, 2003).

Progeny tests and genetic parameters for breeding

Since the extent of plantations raised through seeds obtained from CSOs has been low, their superiority over unimproved seeds in terms of growth and other traits is not well known. However, a few progeny trials were established in different parts of India using open-pollinated seeds collected from different clones in the CSOs. Such one-parent-progeny trials are intended to test the comparative performance of orchard-produced seeds against unimproved seeds and also to obtain reliable estimates of genetic parameters for formulating an efficient breeding plan. Further, genetic thinning of the CSOs based on the findings ensures production of tested varieties thro-ugh recombination of the best progenitors (Mandal and Rambabu, 2000). Another valuable information obtained through these genetic tests is that the estimates of genetic parameters at an early age do not change much at later stage. Therefore, early test results can be used to take breeding decisions in teak.

Improved propagation techniques

Propagation of teak through seeds is constrained by limited seed production, low germination percentage, variability in growth and wood quality among individuals within progenies, and the uncertainty related to the heritability of traits of major economic importance (White, 1991; Monteuuis *et al.*, 1998). Vegetative propagation ensures the transfer of desirable economic traits that are under non-additive control (Cheliak and Rogers, 1990). Apavatirut *et al.*, (1988), used nodal and shoot tip explants from sterile seedlings and buds of mature superior clones for *in vitro* propagation. Monteuuis (1995) reported that tissue culture technology enabled mass micropropagation of any genotype by axillary shoot with exponential multiplication rates of three to four new shoots every two months. Bonal and Monteuuis (1997) observed that *in vitro* rooted microshoots gave high survival.

Gupta *et al.* (1980) developed a tissue culture protocol for clonal multiplication of teak and. Mascernhas *et al.* (1987) evolved a tissue culture method for micropropagation of teak seedlings from 100-year-old trees. Devi *et al.* (1994) reported rapid cloning of 30-year-old trees by *in vitro* multiple shoot production. Kushalkar and Sharon (1996) reported direct and indirect somatic embryogenesis from callus obtained from apical buds from 3-year-old teak. Improved micropropagation protocols using nodal explants were reported by Tiwari *et al.* (2002). Use of improved planting stock is an essential prerequisite for substantial increase in productivity. Establishment of seed orchards is the first asset to get seeds of genetically improved quality. The low seed product-ion in CSO results in insufficient quantity of seeds for planting. One Kilogram on an average has 2200 fruits, with a proper pre-sowing treatment and with 65 per cent viability, 35 per cent germination; it produces 420 seedlings with intensive care. The existing clonal seed orchard (CSO) can thus provide just 15-16 million seedlings of good planting stock. Micropropagation technique perfected at the Institute of Forest Genetics and Tree Breeding, Coimbatore quantitatively enhances production of genetically improved planting stock using seeds from clonal seed orchards. A single seedling can be scaled up to 3000 seedlings per year. The plantable stock can multiply several million-fold. The basic requirement in this approach is to develop network of small tissue culture laboratories for multiplying the identified genotypes and scale up through commercial tissue culture laboratories.

Micropropagation technology parks, one at the National Chemical Laboratory, Pune, and the other at the Tata Energy Research Institute, New Delhi with production capacities of five to ten million propagules have been established by the Department of Biotechnology to facilitate mass multiplication of teak and other important tree species.

LOOKING AHEAD

Teak has come a long way from being a 'product' of forest to a dynamic plantation crop of ecological, socio-economic significance. It requires intensive and coordinated attention for improvement and utilization in selected areas. They are sustainable management of existing natural forests and plantations and developing long-term programmes for productivity enhancement through breeding and conservation of genetic resources.

Need for sustainable management of teak resources

Restrictions on felling in natural forests have resulted in meeting demand exclusively from teak plantations throughout the world except in Myanmar. India has the largest share of world's teak plantations, 44 per cent (Pandey and Brown, 2000) and hence has enormous task of managing these plantations in a sustainable manner so that both ecological and economic considerations are met. As the plantations are in diverse edaphic and climatic conditions, a uniform management strategy cannot be advocated. Productivity of teak plantations is declining in areas, which have a long history of teak cultivation. A meager 2.85 m^3 ha^{-1} $year^{-1}$ is reported on an average for a rotation of 53 years where all thinning schedules were followed in Nilambur, Kerala (Chundamannil, 1998). Decline in the nutrient status of soils, poor quality of planting stock and inadequate cultural practices are the frequently cited reasons for low productivity, all of which can be managed by improving current plantation techniques. Application of fertilizers in the early stages of plantations (Balagopalan *et al.*, 1998), soil and water conservation efforts have to be undertaken to prevent leaching of nutrients and to increase moisture availability. Genetically improved planting stock is necessary to raise new plantations.

Long-term improvement

Progress in teak improvement is constrained essentially by time requirement viz. multi year progeny test, many year delay in flowering, poor seed germination, self-incompatibility, biological and economic problems of large scale vegetative propagation of superior individuals/lines. In recent years, however, advanced breeding strategies and rapid propagation have been refined. The existing popula-tions of seed orchards must be reviewed for reorient-ing them to suit the strategies of new genetics. Thus, to put the teak improvement on the faster track, following strategies have been advocated and initiated by the Indian Council of Forestry Research and Education (ICFRE).

Initiating new selection and formation of breeding populations

In the last decade, valuable new information has been obtained on the population structure, variability patterns, reproductive dynamics and seed production in teak (Kertadikara and Prat, 1995; Kjaer and Suangtho, 1995; Nagarajan *et al.*, 1996; Nicodemus *et al.*, 2003). Since SPAs, which are seedling-raised plantations, produce moderate to heavy seed crops, a seedling seed orchard with seeds collected from superior trees of the same provenance will be a viable alternative to CSOs. Seed handling and germination methods, and nursery practices should be perfected to obtain maximum plantable seedlings from a unit quantity of seeds. It is also necessary to minimize the staggering of germination to meet time schedules and also to achieve uniformity with the planting stock.

Mass propagation of improved planting stock

With the advent of new propagation techniques like rooting coppice shoots (Palanisamy and Subramanian, 2001) and tissue culture of seedlings raised from orchard-produced seeds (Yasodha *et al.*, 2000), propagation of a nucleus material in large scale should be widely practiced. This approach requires strong upstream programmes on tree improvement and downstream strategies on plant quality standards followed up with post planting management and biofertilizer application (Katwal *et al.*, 2001).

Conservation of genetic resources

In situ conservation in natural forests. Teak shows intraspecific variation both within and between populations (Kjaer *et al.*, 1995; Kertadikara and Prat, 1995; Nicodemus *et al.*, 2003). Hence the strategy is to have large populations identified in different regions and maintain them as *in situ* conservation stands. The existing teak forests must be classified into different genecological zones based on rainfall, soil, and molecular marker studies (Graudal *et al.*, 1997). Subtypes proposed by Seth and Khan (1958) and classification adopted by Danida Forest Seed Centre in the international provenances tests (Kieding *et al.*, 1986) are good starting points for evolving a zone system. Available information on the vegetation, population structure and existing forestry practices must be analysed before arriving at a more precise classification. Conservation stands may be identified and marked within each genecological zone taking into consideration the extent of population differentiation within each zone. At present it is not known whether there are gene pool reserves for teak or at least a mixed deciduous forest in which teak is the flagship species. In general, natural populations of tree species possess more genetic diversity than planted populations. But, over the years, most of the natural teak forests have been gradually converted into teak monoculture. Teak plantations occupy areas where teak bearing deciduous forest existed once. The Preservation Plots established within each forest type may qualify to be *in situ* conservation plots of teak. Most of these preservation plots were established over a century ago and no forestry operation was permi-tted within the plot (Rodgers, 1991). Well-maintained large Preservation Plots within teak's natural distribution are likely to have good genetic diversity. Teak bearing forests falling within the boundaries of national Parks, tiger reserves and wildlife sanctuaries have to be managed to retain the diversity.

Conservation of old teak stands

In the absence of Preservation Plots and protected forests, the choice is limited to identifying appropriate plantations for long-term conservation. The seed origin for these plantations is usually not known but presumably obtained from local sources. The gene diversity will be reduced with each rotation of teak plantations as seeds are collected from selected trees of the existing plantations. Therefore, some of the earliest established plantations prior to 1940, which are just one or two generations removed from the wild stands, must be selected. Seed Production Areas established through conversion of such plantations also can be considered as conservation stands. Although SPAs undergo one or two thinnings, they still retain good diversity if the seed origin is from a diverse genetic base. Further thinnings to remove only weak and suppressed trees may not affect the genetic base as they seldom participate in the reproduction for the next generation (Kertadikara and Prat, 1995). The genotypes of such conservation stands could easily be rescued through rooting of mature or coppice cuttings in the event of any damage to them (Palanisamy and Subramanian, 2001). Any gene pool reserve of teak in a given region, can also serve as base population for selection and breeding.

Ex situ conservation

Conservation of teak germplasm outside the forests is mostly in the form of clonal banks. These archives house vegetatively propagated ramets of plus trees. Every State has collections of plus trees selected within it and some have wider collections. The Chandrapur based Forest Research Institute of Maharashtra has a collection of around 250 clones drawn from all teak growing regions in the country. It also supplies ramets of these clones mostly for establishing clonal seed orchards throughout the country. Thus, the clonal collections are replicated in several places in the country and hence their continued safety is ensured. However 250 clones represent only a meagre genetic diversity present within Indian teak. A few plus trees from each population do not help to capture the high variation that is present within the population. Secondly recombination is poor within the clonal archives and CSOs due to low number of clones within an orchard which is compounded by flowering and pollinator related problems It is necessary to widen the genetic base of teak in *ex situ* conservation stands. Collection of buds from trees, vegetative propagation through grafting are labour-intensive and expensive but essential. Seedling based conservation stands are ideal for large and easily manageable stands outside natural forests. If carefully planned, it is possible to combine conservation stands and breeding populations for teak in one plantation. Considering the long gestation period for teak, and the high demand for genetically superior propagules, combination of options is recommended. Seedling Seed Orchards are the best means of capturing genetic diversity within a population. The selection of trees need not be as rigorous as in the case of plus trees, and about 100-200 dominant trees can be randomly selected within the population. While raising progeny of the selected plants, retaining family identity will be helpful for pedigree-based selection.

EMERGING RESEARCH AND DEVELOPMENT ISSUES

Teak deserves intensive research and development inputs for the sustainable management and utilization of its resources. The available technologies have firmly established teak as a viable tree crop in the tropics but did not succeed in increasing productivity and quality, over a period of time. It is necessary to strengthen the currently followed approaches and also to develop new ones. Knowledge on the biology and ecology of teak is still limited and need to widen. Plantation management, tree improvement and conservation of genetic resources are the high priority areas of research and development in all teak-growing countries. An effective networking among these countries will help in avoiding duplication and promote rational utilization of limited resources.

During the last five decades, the demand for teak has increased several fold, resulting in extraction of trees from old plantations and even from natural forests. Extraction of best teak from forests and plantations has resulted in the loss of good genotypes. Yield improvement in teak is essentially silviculture oriented, as genetic improvement cannot be adequate-ly achieved even in 40-60 years time frame. Although new insights have been reported in the recent years, understanding of the genetic principles operating in teak is still inadequate. The foregoing review shows that teak improvement has not progressed beyond the refinement of clonal seed orchards. In clonal seed orchards too, complications like inadequacy in flowering, fruiting, seed viability and germination of seeds has resulted in continued dependency on seed production areas and seed orchards for plantation programmes.

Technologies like fertilizer application, pest manage-ment and improved cultural methods continue to be the approach for increasing productivity. The genetic quality of population derived from seed orchards have declined and hence there is a need to devise strategies to put teak improvement on a fast track. All the seed production populations, viz. SPAs and CSOs have to be made productive to meet major portion of the demand for planting stock. To achieve this basic research must be directed at resolving bottlenecks in flowering and seed production. Developing seed handling and nursery techniques to enhance recovery of plantable seedlings from nursery must also be a high priority area of research. Mass multiplication of nucleus material using tissue culture and further propagation by low cost propagation techniques like rooting of cutting can increase the availability of improved material at modest cost. The concept of new genetics which combines conventional genetics and biotechnology can provide leads for productivity increase.

Propagaules for teak is presently obtained as seeds. Biotechnology can help a great deal, if the propagules to be delivered to the field for plantation development are vegetatively derived material. It will require higher cost but will be in consonance with higher yield. Vegetative propagule production cannot be practiced unless there is a strong upstream programme on selection and hybridization and strategies for *in situ* conservation of teak resources. Biotechnology has provided solution for overcoming the yield barrier in agriculture crops. Yet, it has not been free of controversies. The tools of biotechnology can be effectively used in characterizing natural germplasm and for *in situ* conservation stands. The molecular marker methodologies, for quantitative trait-loci for complex traits such as yield, and organ size has been transferred to breeding populations in agriculture crops. (Xiao *et al.*, 1988; Tankley and McCouch, 1997). Such innovative molecular biology tools need to be developed effectively for long rotation trees like teak where the gene transfer through conventional breeding programmes is not possible within the lifespan of an individual researcher. The approach in teak therefore must be to locate genes such as those controlling xylem and vessel formation, heartwood differentiation, volume growth, photosynthetic efficiency, resistance to insect and diseases, flowering, compatibility and seed set. Such studies are in progress in eucalypts (Ho *et al.*, 1998) and needs to be extended to teak, that can help in improving wood quality, and also enhance the environmental adaptability. Study of gene markers can help locating genes useful for breeders.

Biotechnology research has not been integrated well in the forestry sector. There is a need for long term public sector funding in forest biotechnology so that benefit of bio-technological tools is optimized for improvement. Though conventional genetics will continue to play a large role, the genetic engineering has to be considered as a controversial supplement for teak improvement. This is particularly so when propagule delivered to the field will be vegetative or hybrid seeds which is available only in small quantity. In this context, strong R and D programmes in biotechnology for teak must be developed and implemented.

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Quality Timber Products from Teak Through Sustainable Forest Management in Maharashtra State, India

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ABSTRACT

Teak (*Tectona grandis* L. f.) is the prime timber species found in the forests of Maharashtra State in India. The paper gives an account of the extent of area of natural teak forests and plantations in the State, silvicultural systems practised at present, improved thinning regime for plantations and innovative seed and nursery practices introduced for production of quality planting stock. Thus, by improving site quality and implementing short-term strategies of tree improvement, the Forest Department and Forest Development Corporation Maharashtra Ltd. can be enabled to produce quality timber on a sustainable basis from the natural and artificial teak forests of the State. The current turnover of timber products from teak and measures to increase its availability are also discussed.

Keywords: Teak area, silvicultural practices, tree improvement programmes, seed orchard, clonal propagation, tissue culture.

INTRODUCTION

The total forest area in Maharashtra State is 62,032 km^2, i.e. 20.01 per cent of the geographical area of the State. Teak forests alone occupy 10,180 square kilometers. The types of teak forests found in the State can be broadly categorised intor Very Dry Teak Forests, Dry Teak Forests, Very moist Teak Forests, Moist Teak Forests and Slightly Moist Teak Forests (Seth and Khan, 1958). These teak forests are distributed in the districts of Gadchiroli, Chandrapur, Amravati, Nagpur, Yeotmal, Wardha, Bhandara, Gondia, Akola, Buldhana, Parbhani, Nanded, Aurangabad, Nashik, Dhule, Nandurbar, Jalgaon, Thane, Raigad, Satara, Pune, Kolhapur, Ratnagiri, Sindhudurg, Sholapur and Ahmednagar (Anon., 2000). The main Hill Teak forests are found in the Satpuda Range and northern part of Western Ghats and Eastern Ghats. The best plain teak forests are in the Vidarbha region of Maharashtra. Thus, the teak forests are distributed almost in all the districts in the State barring Osmanabad and Latur. Teak ascends upto 900 m above msl in Melghats and up to 1280 m in Khandesh forests. The geological formations that are normally associated are crystalline rocks in Thane areas, Deccan traps in most of the areas and metamorphic rock in other areas. The teak occurs where the rainfall ranges from 250 mm to 1500 mm (Kaikini, 1956; Majumdar, 1956).

MANAGEMENT

The teak forests were managed under different silvicultural systems in the past. Conversion to uniform system with artificial regeneration/natural regeneration was practiced in managing dry /moist teak forests in certain areas. The famous Allapalli teak forests were managed under this system. The coppice with reserve (CWR) and the selection system, including the selection cum improvement felling, were/are the systems followed predominantly in dry and very dry teak forests. Based on the National Forest Policy 1988 and the Supreme Court Orders, harvesting of timber is slowed down so that the valuable forests are managed in a sustainable way by ably combining the principles of ecology and silviculture.

TIMBER PRODUCTION

Teak is the most valuable timber. The harvested timbers were brought to sale depots and sold in public auction. Teak timber from Vidarbha of Maharashtra are known as CP Teak (erstwhile Central Province), which are best known globally for their grains and hence very suitable for construction works. The level of production of timber in Maharashtra for the period 1990-91 to 1999-20000 is given in Table 1 (Anon., 2003).

Table 1. Teak timber production by the Maharashtra Forest Department (1990 - 2000)

Year	Quantity of timber in 000 cum
1990-91	51
1991-92	52
1992-93	39
1993-94	44
1994-95	36
1995-96	49
1996-97	52
1997-98	62
1998-99	41
1999-2000	37

The Forest Development Corporation of Maharashtra (FDCM) is harvesting timber in the assigned area. The timber production was drastically brought down when the Government of India and the Supreme Court banned clear felling in forest areas.

A study was carried out by the statistical wing of Forest Department on the availability of quality timber in two major well manned depots located at Paratwada (Amravati District) and at Ballarsha (Chandrapur District). The study showed that there is a declining trend in harvesting of teak timber. It also confirmed the fact that the quality of timber available is also getting reduced. The timbers are classified into I-VII grades based on length, girth, straightness, degree of defects, etc. The bulk of the timbers now available are belong to the category of grade III and grade IV. The rate per cubic meter of average teak timber is getting increased progressively (Anon., 1995).

MEASURES TO IMPROVE TIMBER QUALITY

Tree improvement works

Quality of timber can be improved primarily through genetics and also by site improvement. Since 1960, efforts were made by silviculturists of Maharashtra to carry out teak tree improvement works encompassing selection of candidate plus trees by adopting 'mass selection' method, evolving bud grafting technique to establish clonal seed orchards in a randomised block design, establishing seedling seed orchards, establishing seed production areas, provenance trials and progeny trials (Gogate, 1993). It is not out of place to mention that the first clonal seed orchard was established at Lohara. Lohara Research Centre also has the privilege of housing of large teak germplasm bank in India. Though our efforts to get more quality seeds through these could not yield anticipated results, continuous efforts are on to comb both natural and man made teak forests for selection of candidate plus trees and establishment of seed production areas and seed orchards. Recently FDCML has established second generation Seed orchards (Anon., 2003). The details of works done both by Forest Department and FDCM Ltd are given in Table 2.

Table 2. Teak tree improvement works in Maharashtra State

Sr. No.	Category	Details FDCM Ltd	FD	Total
1	CPTS (Nos.)	0	43	43
2	Plus Trees (Nos.)	0	32	32
3	Seed Stands (ha)	7	592	599
4	Seed Production Area (ha)	661	199	860
5	Clonal Seed Orchards (ha)	103	513	616
6	Seedling Seed Orchards (ha)	38	0	38
7	Clonal Multiplication Garden (ha)	2	0	2

The establishment of seed unit by FDCM. paved way for collection and supply of improved quality seeds from the Seed Production Areas and Clonal Seed Orchards. About 50-70 tons of source identified/ quality seeds were supplied to the needy agencies annually (Anon., 2003). The said seed unit has facilities for storing, cold storing, processing and conducting tests. The known origin, graded, pretreated and pregerminated teak seeds give better germination percentage than the untreated, ungraded and unpregerminated seeds (Sardar and Subramanian, 1991). The mesocarp removal through small treatment machine reduces the period required for treatment of Teak seeds (Bapat and Phulari, 1995). The floral biology and embryology of teak continues to remain as riddles which are to be unravelled by more intensive and collaborative research (Subramanian and Seetha Lakshmi, 1997). Current study on floral biology indicates that all the flowers in the teak inflorescence are not getting into matured fruits (Nagrajan, 1996).

USE OF QUALITY PLANTING STOCK

The FDCM Ltd in Maharashtra has established a Nursery Unit in 1992, to make available improved/quality planting stock for the company's plantation programmes. This is to step up productivity of quality timber per unit area. Teak stumps were produced in the centralised nurseries in the past. Now, composite nurseries, ie. six by FDCM Ltd and two by Forest Department were established in 1994 under Maharashtra Forestry Project, and thereby bare rooted traditional planting stock i.e. stumps, root trainer seedlings of 3-4 months age and clonal planting stock could be raised in a single site (Bhagat, 2003). A preliminary study revealed that root trainer planting stock has better survival percentage and better growth rate in the initial stage, as compared to teak stumps in the plantation (Khedkar and Subramanian, 1998). Thus, the FDCM Ltd in the State of Maharashtran has pioneered root trainer nursery in the entire country. Intensive culling in bare root teak nursery also given improved stumps thereby their growth and survival percentage in plantation were better than that of unculled stumps (Subramanian *et al.*, 1999). Small scale clonal planting is also being carried out by obtaining bud grafted planting stock. This has to be continued till the time cloning through juvenile stem cutting technique is standardized.

TISSUE-CULTURE PLANTS

The first tissue culture plants of teak in the world were raised in the National Chemical Laboratory at Pune, through collaborative research, where FDCM was a noteworthy partner by funding the project (Gupta, 1980). The trial teak tissue culture plantations raised in different locations in Maharashtra have shown that stem form and growth rate are better in the tissue culture plants, as compared to stumps and polypot seedlings (Subramanian *et al.*, 1993). Many research institutes like Institute of Forest Genetics and Tree breeding at Coimbatore and many companies have now standardized the tissue culture protocol and thereby quality tissue culture planting stock are made available on commercial scale.

FINE TUNING THINNING IN PLANTATIONS

Tending at the right time is an important aspect for establishing successful plantation with full stocking. Since 1925, research conducted on intensity as well as cycle in the even, aged pure teak plantations has led to the following conclusions.

a. There was a gross under thinning.
b. The different intensity of thinning have no appreciable effect on the height growth.
c. The heavier grades of thinning give progressively higher diameter measurement in the retained crop (Iyppu, 1961)

After analyzing the pros and cons of the results of current intensity and cycle of thinning followed, the FDCM Ltd. has fine-tuned thinning since 1999 (Anon., 1999)

The first two thinnings are mechanical and the latter thinnings are silvicultural. The interval is by and large 7 years. The intensity is normally C or D grade thinning. As per the current guidelines issued by FDCM Ltd, the second thinning in old plantations commences in 15th year, and thereafter, third, fourth, fifth and six thinnings would be carried out in 20th, 25th, 30th and 35th years of age, respectively (Anon., 1999). Apart from rescheduling thinning regime, consideration now given to preparation of stock map based on site quality, enumeration of crop in the sample plot, computation of actual growing stock and application of yield and stand table. This is to ensure appropriate distribution of stems in various diameter classes such that the stocking of the crop at an age and for a specific site quality is maintained after thinning at a level where the CAI is optimum and the diameter is maximised (Tasneem, 2003).

NATURAL REGENERATION

Natural regeneration is found in the dry as well as in moist teak forests. Almost up to 1980, the concentrated regeneration felling in dry teak forests where Bamboo is the natural understorey has given good natural regeneration (seedling), provided final felling is carried out where adequate advance growth is present and the Bamboo understorey is kept under control, as exemplified by Elchil felling series in Allapalli Division. These are less known as "natural plantation" (Majumdar, 1956). Now, natural regeneration from seeds is almost absent or very poor due to factors like overwood removal, control of understorey bamboo / shrubs, etc. In fact, it could be safely said that, in general, the foresters have miserably failed in getting adequate natural regeneration of teak due to factors such as fire, grazing and over-exploitation (Kaikini, 1963). However, natural regeneration through coppice is found in all types of teak forests. Tending the scanty seed origin natural regeneration and coppice origin crops and protecting the same from fire, grazing, etc. will go a long way in maintaining natural forests to produce quality timber. The natural regeneration needs to be aided suitably through well established practice of artificial regeneration. The first priority of foresters' should be to conserve and enhance the productivity of natural forests left with them.

TEAK PLANTATIONS

As per the recommendations of National Agriculture Commission (1974) the State of Maharashtra established Forest Development Corporation Limited (FDCM Ltd.) as a registered company to take up large scale commercial teak plantation with a purpose to convert the less valuable miscellaneous forests into more valuable teak plantations. The activities of FDCM have already been commenced by the Forest Development Board in 1969. From 1969 to 1987, the FDCM has established 1.24 lakh hectares of teak plantation. The FDCM also raised teak plantation by availing World Bank loan, apart from Government loan and loan from NABARD. As per the current inventory assessment of the growing stock of old plantation of FDCM has 24.21 lakhs cubic metres, valuing Rs. 1415.16 crores (Anon., 2003).

Forest Department too has established teak plantations. The total teak plantation raised in Maharashtra up to 1988 is 2,75,907 hectares. Private companies and progressive farmers also started raising teak plantations from 1990 onwards. The productivity of teak plantation in Maharashtra for the teak areas in Chandrapur, in the site quality class II is 8.4 m^3/ha/yr (MA1). The State of Maharashtra has given emphasis on the following aspects to increase the productivity.

- Use of quality/improved seeds.
- Use of quality planting stock introduction of root-trainer nurseries, clonal nurseries.
- Intensify the tree improvement activities to get more improved/quality seeds.
- Clonal/Tissue culture plantations on a pilot scale

CONCLUSIONS

Teak is the most valuable timber tree in Maharashtra. The total teak forest area is 10,180 square kilometers. Broadly the teak forests of the State can be grouped under Dry Teak Forests and Moist Teak Forests. Teak forests are now managed under selection system, Coppice With Reserve (CWR) system and Selection-cum-Improvement Felling system. Both teak nursery and plantation techniques are standardized. There is a declining trend in the production of quality teak timber in the State. Various measures are also under taken to raise large-scale commercial teak plantations, so as to step up the productivity.

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Quality Timber Products of Teak from Sustainable Forest Management pp 24-30

A Report on Teak in Madhya Pradesh with Technical Analysis

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ABSTRACT

Madhya Pradesh, the heartland of India, has the largest forest area of 95,221 km^2 and highest forest cover 77,265 km^2 with growing stock of 50 million m^3. Teak occurs in over 35,000 km^2 of forest area. The forest is managed sustainably according to scientifically prepared working plans. This produces 0.25 million m^3 of teak timber annually. Teak is a light demander species, managed in a rotation of 80-120 years, grows well on deep alluvial soil, in moist and humid climate and produces timber with attractive colour and grain. In Madhya Pradesh, teak is harvested by the Forest Department and marketed through established depots in open auction. Teak is managed well under intensive silviculture systems. Ban on green felling in natural forest over the last two decades has jeopardized the natural regeneration of this light demander species and has posed the danger of retrogression from high forest to coppice forest. This is resulting in reduction of quality and yield. Plantation grown teak, even with high input, maintains its strength properties. Raising plantations on a large scale with high input, therefore, can supplement the productivity of natural forests. Teak requires early and heavy thinning. Experience in Madhya Pradesh and other states of the country is that proper thinning has not been done in most of the plantations. This has resulted in appreciable loss of increment. With innovative efforts of high input, teak plantations have succeeded well in Madhya Pradesh. This may pave way for increasing productivity of teak plantations ensuring their sustainability.

Keywords: Teak plantations, rotation, sustainable, natural regeneration, plantation productivity, increment, high input.

INTRODUCTION

Teak (*Tectona grandis* L..f.) is one of the most important timber trees of India and South-East Asia. It is a large tree, which can attain a height up to 30 metres. Teak has been extensively planted within and outside its natural range. Although most of the plantations have been established in tropical Asia (Indonesia, India, Bangladesh, Thailand, Myanmar and Sri Lanka), considerable plantation area exists in other regions also. The natural teak growing areas in India are Madhya Pradesh, Maharashtra, Tamil Nadu, Karnataka and Kerala, besides Uttar Pradesh, Gujarat and Orissa. It has also been planted in West Bengal, Assam, Bihar, Andhra Pradesh, Orissa, Andamans, Mizoram and Manipur.

Situated in the heartland of India, Madhya Pradesh is second largest State in the country, next only to Rajasthan. It has geographical area of 308 lakh km^2 which is 9.4 per cent of the country's geographical area. A human population of the State is 60.39 million, ie. 5.9 per cent of the country's population, of which 73.3 per cent is rural and 26.7 per cent is urban (SFR, 2001). Madhya Pradesh has the largest forest area in the country and has also the largest forest cover amongst of the States and Union territories. The population density is relatively low at 196 persons per squre kilometere. The tribal population constitutes 19.9 per cent of the state's population, as per 2001 census.

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TEAK IN MADHYA PRADESH

The forest of Madhya Pradesh is classified into Teal

Forest, Sal Forest and Miscellaneous Forest. Area with more than 20 per cent teak by species composition is considered teak forest and so also for Sal forest. 35,000 km^2 teak forest is present in the State which is predominantly distributed in southern and central part of Madhya Pradesh. The rich teak forests are found in the districts of Hoshangabad, Harda, Betul, Chhindwara, Seoni, Mandla, Balaghat. Teak forest of relatively lower site quality is also found in Panna, Sagar, Raisen, Vidisha, Sehore, Dewas, Guna, Khandwa districts. Though teak is found in dry and hot area also but its growth is luxuriant in moist tropical climate. It is found in the rainfall range between 700 mm to 2500 mm. On the basis of rainfall the teak forest mn Madhya Pradesh is divided in 4 categories (Bhatia, 1954).

1. Moist teak forest (1600 to 2500 mm)
2. Semi moist teak forest (1200 to 1600 mm)
3. Dry teak forest (1000 to 1500 mm)
4. Very dry teak forest (Less than 1000 mm)

Growing stock

Madhya Pradesh has a standing volume of growing stock to the tune of 50 million cubic meters. However, the annual production of timber is to the tune of 0.35 million cubic meters. Out of this teak timber is around 0.25 million cubic meters. Besides another 0.15 million cubic meters of teak fuel is also produced from natural forest. The teak poles, (included in timber volume) are used by the local people, for their domestic utilities. Local population also uses teak fuel wood. Besides industries like Central India Board Product, Itarsi also uses it for board manufacturing. The three plywood factories in Madhya Pradesh were dependent on indigenous teak, two of them have closed down and only one industry is surviving on imported teak. Thus there is a potential to produce teak from natural forest as well as plantation.

Soil preference

For raising teak, well drained deep alluvium soil is most suitable. Teak is an extremely hardy tree species and capable of growing on a wide range of soil conditions. However, the primary factors affecting the growth appear to be soil depth, drainage, texture, moisture status, and fertility of both surface and sub soils. Growth of teak is largely related to the moisture retentivity. Adequate drainage is one the most important single-valued factors which determines the distribution and existence of teak. Teak plantations have completely failed in low-lying poorly drained land with clayey soil.(Backman, 1917)
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Spacing

Teak is generally planted in forest area initially at a spacing of 2 x 2 meters. Teak is conventionally planted at this close spacing to enhance initial height growth with natural pruning of branches to get straight and clean bole. However, it needs very heavy and early thinning to reduce the number of stems to allow girth increment. Closer spacing restricts girth increment and wider spacing enhances branching. Therefore, optimum spacing is very crucial for successful plantation of teak because the girth of the timber produced is more important for market value than the biomass produced. This is where the teak plantation necessarily differs from high-density plantation of other fuel and pulpwood species.

Colour and grain

Value of Teak timber in our country is attributed to nice grains which is due to differential growth conditions created in a year with two extreme temperature range. Dry summer months create stress condition in contrast to faster growing period of monsoon up to mid of winter season. With continuous irrigation pronounced ring formation may not take place and different colours may not develop due to faster growth. The fast grown teak of Nilambur in Kerala fetches a lower price than the slower grown teak of Central Provinces (now Madhya Pradesh) and Maharashtra. The rates obtained from sale results of Thanjavur depots show a lower rate as compared to standard market rate of teak in South India

Growing season

The relative humidity and rainfall are the most important climatic variables, influencing growth of teak. However, the increase in their annual value above certain limits result in successively lower increment of the potential yield. These upper limits for rainfall and relative humidity are 2000 mm per year and 70 per cent, respectively. The temp. and day length have not been found to be the limiting factors for the growth of teak in the tropics. However, the maximum temperature beyond a certain upper limit has a negative effect on yield of teak. This upper limit has been identified as 33^{0}C (Pandey, 1996). Growing period, which is determined by physical conditions of the environment, and is expressed in growing season in months per year, is also an important indicator for teak growth, and is determined by interaction of several climatic parameters. Growing season in India varies from 4 months in Amravati (Maharashtra), Sagar (Madhya Pradesh) to 8 months in Nilambur (Kerala).

Rotation and yield

Teak is generally managed on a rotation of 80-120 years depending on the site quality, in natural forest. Volume of a tree depends on diameter (size), height and form factor. Total volume of a tree consist of stem timber having commercial value (20 cm, diameter and above) and small wood (less than 20 cm diameter) having very little commercial value. In India rotation of teak is around 60 years in forests of site quality I (top height 30.5-36.6 m). As per teak yield table in site quality I the volume of 40 cft (stem timber at final felling at 20 years) is obtained at the age of 35 years with retention of 61 trees per acre only with average diameter of 43 cm (girth 135 cm) and a height of 29.56 m. At 20 years the stem timber volume is 975 cft with retention of 153 trees per acre only. In site quality II (top height 18.3-24.4 m) volume of 35.57 cft is obtained at 50 years with 61 trees per acre and diameter 15.7" (39.87 cm) and girth 125 cm. In site quality III, (top height 12.2-18.3 m) stem timber volume of 30 cft. is produced in 80 years with retention of 66 trees per acre having diameter 14.5" (37 cm) and girth of 116 cm (Gangopadhyay,1997).

Flowering

It has been observed that flowering of a tree limits the vegetative growth. It has also been reported that when the apical flowering starts, the length of the clear bole becomes limited up to that point. In the subsequent years flowering shoots come out below the apical buds and dichotomous branching start as a result of early flowering of plantations. This indicates a restriction of clear bole to the flowering height. It is a matter of anxiety in some high input plantations profuse flowering has been observed at an early age which is going to affect the height growth adversely.

Strength properties and timber quality of fast grown teak

A study report of Sanyal *et al.* (1987) has given a finding that 20 year teak logs of Cauvery canal strip plantation in Thanjavur District has shown comparable strength properties when compared to standard teak. The findings are that "In green conditions the plantation grown timber under investigation is stronger than the standard teak on the average by 16 per cent in case of 16 properties, while in case of 9 properties the species is weaker than the standard teak on an average by 8 per cent. In air dry condition this timber has been found stronger in 21 properties by an average of 22 per cent while in 3 properties the species is stronger by an average of 9 per cent than standard teak". According, to this study it can be safely inferred that plantation grown teak evaluated show an overall better physical and mechanical properties than "standard teak".

Silvicultural systems

Teak is light demander species. Silviculturally, it has been managed very well under intensive system of management like clear felling followed by natural regeneration, clear felling followed by artificial regeneration and coppice system. Since teak does not tolerate overhead shed it does not regenerate well under selection cum improvement or improvement felling systems. In the last 100 years system of removal of mature over wood to free natural regeneration has performed very well in Madhya Pradesh. Inadequate natural regeneration was supplemented by raising plantations of teak which has also succeeded in most of the teak areas. In Madhya Pradesh this system has worked very well and most of the teak areas have maintained their canopy cover, stand density and regeneration. The plantations, raised by Forest Development Corporation, by clear felling method have shown very good survival percentage, height growth and girth increment. In the last two decades the general trend has been to discourage intensive working and monoculture of teak. So far, well managed and well stocked teak forest have been put under improvement felling or selection felling in which canopy is not opened to allow overhead light. This has been to the detriment of natural regeneration and most of the teak forests are gradually being converted to coppice forests, instead of high forest (seed origin) capable of producing large size quality timber. Successive coppice rotations are giving rise to poor height and girth growth. Attempt to retain these trees for a longer duration is resulting in defects like hollowness, resulting in deterioration in timber quality. The recent harvesting operation carried out in the submergence area or Khandwa district has shown that out of 3,00,000 cmt. teak timber produced around 70 per cent belongs to lower grade of timber with lot of hollowness and defects fetching an average price of Rs. 8,000, while higher grade logs have fetched more than Rs. 20,000 per cubic meter. The forest of Khandwa has been managed under coppice system for a long time and high forest system was not practiced.

Discouraging high forest system is also bringing down the rotation and selection girth of teak trees. The selection girth in Raisen district has been revised to 90 cm in the present plan in place of 105 cm girth of the previous plan. This has been reflected by gradual reduction and ultimate disappearance of plywood quality, first and second grade teak logs. It is very important therefore to appreciate this silvicultural requirement of the valuable species and manage the teak forest under clear felling with natural or artificial regeneration. The example in the past in many districts of Madhya Pradesh like Hoshangabad (Bori), Harda, Mandla, Seoni, Betul and Chhindwara has shown that this system of management up to mid 80s has achieved very good results.

Productivity and conservation

India is one of the 12-mega biodiversity countries. Conservation of biodiversity is a prime concern. The Wildlife Institute of India has recommended that 5 per cent of the countries area should be kept under protected area network (national parks, sanctuaries and biosphere reserves). Such biodiversity rich areas should remain sacrosanct in the interest of conservation. 7.8 per cent of the country's geographical area is under degraded forest with less than 40 per cent canopy density (SFR, 2001). Such areas will have to be rehabilitated and brought under productivity by involvement of forest dependent communities. Remaining 7.75 % area, which is dense forest and can be managed to produce goods and services should be worked according to scientific principles of forestry. Unless this forests produce usufruct of tangible goods like timber, poles, fuel wood, bamboo, non-wood forest products, then the basic incentives of Joint Forest Management, through usufruct to the local people cannot be made available. Hence, to sustain the interest of Joint Forest Management committees, and also ensure the responsibility of forestry sector to meet the requirement of local population, it is important that the 7.75 per cent production forest areas should be managed under scientific principles of forestry. However, imposition of ban in green felling in most of the states of the country has locked up this potential resource. It is also detrimental to the growth of forestry sector, which has the capacity, not only to become self-sustaining but also to generate sufficient resource to take care of various developmental needs of forestry sector and forest dependent population.

Teak plantations in Madhya Pradesh

Teak plantation in Madhya Pradesh dates back to 1891 when in North Raipur Division, a Forest Guard named Mani Ram on his own initiative planted 8 ha .with teak. He transplanted naturally regenerated teak seedlings with bowl of earth in this plantation. This success in teak plantation was followed by regular plantation activities under teak conversion working circle or teak plantation working circle in various districts of Madhya Pradesh which went on till 1988. Following National Commission on Agriculture's recommendation, after 1976, Forest Development Corporation of Madhya Pradesh was formed and large-scale teak plantations were taken up in 12 districts and so far 1,14,000 ha teak plantation has been raised.

Thinning regime

The thinning regime followed by Forest Department in teak plantations in Madhya Pradesh is early and heavy thinning because teak is strong light demander and also does not tolerate root competition. Initial plantation of 1,000 stems / acre is normally reduced to 500 stems/acre at the end of five years and 250 stems /acre at the end of 10th or 12th years thus

Table 1. Statement showing variation in average sale price for teak wood

Timber Depot	Price in Rs./m³ 2001-02	2002-03	% Change	Timber Depot	Price in Rs./m³ 2001-02	2002-03	% change
Panna	6883	12054	75	Chandrakeshar	7892	7691	-3
Tendukhedha	10412	13856	33	Bhoura	15649	15204	-3
Budni	9260	11467	24	Amla	14782	13300	-10
Sehore	7354	8905	21	Dhuma	13992	12589	-10
Gairatpur	10489	11914	14	Sanavat	10369	8815	-15
Pathakhedha	13107	14743	12	Timarni	15729	13177	-16
Mandla	16886	18657	10	Narmada Ngr1	10015	8386	-16
Kalpi	18604	20209	9	Ashapur	11381	9243	-19
Khwasa	15354	15941	4	Khirkiya	15677	12697	-19
Betul	14306	14242	0	GhodaDongri	17189	13074	-24
Narmada Ngr2	8499	8392	-1	Seoni	19484	12883	-34
Umariya	16475	16120	-2	**GrandTotal**	**13679**	**11854**	**-13**
Harai	13334	12999	-3				

increasing the spacing to 4 x 4 m. These two thinning are mechanically done without considering the quality of the stem form to provide proper growing space. Subsequent thinning are done around the age of 20,30,40 years, etc. depending on the site condition, rotation and objectives of management. According to the Silvicultural needs of teak plantation, it is very crucial to provide appropriate space by executing proper thinning and retaining the target number of plants at the last thinning which should get a growing period of at least one third of the rotation before the crop is harvested. A large number of teak plantations in MP has recently been thinned which were suffering from congestion due to inadequate or no thinning. The dada shows that where number of stem per hectare is much more than it should have been, the girth has not increased to the expected level. A special drive has been launched to complete the due and overdue thinning in teak plantations in MP.

Harvesting and marketing

In Madhya Pradesh teak is harvested departmentally and marketed through notified depots in open auction in traders allover the country participate. The teak timber of MP is famous for its colour and grain and fetches attractive price. The price obtained in the year 2001-02 and 2002-03 for the whole state was analyzed which shows that in the year 2001-02 average price per cubic meter of Rs. 13,680 was obtained with a minimum of Rs. 6,883 and maximum of Rs.19,484. In the year 2002-03, average price per cubic meter of Rs. 11,854 was obtained with a minimum of Rs. 7,691 and maximum of Rs. 20,203. The timber quality, composition by grade, market competition varies widely in depots at various locations. The table below shows the price obtained in depots in two years and how they have changed.

Increasing productivity

Presently, there has been a trend of discouraging monoculture of teak. It has to be appreciated that the silvicultural requirement of teak is clear overhead opening. If it is grown in association with bamboo or some other crop in the under storey it may be feasible. But teak with a mixture of miscellaneous

Table 2. Industrial wood production from forest plantations

Country	Plantation areas in 1000 ha (% of total area)	Percentage share in industrial wood production
Zimbabwe	110 (0.4)	50
Zambia	43 (0.5)	50
Brazil	4805 (1.2)	60
Argentina	830 (2.2)	60
New Zealand	1480 (16.2)	95
Rep of South	1428 (16.8)	100
Chile	1747 (17.3)	95
Spain	2170 (25.8)	81

species with a competing canopy space does not perform well.

Teak plantation with superior planting material of clonal origin, used with higher input of fertilizer, soil working and irrigation, can produce very good growth rate. However, such efforts can maximize the benefit only if teak is planted as a pure crop. Various countries in the world have shown that by putting a small percentage of their total forest area under monoculture of valuable species large segment of their industrial requirement can be met with. This potential of teak to generate resources is under exploited in India. Such plantations can produce valuable growth to meet the domestic demand of local people, industries and can also capture export market. Table 2 demonstrates this.

Private investment in teak plantations

In the mid nineties some private companies floated the concept of green equity and raised huge money ranging from Rs 1.1 million 2.6 million per hectare, from people, promising them very heavy returns from teak plantations with 20 years rotation. They have made very high projections of growth parameters, which are not tenable as per silvicultural and biometric norms. MAI figures of stem wood production projected by the companies are far in excess than the MAI (maximum) figures of total wood production of the best productive teak plantation of the world. The companies could not meet the commitments and the public faith in green investment has suffered a lot.

High input plantations

Recently efforts were made in the state to develop a model of high input teak plantations. Starting from 1998, in several districts, teak plantations have been raised in small patches of 5 to 10 ha each, with drip or flood irrigation, intensive soil working and fertilizer application. The State Forest Research Institute (SFRI) Jabalpur has studied this initial effort and has shown that by and large these plantations have done very well in terms of survival percentage and height growth (Anon,. 2002). However, diameter increment has not been very satisfactory because these plantations need special regime of thinning. In case of irrigated plantation with additional inputs, the growth is faster than in the rain fed plantation, hence thinning regime has to be early and intensive. An under thinned teak plantation in Chhindwara district, was thinned in March 2003 and after thinning within a span of 5 months the plantation has a total canopy closure. This shows that if thinning was done earlier the girth increment could have substantially increased.

Table 3. Growth parameters of high input teak plantation, measured in January 2002

Division	Planting place	Year of planting	Planted trees	Measurement month	Survival percentage	Average Height(m)	Average Girth (cm)
Jabalpur	Sarvahi	1998	25000	Dec-01	89	1.88	6.79
Chhindwara	Karaboh	1998	42700	Sept. 2001	100	6.41	19.94
Seoni	Ludgi	1999	19743	Nov-01	99	3.84	11.88
Seoni	Mohgaon	1999	20405	Dec-01	100	5.01	14.8
Chhindwara	Aamlaa	1999	38871	Oct-01	99	6.5	18.84
Betul	Sonaghati	1999	8542	Feb-02	99	5.38	15.56
Betul	Baretha	1999	7320	Feb-02	99	3.95	10.97
Khandwa	Borgaon	1999	18827	Feb-02	99	6.1	16.54
West Sidhi	Gajri	1999	1728	Nov-01	97	6.09	20.9
Bilaspur	Bamiyadeeh	1999	16952	Jan-02	99	3.41	12.15
Hoshangabad	Dokrikheda	2000	19232	Feb-02	94	3.39	15.32
				Average	**97**	**4.72**	**14.88**
				Minimum		**1.88**	**6.79**
				Maximum		**6.5**	**20.9**

The data of a few high impact teak plantations from SFRI study with respect to their survival percentage, height growth and diameter growth given in Table 3. This shows that these high input plantations have done very well in survival percentage. Height growth is also very encouraging. But due to delay in thinning the girth increment commensurate with the input could not be achieved in some of the plantations.

Way forward

There is a need to use superior planting material raised in clonal nurseries. Madhya Pradesh has 1,160 hectares of teak seed production areas, which are capable of producing good seeds. 385 ha of Clonal seed orchards have been raised which are source of superior clones of teak 474 ha of seedling seed orchards have also been raised Eleven research and extension nurseries have been created with facilities of mist chamber green house and poly propagators, which can produce large scale superior clonal teak plants. There is a potential to raise large-scale teak plantations with these clonal materials thereby increasing the productivity of available of teak timber in the state. Madhya Pradesh, which is now leading producer of natural teak timber, can also come up as largest producer of plantation teak as well.

The Lok Vaniki Act, promulgated in the state for the management of teak forest is also picking up momentum. This is likely to produce a large quantity of teak timber, as the farmers will feel encouraged to raise teak on their own holdings. Thus, the State of Madhya Pradesh with largest forest area can play a leading role in the production of teak timber.

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Status of Teak in Andhra Pradesh, India

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ABSTRACT

The status of teak in the state of Andhra Pradesh, India was reviewed. The major aspects discussed include: teak plantations, germ plasm, seed collection areas and improved seed technology, clonal seed orchards, vegetative propagation including tissue culture, provenance and clonal performances and tree improvement programme.

Keywords: Teak management, clonal orchard, genetic improvement

INTRODUCTION

Teak is an important constituent in the floristic composition of the dry deciduous forests of Andhra Pradesh. It varies from pure to mixed crop occurring as sprinkling in the miscellaneous dry deciduous forests which represent the highest evolved form in Godavari valley and the Krishna basin region of the state. Here Teak is found constituting 30 per cent and more of the crop. Mixed Teak forests constitute about 14 per cent of the total forest area in the state measuring 9,145 square kilometers.

Trees reaching a height of 15 to 20 m and a girth of 130 to 200 cm were a common sight in Adilabad, Warangal, Karimnagar, Nizamabad and Khammam districts and also in the valleys and plateau of Nallamalai Hills in Kurnool District before the biotic interference during the past 3-4 decades made most of these majestic trees disappear. Teak in pole and small timber dimensions is found in Mahaboobnagar and Medak Districts. The principal natural factors determining the composition and distribution of Teak are variations in altitude which range from 250′ to 3000′ above Mean Seal Level and rainfall varying between 750 mm to 1500 mm. The soil conditions where it thrives well are well drained deep sandy loams derived from granitic gneiss formation. Wherever such soils tend to be more clayey, it disappears altogether giving place to other species.

Species commonly met along with Teak mixed with Bamboo are:

Anogeissus latifolia
Lagerstroemia parviflora
Chloroxylon swietenia
Erythroxylon monogynum
Hardwickia binata
Pterocarpus marsupium
Terminalia tomentosa
Adina cordifolia
Cleistanthus collinus

Prior to these forests were being managed on scientific lines, permission to remove selected Teak trees on permit system, even as late as in 1911, ruined some of the lovely teak areas. Thus, some of the Teak bearing zones though imperceptibly, but nevertheless surely, were converted from Teak or mixed Teak crop to miscellaneous forests. Due to population pressure and unabated biotic factors the Teak resources of the state have considerably decreased both in extent as well as in density, quantity and quality. Constant fires in the summer season and overgrazing damaged the existing stock and prevented natural regeneration. Soil conditions have also deteriorated. No where in its natural habitat, natural regeneration is found satisfactory. Past working plans prescribed artificial regeneration of teak in some of the promising blocks in order to introduce new blood and thus maintain natural proportion of teak in some of the mixed Teak forests and create pure teak plantations in miscellaneous forests devoid of teak but having its associates. Following silvicultural systems, viz. selection-cum-improvement felling, coppice with standards, coppice with reserves and conversion of miscellaneous crop by clear felling supplemented with artificial regeneration, are those under which these forests are worked in the State.

TEAK PLANTATIONS

The history of teak planting in Andhra Pradesh is over a century old and the total planted area up to 2000-2001 is 1,11,931 hectares. The oldest artificially raised teak is through seed dibbling in Marripakala RF in Visakhapatnam District, followed by Wood plantations in Nallamalai catchments of Kurnool District. The Marripakala RF is still famous for its giant sized trees. Most of the planting was done in Teak Conversion Working Circle areas. After the imposition of ban on felling of natural forests in the eighties, clear felling and raising pure teak plantations has been stopped. Currently, the natural teak bearing forests, which became degraded due to heavy biotic interference, are being rejuvenated with the involvement of local people constituted into Vana Samrakshana Samithies (VSS) under the concept of Community Forest Management (CFM).

Most of the working plans prescribed four thinnings in teak plantations during 7th, 14th, 22nd and 32nd years, rotation being 50 years when final extraction is taken up. The thinning prescriptions are given in Table 1.

Annually, about 10,000 m^3 of timber is sold from the department's sale depots. During 2001-2002, the quantity sold is 11,670.566 CMT. Most of this is seized in the offence cases.

Management of degraded teak forests

There are vast areas of degraded teak forests of density less than 0.4 with good viable rootstock. Since teak is a very strong coppicer with copious availability of viable rootstock, these forests are now being rejuvenated by involving the local communities under the concept of CFM by coppicing the viable rootstock while ensuring adequate protection from grazing, fire and other biotic factors. Further, the element of 'negative selection', which has crept in as a natural sequel to the events that have resulted in degradation of these forests, is being set right by selective thinning operations, once the regeneration establishes.

Likewise, in the teak plantations which were subjected to illicit felling, stool dressing/coppicing are being taken up. This operation will induce the coppice shoots to come up and after a period of 2-3 years, the promising shoot will be allowed to form the main crop. If already the coppice shoots have come up, the best one will be selected. The plantations which suffered from congestion, are being opened up by prescribing a thinning regime. Cultural operations like climber cutting, hygienic cleaning are being carried out to take maximum advantage of the growth potential of the crop. Following matrix details treatment and harvesting schedule in degraded Teak forests under the CFM programme (Table 2)

The thinning schedule is that, first thinning will be taken up five years after the 'creation' phase of treatment. Subsequent thinnings will be taken up as

Table 1. Thinning prescriptions in teak plantations

Time	Espacement in meters	No. of stems per ha	Remarks
Initial planting	2.0 m x 2.0 m	2500	
	2.5 m x 2.5 m	1600	
7th year	2.8 m x 2.8 m	1250	Mechanical thinning removal of alternate diagonal lines.
		800	
14th year	3.9 m x 3.9 m	600 to 650	Removal of alternate rows
22nd year	4.7 m x 4.7 m	450	Silvicultural thinning
32nd year	5.8 m x 5.8 m	300	Silvicultural thinning

estimated in the above matrix, but could well vary as stand growth is monitored on various sites. Final felling is scheduled for 30-32 years after 'creation' at which point decisions will be made on the future management of the forest, with continuing natural regeneration from coppice and seedlings (leave seed trees) is possible, although conversion to plantations is another option particularly in better sites.

Tree improvement

After the advent of social forestry programme in the State in the eighties, growing of teak has become extremely popular and millions of teak stumps are planted every year in all plantable places ranging from house yards to vast agricultural fields. Teak constitutes one of the major tree species in agroforestry in the State. There is increasing interest in teak plantations for personal investment under shareholder schemes, and for planting even in non-traditional areas by farmers.

The plantations raised by the department are of variable quality due to differences in site, treatment and genetic stock. Illicit removals also contributed to poor yields from the plantations. Records indicate that the MAI is hardly 2-3 m^3/ha/year. Thus there is a general need to increase the productivity of Teak plantations through selection of genetically-improved varieties, by improving the quality of planting stock, by better site selection and/or site management, by more intensive stand management, including alternative agroforestry systems and by better protection measures against insect pests and smugglers.

Teak improvement in Andhra Pradesh has started as long back as in 1972 with the appointment of a Forest Geneticist in the Research and Development Circle. In the initial years the improvement work was concentrated towards selection of plus trees, selection thinning, upgrading, fertilization and registration of Seed Production Areas and grafting trials to evolve a successful and reliable grafting technique for teak in spring and autumn seasons. Andhra Pradesh was a participant of establishment of All India Teak Seed Origin plots (1939) and also International Provenance Trials (1976-80) of FAO–DANISH Seed Centre, Humlebaek, Denmark. A teak seed origin plot was laid out during 1967 in Medipally in Karimnagar District.

The Indo-Danish project on seed and tree improvement functioned at Hyderabad during the period between 1975-85 and the participation of several Indian states in FAO-DANIDA provenance trials of Teak have brought scientific temper, rationale and uniformity in the field designs and experimentation of provenance trials, seed orchards (both clonal and seedling origin), etc., enabling

Table 2. Treatment and harvesting schedule in degraded teak forests under the CFM programme

Year	Operation	Remarks
1	Advance works	Clearance of undesirable growth, stump cutting, soil and moisture conservation
2	Creation	Coppice singling, clearing unwanted growth, soil and moisture conservation, fire management
3	Maintenance	Further singling, clearing unwanted growth, weeding and soil working, fire management
4 to 32	Fire protection and watching	Rehabilitation of water conservation structures will be done periodically as required
7	First thinning	50% stems removed, silvicultural selective thinning, yielding mainly poles plus limited *bajus* and *vasams*
12	Second thinning	Reduced to approx. 300stems/ha. Mainly *vasams* and *bajus* with some *dulam* (small timber)
22	Third thinning	Reduced to 100 stems/ha., Yielding *bajus* and *dulams*
32	Final felling	50 stems left as seed trees. Timber logs up to 120 cm mid girth and firewood

statistical analysis and interpretation of results and draw scientific conclusions at international level.

More recently under the Research plan implemented under the World Bank funded AP Forestry Project, research on teak improvement constituted one of the major programmes designed to bring about an improvement in the average volume increment of Teak plantations to 10 to 12 m^3/ha/year, together with a shortening of the rotation to 25-35 years (normally it ranged from 50 years to 80 years in the old working plans). Teak "tree farms" established with improved planting stock out side the forests, will increase the quality and production of timber and will reduce pressure on the natural forests.

Under the genetic improvement of teak, the objective is to select and breed superior varieties of teak suitable for sites in Andhra Pradesh, through provenance testing, plus tree selection, progeny testing, seed orchards and clonal forestry. A breeding strategy has been formulated followed by a coordinated operational breeding programme. Results of the project will be made available to growers through the availability of good seed from seed orchards and superior clonal propagules.

Coming to genetic research in teak, Andhra Pradesh has started the work in this direction during seventies and the efforts so far put in are mainly intended to exploit the variation existing in the nature by identifying Candidate Plus Trees, conducting Provenance trials, by developing Seed Production Areas and Seed Collection Areas as an interim source of seed production and establishing clonal banks, multiplication gardens and production of certified seed from seed orchards as a next step, with the ultimate aim of production of certified and tested seeds from seed orchards after progeny testing to quickly achieve the genetic gain and heritability of desired characters by family and individual selections and their selective breeding.

The desired characters in teak include faster growth rate, clean and straight bole, natural pruning, etc. Fibre and wood qualities are heritable characters, while colour, size, grain and width of annual rings are reckoned as being more influenced by environment, availability of nutrients in the soil and its climate and parameters like quantum of rainfall, its distribution (number of rainy days) determining the growing seasons (periods). Trials on development and standardization of pre-treatment of seed and vegetative propagation techniques including rooting of green leafy cuttings and tissue culture, nursery technique for bud grafting, production and storage methods of scion (bud wood) material, trials for rooting of leafy cuttings, etc. were also taken up.

Plus trees

The entire range of distribution of teak in natural forests and old plantations in the state was scouted and 75 plus trees were selected for their superior phenotypic characters, form of the tree, vigour, yield etc and registered in 13 forest divisions. A score card was also developed for selection of candidate trees and their performance in field experiments was evaluated after progeny tests for inclusion in multiplication gardens and gene banks. The registration of plus trees is by nomenclature with letters and figures like AP KE AZ 09 indicating that the first two letters represent the State (Andhra Pradesh), next two forest Division (Karimnagar East) followed by Range (Azamnagar) and the figures indicate the serial number of plus trees in the Range. These plus trees were registered and maintained for yield of bud wood and also as future gene conservation material for both presentation and exchange in the tree Improvement programmes.

Unfortunately some of these Plus trees disappeared over a period of time due to biotic interferences and new candidate plus trees were added during the nineties.

Progeny trials

Progeny testing constitutes an important item of tree improvement programme to determine the superiority of the plus trees in different environments. The progeny trials are thus designed to judge the performance of candidate plus trees and pick up the best phenotypes which are genetically superior. The Progeny trials were started in 1974 at Maredumilli in East Godavari District. The best family selection coupled with best individual selection in the family after culling out poor families, is expected to give sufficient genetic gain in the improvement of teak in Andhra Pradesh. Subsequently, the following progeny test plots were established under the Research Plan of AP Forestry Project during 1996-2000.

1. 1997 Teak Progeny test plot at Field Research Centre, Mulugu by State Silviculturist, Hyderabad with 20 families.
2. 1997 Teak Progeny test plot at Field Research Centre, Rajahmundry with 30 families.
3. 1998 Progeny Test Plot established by Forest Geneticist, Warangal with 42 families at Field Research Centre, Achyutapuram.
4. 1999 Progeny Test Plot established by Forest Geneticist, Warangal with 40 families at Field Research Centre, Achyutapuram.

Data is being recorded at an interval of 6 months for initial 2 years of establishment and after that once in a year on growth parameters like Ht. GGL, GBH (Quantitative), axis persistence, straightness, branching mode, health, etc. (qualitative) and estimated by standard scoring procedures to shortlist the best performing families and individuals (Table 3). The recorded data is being subjected to statistical analysis. The interim result of analysis of data reveals the following five families as best performers in the progeny test plot established in FRC, Rajahmundry. Periodic collection and analysis of data from all the above said progeny test plots is going on and it has been proposed to take the technical guidance of scientists of ICFRE to shortlist the best performing families and individuals within the families.

Germplasm Bank

A germplasm bank covering all the 75 plus trees selected and registered has been established at Kundada – Maredumilli Range (area 0.96 ha in 1975) and (0.1125 ha in 1976) in East Godavari District., Borenelagutta, Mancherial Range and Division in Adilabad District (area 5.5 ha in 1980), ii) Kondaparthi (area 2.0 ha in 1981) and Bandal, (area1.0 há in 1983) in Warangal Division and Range with indigenous teak in Andhra Padesh, viz. Godavari basin covering Adilabad, Karimnagar, Warangal and Khammam districts and artificially planted teak areas of East Godavari, West Godavari and Visakhapatnam districts.

Improved seed technology

The Research wing of AP Forest department collects about 100 to 150 tonnes of Teak seed annually from the Seed Production Areas and Seed Collection Areas. However this is not at all sufficient to meet huge demand in the state and in most of the Social Forestry divisions the seed is directly procured. Teak is the most important species handled by the seed centers at Warangal and Rajahmundry where modern seed testing and processing facilities are available. Trials are under way for better and more efficient methods of handling Teak seed at all stages – collection, storage, pre-treatment and sowing.

Seed Production Areas

In the past no attention was paid for the origin of seed in raising teak plantations and in fact the seed used to be steeped from the forest floor to meet large-scale demand of plantation forestry. The importance of seed source for both the qualitative and quantitative improvement of Teak plantations need not be over emphasized. The habit of sweeping forest floor for Teak seed (fruits) without reference to specific origin (even source identified) has been put to an end to increase its productivity.

Table 3. Standard scoring procedures to shortlist the best performing families and individuals

Family	Ht.(m)	GBH(cm)	GGL(cm)	Axis score	Straightness	Branching score	Health score
APNPL-5	6.48	24.4	32.1	2.47	3.03	3.17	2.77
APVSC-1	6.33	24.2 a	33.35	2.18	2.55	2.96	2.70
APKKR-3	5.83	20.38	30.02	2.57	2.87	3.12	2.87
APNBV-1	5.83	22.20	31.30	1.98	2.30	2.76	2.70
APNPMP-1	5.81	22.76	31.68	2.71	2.68	3.02	2.98

Development of Seed Production Areas is the first step towards improvement of any species. The Seed Production Areas are an interim measure of supply of improved Teak seed required for plantation programmes. This work has started for Teak in Andhra Pradesh during 1973, mainly in Adilabad, Khammam, Warangal, Rajahmundry, Visakhapatnam and Kurnool Circles. In all 65 Seed Production Areas consisting an area of 411.58 ha and 22,499 trees were selected and registered. Seed is being collected from these Seed Production Areas from 1974 onward. Development of Seed Production Areas for reliable and improved seed yields consists the following.

1. Retention of all phenotypically superior trees and spacing them at 10-12 m. to give 80-100 trees per ha.
2. Removal of malformed, poor, suppressed, diseased, dead and drying trees and other than those marked for retention.
3. Removal of miscellaneous species and undergrowth interfering with Teak.
4. Application of fertilizers for increased seed production.

Some of the Seed Production Areas which became too old to collect the seed, were deleted from the list and under the Research project–7 of AP Forestry Project (Selection of superior provenances and development of seed stands of Teak in Andhra Pradesh) 24 new Seed Production Areas covering an area of 506 ha have been developed. Thinning of inferior trees which is unfinished under the AP Forestry Project, is being continued under APCFM Project to ultimately retain about 100 best individuals per ha. Seed Production Areas are being maintained by coppice cutting and fertilizer application. Every year about 100 tons of seed is being collected from Seed Production Areas. The collected seed is being processed, tested and distributed to various divisions for including in the plantation programme.

Seed collection areas

Even though nomenclature of seed collection area is not internationally recognized, these are interim areas earmarked for seed collection, which are not thinned, fertilized and upgraded, but actually selected from superior quality patches in the natural forests and plantations, which will be ultimately converted into Seed Production Areas after necessary treatment. Since these operations are time consuming and costly and sources identified are better than that collected by sweeping forest floor, these areas are selected and identified as an interim measure of seed collection. These are definitely inferior to Seed Production Areas in the genetic context as seed sources but the seed collected from them is at least source identified and source known. In view of the huge demand for Teak seed for plantation programme in Andhra Pradesh, the existing Seed Production Areas and plus trees seed are not adequate. Hence, during 1977-'78 promising Teak plantations were selected by the Geneticist's organization for screening them and upgrading in due course as Seed Production Areas. Seed is being collected from these areas from selected Teak trees from 1977-78 onwards. In all there are 49 Seed Collection Areas in the state covering an area of 835 ha.

Clonal Seed Orchards

Planting programmes are increasingly relying on genetically improved seed to maximize returns from unit area of land. Seed orchards are the most common and cost effective means of assured supply of genetically improved seed. This is accomplished by bringing together phenotypically superior clones in one place adopting a special design to allow maximum cross-pollination. A Clonal Seed Orchard is established by setting out clones as grafts or cuttings.

The first Teak Clonal Seed Orchard in the State, consisting 25 clones was established at Maredumilli in East Godavari District in 1978. The area of the orchard is 2.5 hectares. Another Clonal Seed Orchard was established at the same place during 1976 over an extent of 7.5 ha as per design approved by FRI and consists 25 clones. After a long gap, establishment of Clonal Seed Orchards was resumed during ninetees under the Research plan of AP Forestry Project.

So far, in the Clonal Seed Orchards flowering is found to be poor and fruit setting is very low. The seed collected from those plants which were in flowering, ranges just from 20 gm. to 50 grams. Asynchrony in flowering is leading to poor pollination and fruit setting. This variation in flowering habit is found to be primarily due to site and genetic factors. However experiments like inducing flowering with hormone application, increasing the pollination by attracting more insects by Bee keeping and cultivation of species such as *Cajanus cajan* are going on in the field Research Centres.

Vegetative propagation

Vegetative propagation can play a key role in tree improvement programme as a means of large-scale multiplication of superior clones or tested plus trees. Teak is being propagated successfully vegetatively by means of Bud-grafting method. Teak bud grafts have been produced in large scale in Regional Forest Research Centre, Rajahmundry and supplied to various divisions for establishing Clonal Seed Orchards as well as Clonal Multiplication Areas (CMAs). Clonal propagation of teak through rooted juvenile leafy cuttings is also being tried.

Tissue culture

Since its inception, in early nineties, the Tissue culture lab of Biotechnology Research Centre popularly known as BIOTRIM, Tirupati has concentrated on production of genetically superior trees through optimization of protocols. Many forest species' protocols were standardized, and commercial production of teak was started in 2002. Mostly basic micro propagation methods viz. Meristem culture like axillary and shoot tip culture were followed. Applied aspects like somatic embryo-genesis, organo-genesis were also studied for certain species. Clonal propagation of teak through axillary shoot proliferation was standardized.

Base material

Base material is collected from the 5 best teak clones in the evaluated teak Multiplication Garden at Maredumilli, i.e., APNBV-1, APSBC-1, APNDG-1, APNPMP-1 and APNPMP-2. These clones have been included in the teak CMA at Srinivasa Vanam Field Research Station near Tirupati. Part of the CMA with these clones is converted into Hedge garden and the juvenile buds are collected as base material.

In BIOTRIM campus also a hedge garden has been established with the above mentioned 5 best teak clones collected from teak multiplication garden, Maredumilli during 2003, for collection of juvenile material for rooting of cuttings and tissue culture. Production of APNBV-1 clone started in 2003. A total of 4000 plants were already produced out of which 2700 plants were sold @ Rs. 25 per plant fetching an amount of Rs.67500/-. Macropropagation of teak is also being carried out through Thailand technique i.e., rooting of juvenile terminal cuttings using growth hormones like IBA, IAA and NAA at 1000 ppm. The targeted production of Tissue culture plants and rooted cuttings for 2004 is 10,000 plants, and for 2005 it is 0.30 million.

Pilot programme for family and clonal forestry with teak

The pilot programme on family and clonal forestry with teak was established in September, 1999 with 4 treatments, viz. Tissue culture seedlings, Bud grafts, rooted stem cuttings and stumps. The tissue culture seedlings were supplied by National Chemical Laboratory, Pune, and the bud grafts are from the local teak clone, APNBV-1. The APNBV-1 clone is one of the best clones selected as per performance observed in 1974 Teak multiplication garden, Maredumilli. The trial is replicated 5 times with 40 trees/plot. The main objective of the project is to see the growth performance of teak in different treatments. Data collected on height and survival of trees was analyzed. The results of the analysis

Table 4. Growth performance of teak in different treatments

Planting material	Mean height (m)	Mean girth (cm)	Survival %
Bud grafts	2.10	7.04	99
Stumps	1.58	5.09	93
Tissue culture	2.30	8.16	100
Rooted stem cuttings	2.33	7.82	100

indicated that rooted stem cuttings are having maximum height growth of 2.33 m with 100 per cent survival followed by tissue culture plants (Table 4).

Super culture teak plantation

The objective is to demonstrate and evaluate various approaches to increase growth rate and log quality in teak. This may include "super culture" to optimize the mineral supply (fertilizers, organic matter), water (irrigation, mulching, soil cultivation), and photosynthesis (leaf area, leaf health). Log quality could also be improved by artificial pruning. Optimal treatments for growth stimulation by thinning (and fertilizing ?) of over-crowded existing stands. Therefore an investigation was taken up in Forest Research Centre, Rajahmundry. Five treatments were taken up in an area of 1.5 hectares.

TREATMENT - A : Two year old multirooted stumps were planted in 60 cms cube pits at 4 x 5m espacement, Intensive site preparation including ploughing and drip irrigation was done.

TREATMENT - B : Same as "A" . Teak planted with *Annona squomosa* and *Emblica officinalis* as cover crop to enrich Nitrogen status of the soil.

TREATMENT - C : Same as "A" but espacement is of 2.5 x 2.0 m

TREATMENT - D : Same as "C" but planted with VAM (*Azospirillum, Phosphobacterium*) mixed with soil at root zone at the time of planting.

TREATMENT - E : Control, Normal Crow bar holes with one year pruned stumps.

Data were collected and analyzed. The results are presented in Table 5.

From the above results it is observed that Treatment-A (2 year old multi rooted stumps) were seen performing well with a mean height of 4.55 m and mean GBH of 22.54 cm at 3 years of age, followed by treatment-B with mean height of 4.14 m and mean GBH of 20.67 cm.

Evaluation of International teak provenance trial

Teak is indigenous to India and South-East Asian regions. Indian region is considered to be the only known centre of genetic diversity and variability of teak. Experimental work on natural variation and genetic improvement of teak until recent years, has been scattered. Keeping this in view, international provenance trials of teak were initiated by DANIDA Forest Tree Seed Centre, Humlebaek, Denmark, in collaboration with Forest Research Institute, Dehra Dun and AP State Forest Department.

One hectare provenance and conservation plot was established in the year 1973 in North-East Andhra Pradesh. The location details of the test site are:

Longitude	: 81°43'E
Latitude	: 17°36'N
Altitude	: +500 m
Annual rainfall	: 1470 mm (Spread over 86-95 rainy days)
Max. temperature	: 36°C (May-June)
Min. temperature	: 16°C (December)

The provenance plot was well protected and free from biotic pressure and located in the interior of Devarapalli Reserved Forests of Kakinada Forest Division. The trial region corresponds to semi-moist South-East Asia with trial IP 016 of International series of provenance trials of teak. The purpose of provenance trial will be served if any better genes or populations for at least one trait were found which can be used to improve the productivity of planting programs. In Andhra Pradesh, normally 50 year rotation period is followed for teak. Therefore,

Table 5. Growth performance of teak in different treatments

Treatments	Mean height(m)	Standard deviation%	Mean girth (cm)	Standard deviation %
A	4.55	1.36	22.54	0.08
B	4.14	1.27	20.67	0.07
C	3.26	1.26	12.44	0.05
D	2.68	1.07	10.65	0.12

interim analysis was made for this international provenance plot with the dendrometric data collected during August, 1999. Provenance differences, estimates of heritability were presented and the future scope for utilization of these provenances in genetic improvement of teak are discussed. The trial consisted the following seed lots that were supplied by FAO-DANIDA Forest Tree seed Centre, Humlebaek, Denmark, with local standard as control (Table 6).

Provenance differences

Statistically, no significant differences were found among the provenances as far as height, clear bole height, girth and crown were concerned. The provenances differed significantly in survival percentage and significantly highest stocking rate was reported with local standard (control). However, the survival percentage of local was in par with all other provenances except SC 3035. The lowest survival percentage was reported with SC 3035. When all scores (physical characters) are put together, the Kerala provenance is found to be significantly superior among the Indian provenances. Similarly, the Thailand provenance, Ban Mae Pan (Seed lot 3041) was found to be superior to all other Thailand provenances.

Genetic analysis

Heritability (broad sense) estimates of the provenances for different characteristics studied were quite low to medium. The resultant use of these provenances over local standard as control in genetic advancement indicates that among all the characteristics studied, straightness character is having highest genetic gain (20.34%), followed by crown and branching phenomena (19.35%).

Provenance performances

The height growth and clear bole height of provenances was non-significant and ranged between 14.33-22.33 m, 6.27-11.10 m, with mean of 19.74 m and 8.9 m, respectively. The height growth of provenances was not under genetic control of seed and comparable to site quality-II/III, reported for Indian teak. The girth at breast height ranged from 42.80-69.78 cm with a mean of 56.82 cm, and among provenances the highest GBH was recorded with Indian provenance (63.22 cm) from Kerala (seed lot SC 3020), followed by Thailand provenance (seed lot SC 3041). The total score of physical traits for these two provenances was signifi-cantly higher than other provenances and comparable to Thailand provenance 'Ban Mae Pan' (seed lot SC 3041). The performance of these provenances could be attributed to their origin from moist teak forest, i.e. rainfall comparable to test site location.

The survival percentage of provenances reveal that none of the provenance is having fairly uniform

Table 6. Details of seed lots supplied by FAO-DANIDA Forest Tree Seed Centre

Provenances	Seed Lot number*	Latitude	Longitude	Elevation (m)	Annual rainfall (mm)	Provenance region
Konni, Kerala	SC 3020	09°03′ N	76°41′ E	61	2540	India, Moist West Coast
Jhira, M.P.	SC 3032	22°36′ N	78°28′ E	396	1016	India dry Interior
Murda R.F., Orissa	SC 3035	20°22′ N	82°45′ E	300	1200-1500	India semi-moist East Coast
Bak Baha, Orissa	SC 3036	20°27′ N	82°47′ E	315	1200-1500	India semi-moist East Coast
Bouake, Ivory Coast	SC 3037	07°48′ N	5°07′ E	310	1200	African land races
Nan Cham Pui	SC 3038	18°29′ N	99°49′ E	520	1200	Thailand
Ba Maekut Luang	SC 3039	16°49′ N	98°36′ E	220	1644	Thailand
Ban Pah Lai	SC 3040	18°13′ N	99°59′ E	200	1100	Thailand
Ban Mae Pan	SC 3041	19°02′ N	99°02′ E	450	1200	Thailand
Ban Doi Thon	SC 3043	19°03′ N	99°59′ E	562	1200	Thailand
Local source	SN 001	17°36′ N	81°48′ E	500	1470	India semi-moist Control

* FAO-DANIDA Seed lot number

survival and best being local followed by Thailand provenance 'Ban Mae Pan' (Seed lot SC3041). Approximately 50 per cent of the trees survived on an average for provenances from moist West Coast India (SC 3020), African land races (SC 3037) and Thailand (SC 3041). This shows that these provenances were adaptable to semi moist localities of India. It is interesting to note that semi-moist provenance from Orissa (SC 3035) was having very low adaptability with 28 per cent survival in the semi-moist test site location. This was probably due to minute micro-climatic variations with in the seed zones for which provenances could not adapt.

The provenance from Konni (Kerala), followed by Ban Mae Pan (Thailand) were having best scores for health (3.17 and 2.65), crown and branching (2.92 and 3.09). This shows that these provenances were having light and spreading crown with none to few epicormic branches and moderate infestation of skeletonizer and leaf defoliator. However, screening of these provenances for pests and disease resistance need to be further evaluated.

Genetical characters

Basic information on the magnitude and type of gene action, heritability, genetic advance and genetic inter-relationships are of paramount importance in formulating a meaningful strategy for tree improvement. From the estimates of heritability (broad sense), the heritability for height, girth at breast height, crown and branching, health of trees is weakly heritable ($h^2<25.00$) where as straightness and roundness of stems, clear bole height are moderate to highly heritable. These heritability estimates are with in the range commonly reported for teak.

The results on genetic advance show that there was a higher level of genetic advancement for the characters on total height, clear bole height, straightness and roundness characteristics of stem. In the present study, highest gain was observed for straightness of stem (20.34 %). However, genetic gain was less to moderate for all the characters studied. Therefore, it is better to make selections from superior trees in all provenances in order to maintain a broad genetic base.

Performance of teak clones of Andhra Pradesh in Teak Multiplication Garden

Since the plus trees are at different locations, ensured supply of scion material is not always possible and locally available 'bud wood' gives high percentage of success. Bud grafting is one of the methods of vegetative propagation, widely used in forestry for clonal preservation, multiplication of desired genotypes, establishment of Clonal Seed Orchards, and occasionally used for raising commercial plantations where final product is timber. In the present study, bud grafts are used as a plantation for the supply of scion material for future multiplication programmes. Keeping in view of the above fact, a multiplication garden was established in the year 1974 at Maredumilli, East Godavari District, at an altitude of above 500 m above msl, 81° 48′ E longitude, 17° 36′ latitude. The average annual rainfall of the region is about 1470 mm spread over 86-95 rainy days. The soil of the multiplication garden is fertile and well drained with minimum microclimatic variations. The source of scion material for this multiplication garden was from the following 27 plus trees representing various Forest Divisions of the State (Table 7). Some of the clones could not perform up to the mark, probably due to low acclimatization capacity or poor root stock-scion compatibility. Therefore, a study was made to delineate the clones into best, average and poor based on stand volume and growth increments.

The scion material was grafted onto 1-2 year old rootstock by patch budding in the spring of 1974 and planted during autumn, 1974. Each clone is represented by 12 ramets and were arranged in a single row spaced at 5 m apart and clone to clone 5 m distance was maintained. Periodical stand assessments were made for height, girth, mortality rate and were entered in to plantation journal. The existing data were utilized for calculation of stand volume (5x5m or 400 plants/ha). The trees were grouped into two categories, viz. those having straight stems with no branches' and others with branches having some timber value. The total tree volume (m^3/ha), PAI, MAI were calculated with the data. Grafted plants are supposed to flower and fruit early and supply abundant seed but not the timber of commercial value. In the present study, stand volume and MAI values compare well with the values for plantation raised with seedlings in Class-I site. Total

Table 7. Details of scion materials used in the teak multiplication garden

District	Scion material identity code	No. of plants survived	Locality particulars or source of scion material (origin)
Adilabad	1.APADUW-1	11	Adilabad-Utnoor West block
	2.APADUW-2	12	Adilabad-Utnoor West Block
	3.APKZB-1	08	Kagaznagar-Bijjur
	4.APKZB-2	10	Kagaznagar-Bijjur
	5.APMA-1	08	Mancherial-Neelavai Comp.195
	6.APMN-2	11	Mancherial-Neelavai Comp.195
	7.APMN-3	06	Mancherial-Neelavai Kottur
East Godavari	8.APKKA-1	05	Kakinada East Azamnagar
Karimnagar	9.APKEAZ-1	12	Karimnagar, East Azamnagar
	10.APKEAZ-2	10	Karimnagar, East Azamnagar
	11-APKEAZ-3	12	Karimnagar, East Bhoopalapalli
Khammam	12.APSBL-1	11	Bhadrachalam-Lakkavaram
	13.APSBC-1	12	Bhadrachalam South-Chintur 1938TP
	14.APNBA-1	12	Bhhadrachalam North-nagireddi TP
	15.APNBV-1	12	Bhadrachalam(N)Venkatapuram1933 TP
Kurnool	16.APAKD-1	12	Atmakur, Dornala 1908 Woods TP
	17.APAKD-2	10	Atmakur,Dornala 1906 Woods TP
	18.APAKD-3	04	Atmakur, Dornala 1908 Woods TP
	19.APAKB-1	07	Atmakur, Dornala 1906 Woods TP
	20.APAKP-1	11	Atmakur, Peddacheruvu 1910 Woods TP
	21.APNDH-1	08	Nandyala-GBM 1945 TP
	22.APNDV-1	10	Nandyala, Velugodu 1946 TP
Visakhapatnam	23.APVSC-1	03	Visakhapatnam, Chintapalli, 1935 TP
	24.APVSC-2	10	Visakhapatnam, Chintapalli 1935 TP
	25.APNPMP-1	08	Narsipatnam-Marripakala
	26.APNPMP-2	02	Narispatnam-Marripakala
Warangal	27.APNWE-1	11	Warangal North, Eturnagaram

stand volume ranged between 33.47-242.68 m^3/hectare. Clone APNBV-1 is having the highest stand volume (242.68) at 25 years and MAI of 9.70 m^3/ha/year and the lowest stand volume 33.47 m^3/ha and MAI 1.34 m^3/ha/year for APMN-2 clone. The clones ware classified into three categories based on MAI. Out of 27 clones, performance of 5 clones (where MAI is > 8 m^3/ha/year) could be attributed to good genetic constitution and better adaptability. The physical characteristics of these 5 best clones are presented in Table 8.

Based on the physical characters, the APNDG-1 clone had elite characters followed by APNPMP-1. Substantial enhancement of desirable attributes (e.g. volume production, stem form) could be achieved through systematic tree improvement, followed by mass multiplication. The performance of clones according to site matching could be ascertained to derive maximum advantage. The clones having higher MAI coupled with desirable physical attributes could be mass multiplied. Therefore, these 5 best clones are being multiplied, both by tissue culture and rooting of juvenile leafy cuttings, on a large scale for including in commercial planting programmes.

Germplasm bank

A Germplasm Bank was established in 1975 at Maredumilli. Twenty-two clones were planted in rows of 6 ramets in each row, and they are spaced 12 m apart. The main purpose was to study the effect of various factors on production of seed in seed orchards and also the effect of environmental conditions on the genetic structure of individual tree clones with reference to their flowering characters, intensity of flowering, pollen production, reproductivity, etc. in different areas. Since the plus trees are distributed over large distances in the entire State, spread over in different climatic conditions, it

Table 8. Physical characteristics of five best performed clones

Clone	Physical characters				
	Quantitative characteristics			Qualitative characteristics	
	Survival %	Clear bole ht./total ht. (Ratio)	Crown spread (m)	Stem nature	Pests and disease resistance
APNBV-1	100.00	0.62	19.62	1 or 2 bends	Resistant to Skeletonizer
APNPMP-2	16.67	0.42	25.14	1 or 2 bends with medium flutings	Resistant to Skeletonizer
APSBC-1	100.00	0.56	22.91	Round and more epicormic branching	Moderate infestation of skeletonizer
APNDG-1	66.67	0.73	23.15	Straight and round with good tapering	Resistant to Skeletonizer
APNPMP-1	66.67	0.68	26.15	Straight and round stems	Moderate skeletonizer infestation

is desirable to preserve the clones and observe their characters under uniform conditions of soil and climate. Thus, this plot forms a Clonal Bank or Tree Bank, acting as a testing ground on each of the inherent characters of the various clones, under uniform conditions. This information will be used for culling the plus trees selected, if the clone is not genetically superior.

Teak plantation as an investment: Analysis of plantations raised in Andhra Pradesh

An attempt is made in analyzing the results of 50 year rotation fixed for teak plantations in Andhra Pradesh. In order to facilitate the analysis, number of assumptions from among a wide range of possibilities, with regard to inputs applied and outputs obtained or other interrelations have been made. The chosen alternatives, although preempt the analysis to a certain extent, it may not be too objectionable since the assumptions broadly confirm to the plausible range.

Cost and benefit flow: The yields obtained from periodic thinnings and final felling are assumed to follow the All India site quality III Yield Table projections.

Unit Costs: Unit values of Teak timber and small wood of average quality are presumed from the present sale rates being obtained in the forest department sale depots. Unit costs of forest operations for different years are taken from the Forest Schedule of Rates. It is assumed that the plantation activity does not result in any change in prices, either in inputs or outputs. The criteria used to judge financial performance of various alternatives is the net present value or the net discounted revenue, resulting from a hectare of forest land.

Rotation under different discount rates for site quality III: A positive discount rate is required to account for the capital, whether from internal finance or external borrowing. As discount rate is raised, NPV of the crop falls at the fixed rotation of 50 years, which means the rotation needs to be reduced.

In the analysis of site quality III, teak NPV falls gradually as rotation period is extended. For single rotation, optimal rotation is more than 50 years (for that matter more than 80 years) at low discount rates of 1 or 2 per cent. With increased discount rates, rotation needs to be reduced to keep the NDR on the positive side.

The net revenue curve for AIS III teak plantation with 10 per cent discount is reaching its peak around 75-80 years. With the discount rates of 11, 12, 13, 14 and 15 per cents net revenue curve could be seen reaching its peak earlier which indicates need for shortening rotation with increase of discount rates. Net discounted revenue is changing its value from positive to negative with discount rates between 13 and 14 per cents. This means that IRR is between 13 and 14 per cents (13.834% to be exact).

Forest land is owned by the Government and the land can not be diverted for any non forestry purposes. As such, land value or land rent has not been included in the investment costs. However, the land could have functioned as a grazing land in which case some value need to be assigned and the value should find place in the investment costs. For analysis purpose, if the value of land rent per hectare per year is adopted as Rs.250.00, with discount rate of 10 per cent, this works out to Rs.2521.00 in a 50 year rotation. Similarly, if establishment and administrative costs are also worked out for a 50 year rotation plantation per hectare, assuming the annual cost of Rs. 80.00 per hectare, the NPV comes to Rs. 807.00. If these costs are also taken as part of investment for raising the plantation, the cumulative net benefit at 50 years age falls to Rs. 8347.00 from Rs. 11675.00 at 10 per cent discount. This means a lower rotation could have been fixed for the plantation. When these inputs of land rent and establishment and administrative costs are added, the IRR falls to 12.12 per cent. It is but natural for the IRR to fall since more costs have been added to the plantation.

In this context, 50 year rotation of site quality III is able to support higher rental value of the land or is able to earn a higher rent per hectare. Thus, the rental value of the hectare will be higher than a 80 year rotation can support in the run. But in this situation, realization of higher rent is not counted since the land is owned by the Government.

Even a lower rotation would not pay for the services of the land at higher discount rates. For instance, at 20 per cent discount, NPV is negative even at 15 year rotation.

The rotation is maximum i.e. after 80 years for 1 per cent discount. This is much lower at 30 years with 5 per cent discount. The maximum discount rate that can be sustained is around 18 per cent, with however an extremely short rotation at 20 years. Beyond this discount rate, even a 15 year rotation shows negative returns.

Thus, on analysis with various discount rates, rotation of 50 years seem to be on a lower side when low discount rates are applied. On the contrary with higher discount rates of more than 10 per cent, the maximum NDR is at shorter rotation than 50 years, although the NPV, at 50 years is positive up to discount rate of 13 per cent.

The 50 year rotation is able to account for a positive NPV. With moderate discount rates of 10 to 13 per cent satisfies the BCR of more than 1 and IRR of more than 10 per cent. The same is not true in a private sector in Indian situations where higher rate of discount of 20 per cent and above is in vogue.

Root trainer *versus* Stump planting of teak -- a comparative study

In traditional forestry, teak plantations are raised by planting stumps (Root shoot cuttings) of approximately one year age. The stumps are made by cutting the healthier seedlings (grown in beds) at the collar level. If the stumps are planted in rainy season, they sprout within 6-7 days. From the past experience, it is observed that the mortality rate is more in the case of stumps, which may be due to lack of quick adaptability of the root system of the stump in the new soil conditions. The other factor that contributes to the high mortality rate is underdeveloped root system of stump at the time of planting and generally it takes some time for the root system for establishing and developing in the case of stump planting. Hence, an experiment has been conducted with teak plants raised in Root trainers in Forest Research Centre, Rajahmundry in the year 1997.

The treatments (stumps and root trainer seedlings) were planted in blocks of 25, each with a spacing of 3m x 7 3m, and replicated four times. Data was collected on survival percentage, height and basal girth 2 years after planting. Height was measured from ground level to growing tip and girth at ground level was measured by running a tape around the stem at collar region. The collected data was subjected to simple statistical analysis like frequency distribution, mean, standard error, etc.

Frequency distribution of seedlings was maximum at 101-150 cm in Root trainer i.e., 33.33 per cent (height), whereas in stumps the distribution was only 13.58 per cent and most of the seedlings were below 100 cm (43.20%), while in root trainer at the same class interval the frequency was only 30.20 per cent. Therefore, root-trainer seedlings were having higher height growth. Similarly, it is inferred from measurements of girth at ground level that the seedlings' distribution in 3-4 cm interval was 37.50 per cent, while it was only 14.81 per cent in the case of stumps.

The root trainer seedlings were having higher height, girth at ground level and survival (140.81 cm, 3.6cm, 96%) than the stumps (136.53 cm, 3.5 cm, 81%). Further, co-efficient of variation for root trainer raised teak seedlings was comparatively less than the traditional stump planting. The better establishment of root trainer seedlings could be attributed to well developed root system besides the organic potting medium used in them. Therefore, the root trainer technology can be adopted for raising teak plantations for improvedsurvival percentage and better growth than the traditional stump planting.

Teak in Karnataka State, India

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ABSTRACT

Teak has always been a high priority species in tree improvement programmes of Karnataka Forest Department. The major activities include: Provenance selection from natural forests, management of seed production areas, selection of Candidate Plus Trees, clonal testing of seed orchards and vegetative propagation from cuttings and tissue culture techniques.

Keywords: Tree improvement, clonal multiplication, seed orchards, intensive plantation management.

INTRODUCTION

Teak is the premier timber of Karnataka's forests, and Dandeli teak is as famous as Burma teak for its golden colour and fine grain. It occurs mainly in mixture with other hardwood timbers in the mixed moist and dry deciduous forests, mostly in the Western Ghats and some off-shoots of the Eastern Ghats. In the past, these forests were worked intensively under Uniform or Selection systems to increase the proportion of teak, and when natural regeneration failed to come up sufficiently, under clear-felling and (artificial) planting with teak stumps. Teak plantation was a high priority in the forestry operations, with some 139415 hectares raised up to December 1998, and annual targets of 2000 to 2500 ha being the norm. Subsequently, the practice of clear-felling having been discouraged and given up, the planting targets have come down to 250 ha or so per year mainly in open patches and old failed plantation areas. Under the latest Working Plans, even the existing teak plantations will be left to diversify into mixed crops wherever natural recruitment of associate species like nandi (*Lagerstroemia*), *Terminalia* species, *Xylia*, etc. has taken place. Demand for timber being quite high due to the continued growth of urban centres, there has been much interest in teak as a farm forestry species. A number of plantation schemes launched with public subscriptions have failed to deliver the promised high rates of growth of timber, but individual land-owners have planted teak on farm boundaries, vacant patches, etc. Studies are required to work out suitable silvicultural and management practices for farm forestry conditions, e.g. economically optimum spacing, thinning regimes, plant protection, utilisation, marketing, etc.

As is well known, teak is the premier timber of peninsular India and particularly Karnataka, where Dandeli teak is as famous as Burma teak for its golden colour and fine grain. It occurs mainly in mixture with other hardwood timbers in the mixed moist and dry deciduous forests in Karnataka, mostly in the Western Ghats and some off-shoots of the Eastern Ghats.

These forests were worked intensively in the past under Uniform or Selection systems, with a view to removing inferior trees, increasing the proportion of teak by selectively removing non-teak species, and improving the quality of the future teak crop by removing inferior stems. When natural regeneration failed to come up sufficiently (ascribed to various factors like heavy grazing, frequent occurrence of fires, and site degradation), artificial regeneration practices were developed, e.g. clear-felling and planting with nursery-raised teak 'stumps'.

Teak plantation has traditionally been a high priority in the State's forestry operations, and some 146,367 hectares have been raised up to December 2001, with annual targets of around 2000 ha being the norm. During the late 1970's and early 1980's, owing to the general disapproval in the country of clearfelling and other drastic interventions in the natural forest, the practice of clear-felling and burning in concentrated patches to create conditions favourable for stablishment of planted teak stumps in the moist deciduous forests (the so-called 'rab' system) has been given up. Teak planting has since been relegated to open patches and old failed plantation areas, which naturally do not provide the best conditions of soil and moisture, although once established the tree fights hard for survival and growth even if cut back or affected by fire. However, there is no doubt that growth and form will not be very good in the degraded sites left for fresh plantings, unless ameliorative measures like manuring, irrigation etc. are experimented with. Under the latest Working Plans, even the existing teak plantations will be left to diversify into mixed crops wherever natural recruitment of associate species of *Lagerstroemia*, *Terminalia*, *Xylia*, etc. has taken place.

Demand for timber being quite high due to the continued growth of urban centres, and declining production from indigenous forests, a substantial quantity of timber, including teak, is being imported, not only from traditional exporters like Burma, but even, ironically, from plantations. grown in Africa. Correspondingly, there has been much interest in teak as a farm forestry species. Unfortunately, a number of commercial plantation schemes, launched during the 1980's with public subscriptions, have failed to deliver the promised high rates of growth of timber (unreasonable projections of 1 cubic metre per tree at 15 years), leading to fall in confidence in corporate forestry, but individual land-owners have continued to plant teak on farm boundaries, vacant patches, etc. One example in Karnataka State is available in villages around Bijjawara some 40 km from Bangalore, in Devanahalli Taluk, involving dozens of land-owners and around 100,000 trees planted. Individual trees have shown remarkable growth, especially a couple of trees planted behind a house in Venkatagirikote village, which has grown to some 130 cm. Girth at 10 years, possibly because of flowing waste water and proximity to a manure dump. Block plantations of the same age on dry land have not done so well, and presumably require heavy thinning and ameliorative measures to boost growth. Some timber from farm forestry plantings tested at the Institute of Wood Science and Technology, Bangalore, were seen to have satisfactory strength qualities. Studies are required to work out suitable silvicultural and management practices for farm forestry conditions, e.g. economically optimum spacing, pruning techniques, thinning regimes, plant protection, wood quality, wood treatment and seasoning, utilisation, marketing, etc.

TREE IMPROVEMENT

Teak has always been a high priority species in tree improvement programmes of Karnataka Forest Department. The following are the main activities:

i. Identification of provenances in natural forests.
ii. Identification and management of Seed Production Areas (SPA) and Seed Stands, both mainly in older plantations (hence of unknown seed source/locality), amounting to some 964 hectares as per KFD Research Report, 2001.
iii. Selection of Candidate Plus Trees (CPT), 569 identified by 2001.
iv. Testing of provenances, of half-sib progeny (seedlings with known mother tree), and of clonal propagules.
v. Raising of Seedling Seed Orchards (SSO, 30.6 ha) and Clonal Seed Orchards (CSO, 355 ha), mainly with offspring and grafts/cuttings of Candidate Plus Trees.
vi. Experimentation with tissue culture.

Since clear-felling and concentrated planting in the high forest has been (rightly) given up, it is likely that the main application of intensive culture techniques will be in private and institutional lands, often in an agro-forestry environment. Research and Development will need to focus on these non-traditional contexts and conditions, and suitable modifications will have to be suggested to the classical, forest-oriented yield models and silvicultural regimes.

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Status Report of Teak in Tamil Nadu

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ABSTRACT

After a brief review of historical aspects of teak in Tamil Nadu State of India, natural distribution was elucidated. The teak improvement programme includes: establishment of seed stands and production areas, selection of provenances and Plus trees, progeny trials, standardization of vegetative propagation methods and establishment of clonal seed orchards. Teak plantation trials were initiated with irrigation for better growth of teak and higher production of quality timber.

Keywords: Improvement, clonal multiplication, seed orchards, intensive plantation management

INTRODUCTION

Indian region is considered to be the only known center of genetic diversity and variability of teak with a distribution of over 8.9 million hectare. In India, Teak is naturally found in the Peninsular region below 24 degree latitude. The most important Teak forests are found in Madhya Pradesh, Maharashtra, Tamil Nadu, Karnataka and Kerala.

Tamil Nadu has a great tradition of preserving it's forest wealth and concern for environment, respecting the nature. The ancient Tamil poets have emphasized the importance of dense forests, clean water and fertile soil in providing ecological security to mankind. Teak in Tamil Nadu is confined to lower slopes of Nilgiris and in Coimbatore, Madurai, Kanyakumari and Tirunelveli districts.

HISTORY OF TEAK IN TAMIL NADU

Teak (*Tectona grandis* L. f.) is one of the most valuable trees of Tamil Nadu and is indigenous to to the State. Teak planting in Tamil Nadu was initiated during the early years of the last century in selected, suitable places. Attempts were made to raise teak plantations earlier in Mudumalai forests of Gudalur Division, between 1863 and 1875. It is documented that the natural teak population spread to many parts of the southern tracts from Parambikulam, Anamalai belt, i.e., the Seechally area of the present Indira Gandhi Wildlife Sanctuary.

GEOGRAPHICAL LOCATION OF TAMIL NADU

Tamil Nadu is located between 8°5' and 30°5' of North latitude and 76°15' and 18°20' of East latitude. It is bound on the North and West by the State boundaries of Andhra Pradesh, Karnataka and Kerala, respectively. In the South, the Indian Ocean and in the East, the Bay of Bengal forms the boundaries. It has a coastal line of 990 km and a boundary of 1200 kilometres.

The Western Ghats flank the western boundaries of Tamil Nadu. The Nilgiris, the confluence of Western and Eastern Ghats are a massive ranges of hills with average elevation of 200 metres. All the rivers in the state flow East to Bay of Bengal. The climate is mostly hot and dry in the plains, the coolest month being January. April, May and June are the hottest months with a maximum temperature touching 45 degrees. Humidity in the coastal region is 60-80 per cent. The bulk of rainfall in the plain is received during October to December, i.e. by the North-East monsoon. The annual rainfall varies from 600 mm in the inland to 1250 mm in the coast. The hilly regions in the West receive about 2000 to 3000 mm on an average from both the monsoons.

The highly developed southern most State of the country, Tamil Nadu has a geographic area of 130, 058 km² (4% of country's geographic area). The main rivers flowing through the State are the Cauvery, the Pennayar and the Vaigai.

The forest area in Tamil Nadu is 22,871 km², which is about 17.6 per cent of the total area and three per cent of the country's forest area. The State is blessed with diverse ecosystems like Evergreen Forest, Tropical Dry Evergreen Forest, Sholas, Grass lands, Moist Deciduous Forest, Dry deciduous Forest, Thorn Forest, Wet lands, Littoral Forest, Mangroves and the Marine ecosystem. Based on the classification of forest types by Champion and Seth (1968), 9 major Forest types occur in Tamil Nadu. They are given in Table 1.

Table 1. Forest types of Tamil Nadu

	Forest types	Area in km²
1.	Tropical wet evergreen	602
2.	Tropical semi evergreen	227
3.	Tropical moist deciduous	2500
4.	Littoral and swamp	227
5.	Tropical dry deciduous	12455
6.	Tropical dry thorn	4999
7.	Tropical dry evergreen	261
8.	Sub tropical broad leafed	1136
9.	Montane wet temperate	341
10.	Others	175

The wide variations in climate ranging from tropical to temperate with rainfall as low as 600 mm on a semi arid plains to over 3500 mm in the Western Ghats, contribute to diversity of the natural vegetation.

Distribution of teak in Tamil Nadu

Teak occurs in the moist deciduous forests of Coimbatore, Nilgiris, Madurai, Kanyakumari and Tirunelveli. Teak forests of the State are divided into Southern Tropical moist deciduous forests (3B/C 1B), and Dry Teak forests (5A/C1b). Teak grows typically in the moist and dry hilly tracts of the Western and Eastern Ghats, between an elevation of 200mt to 1000metres. Good plantations have been raised by the Forest Department and Ryots in many places in the plains of Tamil Nadu. The general climate of teak is hot wet to dry and prefers temperature varying from 20 to 43^{0}C. Teak is found mostly in the south Indian moist deciduous forest and southern tropical moist deciduous forest.

The South Indian Moist deciduous forests are found in the lower slopes of Anamalai, Nilgiris and Palani hills. Rainfall varies from 1500 to 2000 mm with dry season of four to five months. The chief features of this forest type are the prevalence of a leaf less period in dry season from February to April. *Tectona grandis* is the most characteristics species. The important associates of teak are *Terminalia* species, *Dalbergia latifolia, Pterocarpus marsupium, Lagerstromia lanceolata, Adina cordifolia* and *Bambusa bambos.*

The southern tropical dry deciduous forest is usually found in lower slopes of Nilgiris, Anamalais, Palanis and also on plateaus of Javvadis, Hasanur and Hosur. The annual rainfall is 1000 to 1200mm. The common species associated with *Tectona grandis* are *Anogeissus latifolia, Dalbergia latifolia, Terminalia tomentosa, Terminalia chebula, Terminalia bellerica, Pterocarpus marsupium* and *Dalbergia latifolia.* The chief Bamboo species is *Dendrcalamus strictus.*

Most of the teak forest bearing forest tracts of the Western Ghats of Tamil Nadu state have also been gifted with bio diversity, both floral and faunal. They have been declared as wildlife sanctuaries or national parks and are protected from biotic interference. Therefore, harvesting of teak trees from these forest are not carried out for commercial purposes. Natural teak and plantation teak population of these protected areas have become part of the eco systems of these tracts.

TREE IMPROVEMENT WORK

The teak improvement work in Tamil Nadu included the following works like formation of seed stands, seed production areas, selection of plus trees, provenance trials and progeny trials, standardization of vegetative methods of propagation in many research centres. Tamil Nadu Forest Department has the distinction of having 63 research centres and 6 modern nurseries. Teak tree improvement works ensuring quality timber production is one of the thrust areas of forestry research. Full tree utilization studies have also been done with teak by the Forest utilization wing of the Research Circle of Tamil Nadu Forest Department. The performance of teak have been evaluated in the various research centers, which are located in the 7 agro climatic zones of the state. For any species tree improvement works starts with selection of plus trees from various agro climatic zones. Tree improvement work in Tamil Nadu commenced during 1967. Tamil Nadu is the home for many distinctively different native provenance of teak populations found in areas like Hasanur, Kalakad, Topslip and Annamalai. In this state, 73 candidate plus trees were selected and details of various plus trees selected from different localities are furnished in Table 1.

Establishment of seed production areas started in Tamil Nadu in 1970's. Details of various seed production areas in Tamil Nadu are as follows. Superior performing plus trees were propagated vegetatively and clones from different localities were assembled to form Clonal seed orchards. Particulars of Clonal Seed Orchard of Tamil Nadu are as follows The teak seed stand covers an area of 20 ha in Pollachi Range. The Teak seed production area covers an area of 73.5 ha. The Clonal seed orchard area is 11 ha and the seedling seed orchard area covers an area of 2 ha in Pollachi Research center.

Research in teak on the seed production, collection, cleaning, handling, storing germinability and viability test are being carried out by Deputy Conservator of Forests (Genetics), Coimbatore. Tamil Nadu is the only state, which processes a full-fledged seed center with all infrastructure, where more than seeds of 140 tree species are handled annually. Teak seeds are one of the important species handled in the tree seed center at Coimbatore by Deputy Conservator of Forests, Forest Genetics Division, Coimbatore. Over 10 tonnes of teak seeds are handed annually in the seed center at Coimbatore. Apart from this standardization of various pre treatment methods is also carried out.

The various pre treatment methods tried were:

i. Boiling water treatment followed by immediately soaking in cold water for 1 day, repeated thrice.
ii. Treating with Concentrated Sulphuric acid followed by hot water soaking for 24 hours.
iii. Mechanical scarification
iv. Mechanical scarification followed by treating

Table 1. Details of candidate plus trees selected from different localities

Sl. No.	Name of species	Year of forming	Area in ha	Location	Range
SEED PRODUCTION AREAS					
1.	*Tectona grandis* (SPA II)	1971	1.60	Kozhikamuthi	Pollachi
2.	*Tectona grandis* (SPA I)	1972	9.60	Seechally Valley	Pollachi
3.	*Tectona grandis* (SPA III)	1973	3.20	Seechally valley	Pollachi
4.	*Tectona grandis* (SPA IV)	1982	10.00	Seechally valley	Pollachi
5.	*Tectona grandis* (SPA VI)	1989	9.12	Seechally Valley	Pollachi
6.	*Tectona grandis* (SPA VII)	1999	20.00	Kozhikamuthi	Pollachi
7.	*Tectona grandis* (SPA IX)	1999	20.00	Varagaliar	Pollachi
CLONAL SEED ORCHARDS					
1.	*Tectona grandis*	1972	0.920	Erumaiparai	Pollachi
2.	*Tectona grandis*	1992	6.50	Ambuliparai	Pollachi
3.	*Tectona grandis*	1996	2.53	Erumaiparai (Damaged)	Pollachi
4.	*Tectona grandis*			Neyveli	State Forestry Research Institute, Kolapakkam

with concentrated sulphuric acid followed by boiling water. Cooled and sown.

v. Seeds kept in hot air oven for 30 minutes and cooled. This was repeated thrice and seed sown.
vi. Seeds placed on hot pan and given scorch. They were immediately soaked in hot water for three days.
vii. Seeds soaked in cow dung slurry, covered with straw and allowed to sprout.
viii. Seeds were broken and exposed embryos were sown.
ix. Gibberellic acid treatment
x. Seeds were kept in a cloth bag and kept in a termite hill. After 2 weeks, the seeds were collected sown.

Among all treatments, seeds kept in termite hill germinated well and germination percentage was above 50 per cent. All other treatments did not give germina-tion more than 15 per cent. Removing the seed coat increased the germination but the seedling survival was less.

Teak productivity has been evaluated with convergent technology applications, which included application of Vermicasting, VAM and Bio fertilizers like Azospirillum and Phosphobacteria both in the nursery and in the field. This has exhibited marked improvement in the productivity of Teak. Research is concentrated on short rotation teak. Through intensive genetic combing, Teak clones for various forest types and degraded sites have been identified and developed.

In the Research wing all the plus trees of Teak identified have been multiplied through bud grafting and planted in Clonal Seed orchards in different locations for seed collections and further multiplications. Clonal Seed orchards are producing sufficient quantity of quality seeds. However, it was observed that there is lack of flowering among various clones planted during 1985-1986 in Clonal Seed orchards at Neyveli, which has a soil pH of 4.2. Therefore study on induction of flowering was taken up during 2000 in this center.

INDUCING FLOWERING IN TEAK CLONAL SEED ORCHARD AT NEYVELI

A study was undertaken to find out the effect of different flower inducing nutrients, chemicals and hormones in Clonal seed orchards at Neyveli, State Forestry Research Institute, Kolapakkam. The details of the study are as following. The study commenced during 2000-2001 with an objective to induce flowering in Teak by application of different chemicals and the treatment details are given below.

T1	-	Control
T2	-	Micro nutrients, Borax 100g + zinc sulphate 100g + Copper sulphate 50g
T3	-	Potassium nitrate 1% spray
T4	-	Paclobutrazol application 15ml/tree
T5	-	Planofix 4.5ml/tree
T6	-	Salicylic acid 100ppm
T7	-	DAP 2% spray
T8	-	Micronutrient mixture spray 2%

Initially, it was observed that application of Paclobutrazol and Salicyclic acid induced flowering compared to all other treatments. The experiment is under observation.

The forest policy of Tamil Nadu is governed by the National Forest policy 1988. While ensuring the maintenance of environmental stability and ecological balance the Forest Department is also doing its best for increasing the forest cover / tree cover in the state through various state and centrally sponsored schemes. Teak along with 50 other important tree species are being evaluated and to make it available to people for agro forestry practices. Teak constitutes an important species planted in various programmes to meet the timber requirement of the local people under production forestry it is grown in forest lands, community lands, canal bunds and also in private lands.

TEAK UNDER DRIP IRRIGATION

The trial was initiated at Seshanchavady Research Center during 1999-2000 with an objective to observe the growth performance of important timber species under drip irrigated conditions and to find the suitable water regimes for achieving good growth. It was found that watering, schedules 6lt/hour is the ideal condition for better growth of teak as compared to control. A study was also taken up at Melchengam

Table 1. Current status of plus trees selected in Tamil Nadu

Sl. No.	Division	Range	Tree No.	Year of planting	Remarks
1.	Topslip	Thunakadavu	TE-1	1972	FG, Coimbatore
2.	Mudumalai	Kargudi	TNM-4	1925	
3.	Mudumalai	Kargudi	TNM-1	1925	
4.	Mudumalai	Kargudi	TNM-2	1925	
5.	Mudumalai	Kargudi	TNM-3	1925	
6.	Pollachi		TNT - 13		
7.	Pollachi		TNT - 2		
8.	Pollachi		TNT - 3		
9.	Pollachi		TNT - 4		
10.	Pollachi		TNT - 5		
11.	Pollachi		TNT - 6		
12.	Pollachi		TNT - 7		
13.	Pollachi		TNT - 8		
14.	Pollachi		TNT - 9		
15.	Pollachi		TNT - 10		
16.	Pollachi		TNT - 1		
17.	Pollachi		TNT - 12		
18.	Pollachi		TNT - 14		
19.	Pollachi		TNT - 15		
20.	Pollachi		TNT - 16		
21.	Pollachi		TNT - 17		
22.	Pollachi		TNT - 18		
23.	Pollachi		TNT - 19		
24.	Pollachi		TNT - 20		
25.	Pollachi		TNT - 11		
26.	Topslip	Thunakadavu	TE-2	1972	FG, Coimbatore
27.	Topslip	Thunakadavu	TE-3	1972	FG, Coimbatore
28.	Topslip	Thunakadavu	TE-4	1972	FG, Coimbatore
29.	Topslip	Thunakadavu	TE-5	1972	FG, Coimbatore
30.	Topslip	Thunakadavu	TE-6	1972	FG, Coimbatore
31.	Topslip	Thunakadavu	TE-7	1972	FG, Coimbatore
32.	Topslip	Thunakadavu	TE-8	1972	FG, Coimbatore
33.	Topslip	Thunakadavu	TE-9	1972	FG, Coimbatore
34.	Topslip	Thunakadavu	TE-10	1972	FG, Coimbatore
35.	Topslip	Thunakadavu	TE-11	1972	FG, Coimbatore
36.	Topslip	Thunakadavu	TE-12	1972	FG, Coimbatore
37.	Topslip	Thunakadavu	TE-13	1972	FG, Coimbatore
38.	Topslip	Thunakadavu	TE-14	1972	FG, Coimbatore
39.	Topslip	Thunakadavu	TE-15	1972	FG, Coimbatore
40.	Topslip	Thunakadavu	TE-16	1972	FG, Coimbatore
41.	Topslip	Thunakadavu	TE-17	1972	FG, Coimbatore
42.	Topslip	Thunakadavu	TE-18	1972	FG, Coimbatore
43.	Topslip	Thunakadavu	TE-19	1972	FG, Coimbatore
44.	Topslip	Thunakadavu	TE-20	1972	FG, Coimbatore
45.	Topslip	Thunam	TE-21	1972	FG, Coimbatore
46.	Topslip	Thunam	TE-22	1972	FG, Coimbatore
47.	Topslip	Thunam	TE-23	1972	FG, Coimbatore
48.	Topslip	Thunam	TE-24	1972	FG, Coimbatore
49.	Topslip	Thunam	TE-25	1972	FG, Coimbatore
50.	Topslip	Thunam	TE-26	1972	FG, Coimbatore
51.	Topslip	Thunam	TE-27	1972	FG, Coimbatore
52.	Topslip	Thunam	TE-28	1972	FG, Coimbatore

(contd.....)

Sl. No.	Division	Range	Tree No.	Year of planting	Remarks
53.	Udhagai	Mudumalai	TE-29	1973	FG, Coimbatore
54.	Udhagai	Mudumalai	TE-30	1974	FG, Coimbatore
55.	Udhagai	Mudumalai	TE-31	1971	FG, Coimbatore
56.	Udhagai	Mudumalai	TE-32	1973	FG, Coimbatore
57.	Udhagai	Mount stuart	TE-33	1972	FG, Coimbatore
58.	Udhagai	Mount stuart	TE-34	1972	FG, Coimbatore
59.	Udhagai	Mount stuart	TE-35	1972	FG, Coimbatore
60.	Udhagai	Mount stuart	TE-36	1932	FG, Coimbatore
61.	Udhagai	Mount stuart	TE-37	1931	FG, Coimbatore
62.	Udhagai	Mount stuart	TE-38	1934	FG, Coimbatore
63.	Udhagai	Mount stuart	TE-39	1935	FG, Coimbatore
64.	Udhagai	Mount stuart	TE-40	1931	FG, Coimbatore
65.	Udhagai	Mount stuart	TE-41	1930	FG, Coimbatore
66.	Udhagai	Mount stuart	TE-42	1934	FG, Coimbatore
67.	Udhagai	Mount stuart	TE-43	1934	FG, Coimbatore
68.	Udhagai	Mount stuart	TE-44	1934	FG, Coimbatore
69.	Udhagai	Mount stuart	TE-45	1931	FG, Coimbatore
70.	Udhagai	Mount stuart	TE-46	1931	FG, Coimbatore
71.	Udhagai	Mount stuart	TE-47	1931	FG, Coimbatore
72.	Udhagai	Raman pillai	TE-48	1930	FG, Coimbatore
73.	Udhagai	Export Road	TE-49		FG, Coimbatore

Research Center to induce ring formation in teak by alternate water regimes through drip irrigation creating artificial stress and favorable conditions to a set programme. Another experiment was taken up for introduction of *Tectona grandis* in the Theri sand dunes of Nazerath (Tuticorin). The experiment was initiated during 200 with an objective to study the growth performance of Teak in different escapements in the Theri sandy soils. The espacements adopted were 1 x1m, 2 x 2m, 2.5 x 2.5m and pit size followed was 30cm^3. It is seen that teak is performing well with an espacement of 1m x 1m with bio nutrient and bio fertilizer inputs. The study is under further observation.

TEAK PLANTATIONS

Organized teak planting programme started since the first five-year plan, which also included other species like *Acacia, Casuarina* and *Eucalyptus*. Teak was planted for production of high quality timber. The plantation activity got a boost after launching of externally aided social forestry in early 1980's. Currently teak plantations are available in 20,000 ha in Tamil Nadu, which also includes 2000 ha along canal banks in the Tanjore districts.

ESTABLISHMENT OF CLONAL TEAK PLOT

This experiment has been taken up in Sholapuram, Seshanchavady, Lokkur, Melchangam and Maragatta during 1999-2000 with a project period of 10 years. 15 clones of teak have been selected after wide genetic combing from Anthiyur (farm land), Sadivayal and Topslip forest areas and assembled as hedge stools in Bhavanisagar Research Center. The ramets exhibited km per month gbh at 100 months after planting. For the first time, during 1999-2000, branch spouts from the cut stumps of these short rotation heartwood teak phenotypes were successfully rooted and over 10,000 ramets were produced within 2 years time through macro propagation. They were planted out in all the research centers and extension centers to evaluate their growth performance in comparison to the mongrel population. This Clonal plants is exhibiting twice the rate of growth and biomass, when compared to the local teak. Based on the success of this venture experiments have now been taken up in many centers with an objective to

i. Standardize vegetative propagation technique for the different clones

ii. Mass multiplication of various top-performing clones
iii. Supply of clonally propagated material to all the centers
iv. To maintain a bank population
v. Establishment of Clonal seed orchard of Teak

The trial is under observation. Till date around 20,000 Clonal propagules of this very fast growing teak have been produced.

Thus the teak tree improvement work in Tamil Nadu has crossed various steps like genetic combing, selection of plus trees, Establishment of Seed stand, Seed production areas, Seedling seed orchards, Clonal seed orchards, Macro propagation (clones) and Multi locational trials. In future based on the analysis of multi locational trial, top performing clones are to be tried for micro propagation and DNA finger printing.

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Quality Timber Products of Teak from Sustainable Forest Management pp 54-62

Teak in Kerala State, India: Past, Present and Future

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ABSTRACT

Teak was first raised on a plantation scale in Kerala during 1842. Since then, Kerala Forest Department (KFD) has raised large extent of teak plantations, which are now in various age groups and site quality classes. A considerable extent of them are in site quality classes 2 and 3. As on today, the Department manages 74,872 ha of teak plantations in the State, and on an average, 1000 ha of the plantation is being felled and regenerated every year. Considering only the average final yield, which is 60 m^3 ha^{-1} and an average price of Rs.25,000 m^{-3}, State earns a revenue of Rs. 1500 millions/year. The present MAI of the standing crop works out to be 2.423 m^3 ha^{-1} at 60 years, whereas potential MAI could be in the range of 4.9688 m^3 ha^{-1} at same age, which indicates the need for futher improvements with research and management inputs. After the first teak plantation was raised in 1842 by direct sowing/planting natural seedlings and stumps, in order to improve the productivity, Kerala Forest Department has introduced root-trainer technology during 1998. Crop rotation with short rotation leguminous tree crops such as *Acacia auriculiformis* and *Acacia mangium* has also been introduced during 2000. At present, the Department is also attempting to raise clonal teak plantations utilizing 30 clones developed by the Kerala Forest Research Institute(KFRI). There are also some other departures from the conventional teak planting method, with the intention to improve the productivity on a sustainable basis. The paper discusses the present and future management and marketing aspects of teak - a species that stood by the foresters for such a long period.

Keywords: Teak plantations in Kerala, area, productivity, management, marketing.

THE EARLY BRITISH PERIOD

History of teak in Kerala begins with acquisition of Malabar by British during 1792. Till then Malabar coast was generally known to Western World for its spices. With the advent of British regime in Malabar, malabar teak became world famous and vergin forests of Travancore, Cochin and Malabar were opened up for extraction of teak. During later half of 18th century, England was passing through a critical period due to Napolionic aggression and her safety mainly depended on naval vessels, which required large quantity of timber. The main source of supply was Oak. As the Oak depleted towards the end of 18th century, teak became an admirable substitute for Oak (Kunhi Krishnan, 1997) and Malabar teak played a heroic role in maintaining Englands Naval strength. Large numbers of ships were built at dockyards of Goa and Malabar coast for Royal Navy using Malabar teak. The exploitation continued till 2nd half of 19th century when iron was replaced by wood as principal material for ship building. By that time, enough damage was done to teak and teak completely depleted in the natural teak bearing forests of Kerala.

At this point of time, to maintain the supply of teak to Navy and Railways, it was decided to raise man made teak plantations. Accordingly first teak plantation in the World was raised in 1842 at Nilambur, by sowing 30,000 teak seeds and 10,000 teak seedlings uprooted from natural forests. This initiative was taken by the British Collector, H.V. Conolly. In the memory of this novel work, 2.28 ha of this plantation is still retained at Nilambur as Conollys plot. There are 199 trees with average girth of 270 cm. This is one of the most famous forestry plots in the world and foresters all over the world visit this plot even today, to pay homage to the stupendous original work done by Conolly and Chathu Menon. Between 1844 and 1862, about 1513 acres of teak plantations were raised by Chathu Menon under highly inhospitable conditions of Nilambur (Shanmuganathan,1997). During 1862-1883, J. Ferguson continued the work and he raised another 3436 acres during this period. Thus, Nilambur became Mecca of teak in the world.

HOW THE EARLY PLANTATIONS WERE RAISED?

From 1842 to 1857, no regular spacing was followed in teak plantations. Later, the various combinations of spacing like 7x7, 6.5 x 6.5 and 9 x 9 ft^2 were tried (Shanmuganathan, 1997). The present spacing of 2 x 2m came into being in 1886. The planting of natural seedlings collected from forests was done in 30-cm3 pits. Sowing of seeds was also done in pits. As this was unsuccessful, the seedlings were raised in raisen beds of 12m length x 1.2 m width and 0.3m height. This standard bed size is followed even today to raise teak stumps. The plants with full taproot and shoot were planted, till Bourdillon introduced the technique of stump planting in 1891.

From 1920 to 1980, almost all teak plantations raised were under taungya system. Under this system the right to cultivate the area was leased out to societies/ individuals for intercropping with short rotation crops like zinger, hilly paddy, tapiyoka *etc*. The operations like planting teak, maintenance, casualty replacement and other cultural operations like manuring, fire protection *etc.* were carried out during the first three years of plantation by taungyadars.

During 1980's, the approximate expenditure for raising one ha of teak plantation for the first 3 years of cultivation, under taungya system was Rs.1250 in comparison to Rs.20,000 to 25,000 ha^{-1} as on today. The plantations raised under taungya were cheaper and successful. But subsequently, the taungya system was given up due to following reasons.

- Change in cropping pattern of taungya affecting the growth of teak
- Intensive intercropping during monsoon season leading to soil erosion and loss of fertility.
- Lack of proper institutional arrangements to supervise the taungya operation

Thinning was practiced in all the early teak plantations with different intensity. The thinning were carried out at 9th, 13th, 16th, 20th and 32nd years (Beddome, 1879). The anticipated rotation period was 70-120 years. This was continued till 1960's. From 18th century to till date teak has travelled a lot with Foresters. Many of the plantations raised in earlier periods have been felled and replanted after 2nd rotation. Some of them are in 3rd rotation!

As on today, teak is a most preferred forestry species for raising large scale plantations due to the following reasons:

- It is one of the most durable timber species used for construction, furniture, carving, veneer and plywood.
- Teak has a steep price increment curve and is an ideal forestry species to venture with for maximum financial gains, both for public sector units, private firms and individuals.
- It is an indigenous species that comes up satisfactorily without much serious pest and disease problems.
- Technique of raising teak plantation is extremely simple with minimum initial investment and maintenance costs.
- Yields returns at regular intervals in the form of thinning.
- Provides employment opportunity for labour all throughout its rotation period.

Right from Conolly's period, large extent of teak plantation have been raised, felled and replanted. As on today 44 per cent of the Worlds teak plantations are in India. (2,76,250 ha). Out of this, Kerala state shares about 74,872 ha. A major portion of teak plantations in Kerala were raised from 1960-1980 and majority of teak plantations in Kerala are in the age group of 35-40 years. Around 6000 ha fall in less than 10 years age group.

Table1 indicates the distribution of teak plantations in different forest circles of the state (as on 31-3-2002).

Table 1. Circle-wise distribution of teak plantation

Forest Circle	Area (ha)
Northern Circle	4140.00
Central Circle	15955.00
Southern Circle	16770.00
Eastern Circle	12851.00
High Range Circle	8139.00
Wildlife Circle	17017.00
Total	**74872.00**

(*Source:* KFD Administration Report, 2002)

The first rotation teak raised on virgin forest soils gave good results. A consultant study report from Kerala Forest Research Institute (KFRI), Peechi states that the present MAI of standing crop of teak works out to be 2.423 m^3 ha^{-1} at 60 years in comparison to potential MAI of 4.968 m^3 ha^{-1} at same age under site quality Class-I with full stocking as reported in All India yield table (Anonymous, 1970). This indicates the gap and the declining trend of productivity of teak plantations in Kerala (Jayaraman *et al.*, 1996). This situation needs to be ameliorated with active participation of foresters, scientists and international agencies involved in such ventures.

WHY THE PRODUCTIVITY OF TEAK IS DECLINING IN KERALA?

If we analyse scientifically, over the years certain factors are not in favour of teak, a toughest species that stood by the foresters for such a long period. The following are some of the reasons for declining productivity of teak in Kerala.

- The deterioration of site under 2nd and 3rd rotation teak due to repeated fires, heavy grazing, enormous soil and water erosion year after year during torrential rains.
- Removal of nutrients by teak itself to support its growth over a long period of 60-120 years.
- Poor quality planting stock raised out of genetically inferior seeds
- Initial competition by gregarious weeds like *Mikania, Eupatorium, Strobilanthus,* etc. before the closure of canopy, leading to poor establishment and stocking.
- Untimely thinning leading to competition, suppression and consequent reduction in yield
- Improper site species matching.
- Financial constraints for timely planting and after care.
- Inadequate research inputs.
- Attack by teak defoliator, *Hyblea puera.* In severally effected 4-9 year old plantations the yield is reduced to the tune of even 40 per cent (Nair *et al.*, 1985).
- Lack of crop rotation to enrich the 2nd and 3rd rotation teak soils.

For the reasons stated above, after having performed very well in the initial years on the virgin forest soils, now the productivity of teak is declining. A rough estimate shows that, even if we could increase the MAI of teak by 1m^3 ha^{-1}, at the present average price of Rs.25,000 m^{-3} of teak timber, the State is likely to gain Rs.150 crores at the end of rotation period of 60 years, for approximately 1000 ha of teak plantation it raises every year (1 x 1000 x 60 x Rs.25,000 m^{-3}). It is really a big jump for a resource hungry State like Kerala.

THE PRESENT PRACTICE OF ARTIFICIAL REGENERATION

KFD has 1250 ha of seed production area spread over entire stretch of the state (Nilambur, Manantha-vady, Parambikulam, Erumeli and Konni). The fruits start ripening during December to January. Average number of fruits per kg is 2000-2500 and average germination percentage is 30-40. The fallen seeds are collected from the ground and the graded seeds of size >10 cm diameter are used for raising nursery stock, after subjecting them to alternate wetting and drying for 3-4 days. The 3-4 kg of treated seeds are sown on beds of standard size. Germination starts after 10-15 days. The beds are nurtured for almost one year. Along with the onset of pre monsoon showers, stumps of size 8″ x 1″ (approximate) with a collar diameter of 1.5 to 2.0 cm are prepared and planted in crow bar holes at a spacing of 2 m. x 2m. The above nursery and plantation techniques though ancient still yield good results. However, almost after 100 years of stump planting, Kerala Forest Department (KFD) has introduced root trainer nursery technology during 1998 for raising and planting quality nursery stock of teak. The advantages of this new technique are as follows:

- Unlike stumps that take almost one year, the root-trainer teak seedlings will be available for planting within 60-80 days.

- In root-trainers, teak forms a network of massive root system consisting of multiple taproots, large number of secondary and tertiary roots. This kind of root system facilitates the efficient absorption of water from deep layers and nutrients from top layers. Probably, this is a boon for depleted 2nd and 3rd rotation soils.
- Teak being a rain-fed crop, the root trainer seedlings with excellent root system can help teak in the maximum absorption of water and nutrients available to it from all the layers of soil for an active growing period of just 3-4 months in a year, *i.e.*, from June to September.
- The planting stock produced in root trainers can establish very fast thus overcoming the initial competition by gregarious weeds.
- The survival rate of culled root trainer nursery stock is usually more than 95 per cent leading to excellent stocking and uniformity of the crop.
- As the root system of teak is shallow, it is believed that, teak develops flutes to support itself. If that is so, with an excellent root system of root trainer seedlings that provides strong anchorage; teak may not flute any further. This may result in formation of better quality timber with clean boles. This is only an assumption.

From 1998 onwards KFD has raised roughly 28 lakhs of root trainer seedlings for its afforestation programmes. The initial observations show a mixed response. With additional research inputs and quality management inputs, root trainer teak seedlings can bring a sea of change in raising the productivity of teak on 2nd and 3rd rotation teak soils.

After planting normal tending operation like soil working, weeding, application of fertilizers are carried out for the first 2-3 years. Till the closer of canopy there is tremendous competition by gregarious weeds like *Mikania, Eupatorium, Strobilanthus,* etc. Hence, the initial maintenance operations shall be carried out till the complete closure of canopy.

THINNING AND GROWING STOCK

Different thinning regimes are practiced in the state. Usually there are two mechanical thinnings at 5th year followed by 2nd mechanical thinning at the age of 8-10 years. After two mechanical thinnings, there will be 4 silvicultural thinnings at the approximate age of 15, 25, 35, 45 years. Only the silviculturally available trees like suppressed, diseased, pest infested, dead, *etc.* are removed. After the final thinning approximately 80-120 trees ha^{-1} are retained till the rotation age of 50-60 years. Large extent of teak plantations are due for different kinds of thinning due to paucity of funds, approved working plans and labour problems. The site quality distribution of area under teak indicates that only 5 per cent of the area comes under site quality class-I. Nearly 86 per cent of area is under site quality classes-II / III and 9 per cent of the area is under site quality class- IV (Jayaraman *et al.*, 1996) A large quantity of growing stock is available in plantations of various age groups and site qualities in the teak plantations of Kerala

The circle-wise growing stock of teak in plantations more than ten years as on 1996 is given in Table 2. Excluding small wood if we consider timber alone at an average price of Rs.25,000 m^{-3} the approximate value of teak timber available in teak plantations of Kerala is roughly Rs. 8120 crores. This is an assist worth managing sustainably with required research, silvicultural and financial inputs for the welfare of the state.

MARKETING

The materials obtained from thinning are auctioned at site to meet the local requirements. The timber obtained from thinning as well as final felling are transported to different timber depots located all over the state. There are totally 28 timber sale depots in the state dealing in auction of teak timber. People

Table 2. Circle-wise growing stock of teak plantations

Forest Circle	Timber (m^3)	Small wood (m^3)
Northern	253,157	178,272
Central	870,139	460,086
Southern	1,104,742	435,466
Olavakkode	668,890	302,978
High Range	351,312	213,415
Grand Total	**3,248,240**	**1,590,217**

Source: Report of the KFRI Research Project No.250/96 from neighbouring states like Karnataka, Tamil Nadu and Andhra Pradesh also take part in the auction. Approximate quantity of timber and teak poles obtained and auctioned during the last few years is given in Table 3.

Teak timber is a major source of revenue to KFD, earning an average revenue of Rs. 95 crores per year. Though 44 per cent of the World teak plantations are in India and Kerala contributes almost 27 per cent of it, hardly any timber is exported from the state. In fact, due to removal of import licensing system during 1992, large extent of teak timber is being imported into India. The Major players in the international market are Myanmar, Indonesia and Thailand. There is tremendous scope for teak both in domestic and international markets. The price curve of teak is always bullish. During 2003, one export (B) quality log of 1.6m^3 has fetched a price of Rs. 75,900/- m^3 at Aruvacode depot of Olavakkode circle! The following schedule of rates for teak in Kerala for the last 10 years, which is based in the average market price shows the bullish trend of teak price curve in Kerala. From the above one can see that within a span of just 10 years in the domestic market itself the price of teak has increased by minimum threefold.

PLANTING STOCK IMPROVEMENT

With the assistance of KFRI, from 1976 onwards KFD has identified 1250 ha of promising teak plantations and converted them into Seed Production Areas (SPAs) by removing inferior trees. This is mainly to supply the source identified quality seeds for raising plantations. These SPA's are located in Nilambur, Parambikulam, Mananthawady, Konni and Erumeli. Based on certain tree parameters, germination percentage and total seed production, Nilambur and Parambikulam provenances are considered to be the best seed sources. The 250 ha of these SPA's have

Table 3. Quantities of timber and poles auctioned during 1993-2001

Year	Timber (m^3)	Poles (number) (IV to I class)	Revenue in crores (timber @ Rs.25,000/m^3 and poles @ Rs.500/pole)
2001	24,000	129,000	66
2000	34,000	455,000	108
1999	18,000	275,000	59
1998	12,000	287,000	44
1997	33,000	683,000	117
1996	27,000	36,000	69
1995	57,000	739,000	179
1994	23,000	725,000	94
1993	32,000	868,000	123
Total	**260,000**	**4,197,000**	**860**

Schedule Rates (Rs. in lakhs m^3)

Year	Timber classes							
	IB	IIB	IIIB	IVB	IC	IIC	IIIC	IVC
1992-93	0.15	0.13	0.10	0.08	0.10	0.09	0.10	0.06
1993-94	0.15	0.13	0.10	0.08	0.10	0.09	0.10	0.06
1994-95	0.27	0.19	0.14	0.10	0.21	0.14	0.11	0.09
1995-96	0.29	0.22	0.18	0.13	0.23	0.18	0.15	0.11
1996-97	0.36	0.27	0.21	0.17	0.31	0.22	0.17	0.13
1997-98	0.37	0.27	0.23	0.18	0.34	0.25	0.21	0.15
1998-99	0.43	0.34	0.26	0.19	0.37	0.28	0.23	0.16
1999-00	0.43	0.39	0.26	0.19	0.37	0.30	0.23	0.16
2000-01	0.13	0.39	0.26	0.24	0.37	0.30	0.23	0.16
2001-02	0.43	0.39	0.28	0.24	0.37	0.30	0.23	0.16

Source: Administration Report of KFD, 2001.

been taken up for genetic culling from 1998 to 2002 with the assistance of Indian Council of Forestry Research and Education (ICFRE).

KFRI has established three pilot clonal seed orchards of teak over an area of 6.1 ha utilising 25 clones developed by them. In addition to this, KFD has established over there 30 ha of clonal seed orchard with the assistance of KFRI. However, these clonal seed orchards are not producing seeds required for large scale planting. During 2002-03, a Forest Seed Centre has also been established in KFRI with the collaboration of KFD and financial assistance of World Bank, mainly to supply, certified quality seeds of teak for plantation activities of KFD and other interested agencies.

In the recent past *i.e.,* from 1980 onwards, KFD has brought in certain changes to improve the productivity and sustainable management of teak. The following are certain departures from the ancient system of management of teak in Kerala.

- The taungya system has been discontinued due to some of its disadvantages listed above from 1980 onwards.
- The selection felling in natural forests including teak has been banned from 1987 on wards to encourage natural regeneration of teak.
- As per the recommendations of KFRI burning of slash felled material is discontinued. The slash after felling is heaped on rocky patches or across gullies for natural decay. This prevents soil erosion, loss of nutrients and emission of green house gases into the atmosphere.
- Instead of stumps, root trainer nursery stock has been introduced from 1998 onwards
- As per latest working plan prescriptions the valuable tree species like sandal, ebony, rosewood are retained to develop a multiple use cropping system.
- The rotation age has been reduced to 50-60 years from 70-120 years.
- Crop rotation with leguminous tree crops has been introduced from 2001 onwards to enrich the depleted 2nd and 3rd rotation soils.
- To ensure the continuous flow of funds during nursery and planting seasons a system revolving fund has been introduced from 2002 onwards. This involves deposition of part of the revenue generated by sale of teak in Personal Deposit accounts of Divisional Forest Officers, which do not come under the purview of government treasury systems.
- Cloning of teak has been attempted and clones are in testing stage.

FUTURE OF TEAK IN KERALA

Most of the teak plantations in Kerala are in the age group of 35-40 years and they are at the prime of their productivity. Some of the new plantations approximately 6000 ha which are less than 10 years old are on 2nd and 3rd rotation teak soils, which require intensive management to get the expected results. With little more silvicultural, financial and marketing inputs, State can harvest rich dividends from these plantations in the coming 20-30 years. The following aspects need consideration for the sustainable management of Teak plantations in Kerala.

Restore the glory of natural teak

The total extent of teak bearing Natural forests of Kerala is roughly 4 lakh ha and they are located in Wayanad, Nilambur, Parambikulam, Nelliampathy, Achencoil, Arayankavu, Konni, Ranni and Malayattoor. The selection felling of all species in natural forests including teak has been banned in Kerala from 1987 onwards. Still, the population of natural teak, in teak bearing moist deciduous and dry deciduous forests has come down drastically due to over exploitation in the fast, complete lack of regeneration, illicit felling and damage due to repeated fires.

Natural teak has its own place in the market in comparison to plantation teak. Kerala once considered to be a Mecca of teak is no more supplying natural teak to the market. Today in the international market only Myanmar is supplying natural teak. At the present rate of supply probably, within few decades natural teak of Myanmar will also be exhausted. Kerala has roughly 4 lakh ha of teak bearing moist and dry deciduous forests. All attempts shall be made to regenerate teak in its natural forests by following canopy opening, artificial sowing of treated seeds, protection from fires, raising nurse crop with its associates like Rosewood, Venteak, Terminalia, *etc.*

There could be many more such methods. All sincere attempts to regain the glory of natural teak with additional research and silvicultural inputs will be highly rewarding.

Site selection for plantation teak

As the clearing felling is completely banned from 1980 onwards, no more virgin sites will be available for raising future teak plantations. The state shall play with available area with modern tools to increase the productivity. Almost of 25-30 per cent of teak plantations are in the steep slopes of 15-30^0. Around 2 per cent of the area has a slope of even more than 30^0 and around 9-10 per cent of the area is under site quality-IV or degraded class. In all future plantation degraded as well as steep sloppy sites shall be avoided. The sloppy sites may be allowed as such for multi purpose trees with teak as one of the species. As it is being done for all other plantation crops in the state, the cultivation shall be carried out along the contours and the planting shall be done on the platforms with inward slopes. This will help in each establishment and retention of soil and moisture. Along with this, other soil and moisture conservation measures like gully plugging and contour trenching shall also be carried out wherever essential.

Mixed plantations with teak

Teak is becoming an expensive timber for an ordinary man. To safeguard the teak from the effects of monoculture and also to meet the timber needs of an ordinary man an attempt shall be made to raise mixed teak plantation with other associates like Rosewood, Venteak, Terminalias, Bamboo *etc*. If the mixture of species does not give encouraging results at least alternate blocks of teak and its associates, which are generally used by an ordinary man shall be raised. This will have the advantages of biodiversity conservation, improvement of soil and meeting the timber requirement of local man at affordable prices.

Clonal plantations

Large scale clonal teak plantations are being raised in Thailand, Coasta Rica and other countries for the last few years. Though the history of teak plantations in Kerala is more than 150 years old, the attempts to improve the productivity of teak are limited to use of quality seeds, improved nursery stock and management practices. To increase the productivity of teak to manifold, cloning of teak has to be attempted utilizing the promising trees standing in natural forests as well as in teak plantations before the promising trees disappear from Natural forests and plantations. KFRI has recently developed 30 clones, which are under testing. Some of the clones in the clonal testing area at Chettikulam central nursery in Thrissur have an average ht of 4.30 m and DBH of 3.10 cm, respectively after 18 months of growth. Clonal teak has promising future in Kerala and any amount of investment is worth venturing.

Deregulation and investor education

Tippu Sulthan declared teak as Royal tree almost 200 years back to prevent its over exploitation. Even today, there are lots of regulations for felling and transportation of trees grown in homesteads. In fact it is a disincentive. In Thailand US $ 780 ha^{-1} is being paid as incentive to raise teak on private lands (Pandey and Brown, 2000). The information about cultivation and marketing of teak are not available to the prospective planters. Reducing rubber price and raising labour cost will definitely tempt large scale rubber planters in the state to go for teak, after slaughter felling of rubber, if there are sufficient incentives, deregulation and investor education programmes, as teak is investor friendly species that can be raised with minimum efforts.

Cover crop and crop rotation

During the 2-3 years of initial growth, the gregarious weeds like *Mikania*, *Eupatorium* and *Strobilanthus* compete with teak for moisture, nutrient and growing space, making the life of teak miserable. Growing certain annual leguminous crops as cover crops will not only check the growth of weeds but also enrich the soil by fixing atmospheric nitrogen. This will also improve the soil texture and structure by adding a new variety humus to the soil which has seen the humus of only teak leaves for decades.

Introducing a short rotation leguminous tree crop like *Acacia auriculiformis*, *Acacia mangium*, *Leucaena leucocephala*, *Albizia* spp., *etc*., will not only meet the needs of pulpwood, firewood or fodder requirements, but also improve the soil under teak. The recent working plans have introduced the system of crop rotation with leguminous tree crops. During the last 2-3 years few such plantations have already been raised

Reduced rotation to meet social and commercial needs

In this fast changing world, 60 years is too long a period for any commercial plantation venture. Moreover, advent of plywood and other particleboards has reduced the demand for large size teak timber. This was the luxury of yester years when everything was available in plenty. The need of the hour is small size teak timber for construction and furniture purposes. There is a vast demand for this class of timber by majority of middle and below middle class families in India. A research report from KFRI states that teak can attain optimum timber strength properties in 20-30 years and recorded MAI for this short rotation crop is in the range of 10-20 M^3ha^{-1} (Bhat and Indira, 1997). This is phenomenal. When the short rotation teak can meet the social and commercial needs of the society, we should think of short technical rotations of 20-30 years instead of 60 years rotation, which aims at maximum volume. This we can attempt with the portion of teak crop growing on site quality classes II, III and IV. The teak growing on site quality class-I can be allowed to grow till the present rotation age of 60 years to produce the timber of bigger dimensions.

Timber certification and export of teak

According to the definition of International Tropical Timber Organization (ITTO), Sustainable Forest Management means 'The Process of managing permanent forest land to achieve one or more clearly specified objectives of management with regard to the production of a continuous flow of desired forest products and services without undue reduction in its inherent values and future productivity and without undue undesirable effects on the physical and social environment'. The export of timber is usually allowed after obtaining a certificate from ITTO to the effect that the timber has come from sustainably managed forests.

Though India has 44 per cent of the world teak plantation area, and 4 lakh ha of teak bearing natural forests, which are sustainably managed as per the above definition, export of teak timber to earn revenue to the state exchequer is almost nil. Attempts shall be made to raise the productivity of teak to meet the nations demand. Once the internal demands are met state should plan for the export of teak. Today, only 4 counters out of 35 counters raising teak plantations have Forest Stewardship Council Certificate for export of teak. Unless we raise the productivity of site and generate additional revenue through effective marketing and export, the public sector plantation venture may suffer a set back. Efforts shall be made to obtain ITTO certificate for the export of teak once the internal demands are met as there is tremendous potential for teak in international market.

Global warming and carbon sequestration

Pine, eucalyptus and teak constitute 87 per cent of the tropical forestry plantations. Through photosynthesis a tropical forest plantation can accumulate 15-25 tonnes of dry biomass $ha^{-1}year^{-1}$ with a mean figure of 20 t/ha^{-1}! Roughly half of this dry biomass is in the form of carbon trapped from atmosphere during photosynthesis (Myers, 1991). This means roughly 1000 ha of teak plantations raised by the state in the coming 10 years there will be a assimilation of approximately 100000 tonnes of carbon from atmosphere effectively contributing to the reduction of green house gases from atmosphere. This is a cautious conservative estimate with almost nil slash burning and excluding 0.5 ton of carbon ha^{-1} $year^{-1}$ released by the plantation to the atmosphere in the form respiration. In addition to this, when the teakwood produced becomes a substitute for various wood substitutes like metals that are produced at the cost of releasing green house gases to the atmosphere, there will be additional contribution in reduction of release of green house gases to the atmosphere.

Probably, many developed countries that have mandate to reduce the emission of green house gases to the atmosphere through concerted efforts in their own countries as well as through funding such activities in developing tropical countries may come forward to support teak plantation ventures in Kerala. This will be a great step forward in saving the planet earth from global warming.

FUTURE RESEARCH NEEDS

From Conolly's period, the teak sites have changed a lot and teak may not perform well unless additional research and management inputs are provided. The demand supply pattern has also changed with pressure to produce more timber to meet the demand at regional, national and international levels. Under changed site and management conditions new pests, weeds and diseases have emerged. New production and consumption centers have emerged outside the natural teak growing and marketing zones due to growth of teak trade in international market. Development of processing technologies have opened up new avenues for value addition to any class of teak wood. Attention of foresters, administrators, scientists and politicians are being continuously drawn to the ecological, economic and social functions of sustainably managed teak plantations. Under these changed circumstances following are some of the research needs of teak in Kerala.

- Research on natural regeneration of teak in the teak bearing natural moist and dry deciduous forests.
- Mixed teak plantations to meet the needs of Biodiversity conservation, Ecological needs of the region and timber requirement of an ordinary man.
- Site species matching.
- Supply of genetically improved quality seeds till the tested clones are available for raising large-scale teak of plantations.
- Low cost techniques to control the obnoxious weeds like *Mikania, Eupotorium, Strobilanthus*, etc.
- Mechanised harvesting to save wood and overcome the labour problems.
- Enrichment of degraded sites.
- Continuous research on development of clones utilizing the Elite genetic material available both in plantations and natural forests.
- Short rotation management and its social, economic and ecological consequences.
- Market survey to identify the niche markets, at regional, national and international levels.
- Carbon sequestration in teak plantations and reduction in green house gases.
- Performance of root trainer teak vs stumps in changed site conditions.
- Sustainable management of teak plantations and certification by ITTO
- Grading and certification of teak timber to meet the international standards.

CONCLUSIONS

From the British period till today there are tremendous changes in the silviculture, management and marketing of teak. To march with changing time and to manage the teak plantations of Kerala on sustainable basis additional research, management and financial inputs are required and the state is already moving in this direction. There is already an established glory for Malabar teak and with 4 lakh ha. of potential teak bearing natural forests and 74872 ha teak plantations with major area at the prime of their productivity, Kerala teak has a bright future in the national and international market under the changed ecological, economic and social functions of sustainably managed teak plantations.

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Ups and Downs of Teak Forest Management in Indonesia

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ABSTRACT

In Indonesia, teak was introduced during the fourteenth century, especially in Java, where it spread quickly in central and eastern parts. The Dutch colonial rule extensively extracted the timber, leading to degradation of teak forests in the country. They eventually introduced modern methods to manage the teak forests, which are also in use at present. There are State teak forests and Community teak forests in Java, apart from teak grown outside the island. The State teak forests, extending to about 600,000 ha are managed by the government enterprise called *Perum Perhutani* and the teak areas outside Java are looked after by the local government. Community forests containing teak are in private lands, which are more widespread due to improved demand and price. The timber from government sector is either sold directly or by auctioning, and in general, they fetch more price than that of the private sector due to improved quality. Since 1998, there is decline in the standing stock of teak forests in the country mainly due to illegal and widespread logging consequent to the political crisis. However, these non-productive areas are being rehabilitated since 2002. Improved planting stocks are used for the purpose, and for that, clonal seed orchards are established. Intensive silvicultural practices, including fertilization, are adopted to increase the productivity. Also, community-based forest management programmes are implemented. Improved environmental protection measures to improve the ecosystem and the biodiversity are also part of the management of teak forests in the country. Ecoglobal certification, even though introduced, could not be contained for many forest districts and only one fourth of the districts are maintaining it at present.

Keywords: Plantations, Java, State and Community teak forests, improved management.

INTRODUCTION

Teak was first introduced in Indonesia by the Hindus in the 14th century, particularly to the Island of Java. Due to the suitable site conditions, teak spread quickly to the most part of Java, especially to the central and eastern parts. The history of early establishment of teak forest in Java has been described in detail by Simatupang (2000).

In Java, teakwood has been the most preferred wood due to its strength and durability. It has excellent properties and suit to a variety of uses such as furniture, handicraft, construction and shipbuilding. Teakwood had been a very important commodity, particularly for shipbuilding since the Majapahit Kingdom in East Java. The Dutch continued to use teakwood for their ships. In the Dutch colonial time, timber extraction from the teak forests of Java was done very extensively, which resulted in massive degradation of teak forest. A sound and modern forest management strategy was eventually introduced by the Dutch to manage the teak forests in Java. The evolvement of teak forest management in Indonesia has been described in a number references (Simon, 1997, 2000). Teak forest management principles set up by the Dutch colonial government are basically still in current use. The paper describes the current management and policies adopted in teak forests of Indonesia with particular reference to the period after the economic and political crisis in 1998.

KIND AND MANAGEMENT OF TEAK FOREST

State forest

State forest is the forest grown on the State land. Presently, approximately 90 per cent of teak forest in Indonesia is located in Java, which is managed by *Perum Perhutani*, a government owned forest enterprise. In total, *Perum Perhutani* is responsible for the management of 2.5 million ha of forest land in Java, including 1 million ha of teak forest land with an effective area of around 600,000 ha.

Community forest

Teak is also grown on the private land due to high value of its wood. It is estimated that the total area of teak planted in the private land is about 10 per cent of the *Perhutani's* teak forest. Teak in the community forest is generally grown in mixture with other tree species and harvested at relatively young ages, ie. around 20 years. With increasing wood price and teakwood demand, as well as the introduction of genetically improved planting materials, recently, there is widespread of teak growing in private lands.

Teak forest outside Java

The development of teak forest in other islands began in the 15th century. In these areas, teak forest is managed by local governments. It is recorded that the total area of teak forest outside Java is about 150,000 ha, which was reduced to 60,000 ha in 1998. With the extensive marketing of improved planting stocks, the teak planting outside Java has increased to a total area of about 5 per cent of *Perhutani's* teak forest.

MARKETING

All teak logs produced by *Perum Perhutani* are sold to meet the domestic demand for wood industry. Teak logs are marketed by direct selling or auction. The smallest quantity of teak logs for sale is 3-4 m^3 of similar qualities. Teak logs from community forests are sold based on the price prevailing in the local market which is generally lower than that of *Perhutani's* teak log due to low log qualities.

Every cubic meter of teak log sold by *Perhutani* is subject to the following taxes.

- Value added tax amounting to 10 per cent of log price, which goes to the central government.
- Forest resource provision ; it is a type of tax taken by the government (Ministry of Forestry) and intended as reserve fund to rehabilitate degraded forest. The accumulated taxes are then redistributed to all provincial and district governments, based on the criteria whether the province or district is producing wood or not; in this case some subsidies are applied for the non-wood producing districts.
- Redistribution to the local government for local developments.
- Auction fee and charity fund.

It is estimated that every cubic meter of teak log will be taxed around Rp 450,000 (USD 50) for direct selling and Rp 650,000 (USD 65) for auction. Details of the expenses are given in Table 1.

Table 1. Kind and the amount of tax for every cubic meter of teak log

No	Fee type	Diameter class (cm)		
		10 - 19	20 – 29	> 29
1	VAT (%)		10	
2	Forest resources provision (Rp)	19.200	48.500	74.400
3.	Local retribution (%)	1.5	1.5	2.5
4	Auction fee (%) etc.		6	

Sale and the amount revenues obtained from teak logs for the last five years is given in Table 2.

Table 2. Teak log sale and revenue for the last five years

Year	Volume (m^3)	Revenue (Rp 1000)	
		Total	Average
1998	703 005	550 602 273	783
1999	567 715	656 779 314	1156
2000	726 653	675 994 415	930
2001	645 041	813 704 787	1261
2002	613 219	836 439 281	1364

The average price of teak logs is determined by a number of factors such as:

- Log composition according to diameter size and quality.
- Illegal logging making over supply of teak log and decreased price

- Economic crisis causing the declined purchasing power of the consumer

For the last five years the teak log composition sold are as follows:

Table 3. Teak log composition sold for the last five years

Year	Volume (m^3) according to diameter classes (cm)			Total vol. (m^3)
	10-19	20-29	>30	
1998	255,712	197,770	249,523	703,005
1999	189,524	157,113	221,079	567,715
2000	249,713	201,531	275,409	726,653
2001	240,012	174,675	230,354	645,041
2002	225,388	172,290	215,541	613,219

DECLINING STANDING STOCK

Teak forest in Java is managed based upon the principles of sustainable forest management. To mark one century of the sustainable forest management of teak forest in Java, an international seminar was held in 1994. In the same year, *Perhutani* received a ecolabel certificate from Forest Stewardship Council (FSC).

In 1998, a political crisis occurred, preceded by an economy crisis. The demand for political reforms and decentralization emerged in many aspects, including the forestry sector. An additional negative side effect of this reform is the widespread of illegal logging on the State forest, including teak forest managed by *Perhutani*. Consequently, the standing stock of teak forest has been declining as shown in Table 4.

Rampant illegal logging and land occupation for farming has led to the dramatic decline in standing stock, in all age groups. The reduction in the size of younger age groups is related to the land occupation for farming, while that of older age group (> age class III) is definitely due to illegal logging. The decline in standing stock can also be seen from the existing non-productive teak forest in 2002, amounting to 206,370 ha. The rehabilitation of this unproductive teak forest land is in progress.

Table 4. The size of teak forest managed by *Perhutani* before and after the economic and political crisis

Age group	Age class (year)	Before crisis 1997 (ha)	After crisis 2002 (ha)
I	1 - 10	138,521	134.962
II	11 - 20	142,673	84,587
III	21 - 30	121,083	98,770
1V	31 - 40	86,715	78,598
V	41 - 50	24,933	35,107
VI	51 - 60	21,328	14,060
VII	61 - 70	16,145	10,918
> VIII	71 - 80	19,767	11,489
Low standing stock			18,773
No standing stock			187,597
Total			674,868

MANAGEMENT POLICIES

Rehabilitation plan

The decline of standing stock is likely lead to the reduction in future teak log supply from *Perhutani's* teak forest. To alleviate this problem, a rehabilitation plan to replant unproductive teak forest land has been formulated. Details of the size and time for teak forest rehabilitation plan are given in Table 5.

Table 5. Size and year of teak forest rehabilitation plan

No	Year	Area (ha)
1	2002	36.894
2	2003	40.903
3	2004	32.631
4	2005	24.353
5	2006	18.902

The priority target for rehabilitation is low standing stock area and barren teak forest land, resulted from illegal logging. Improved planting stocks are used, mainly from clonal seed orchards (30%) and seed production areas (70%). The expected increase in wood production by using improved planting stock could fill the gap in teak log production due to illegal logging. The spacing used is 3 m x 3 m, with a thinning frequency of 5 years. *Taungya* system is normally employed.

The use of improved planting materials

A tree breeding program of teak was started in 1983 by selecting plus trees and establishing progeny tests and clonal seed orchards. The seed orchards had produced improved seeds, used for the establishment of operational plantations. The use of better planting materials, combined with proper silvicultural practices, is expected to reduce the time needed to achieve commercial stem diameter (> 30 cm). This will also lead to the creation of more job opportunities for local people in planting, thinning, harvesting and log transport.

Intensive silvicultural practices

Proper silvicultural practices are adopted to increase the productivity of teak forest. This includes site preparation, use of better planting materials, fertilizer application, timely tending, fire prevention and suppression. Normally, site is ploughed to the depth of 20 cm, to loosen the soil structure. It is particularly important if the plantation establishment uses taungya system in which farmers grow cash crops between rows of teak trees. Site preparation will also benefit the teak trees which need good soil aeration. The fertilizer application in the form of both organic manure and inorganic fertilizers are mandatory for planting teak. Nutrient input to the site will improve nutrient status which are generally poor in many teak sites due to nutrient depletion by various factors, including harvesting of cash crops and teak trees, soil erosion and fire incidences.

Fire occurs regularly during the dry season in many teak forests. Better fire prevention and suppression are needed. Despite teak survives fire, the fire incidence could impoverish site quality through the loss of litter and organic matter, depletion of certain nutrients such as nitrogen through volatilation, destruction of soil structure, etc. In addition, better control in cattle grazing is of importance to reduce soil compaction, as teak will not grow well on compacted soil.

Community based forest management

Perhutani has long experiences in social forestry programmes with the objective of improving the welfare of people living nearby teak forests. However, such programmes appear inadequate and the demand of local people to participate in teak forest management has increased since the political reforms began in 1998. A partnership programme in the teak forest management with local communities has recently been adopted. In this scheme, local communities have the right to have some portion of forest product from the nearby forests, under the coordination of a village institution. The village institution has the right to have 20-30 per cent of the wood harvested from certain forest areas, as agreed by the local community and *Perhutani.* The community also has working opportunities in all plantation operations such as establishment, tending and harvesting.

In the partnership scheme, both local communities and *Perhutani* must oblige to certain terms agreed by both the parties. *Perhutani* is to help in the preparation of management plan, provide necessary planting materials and production cost as well as to support all activities in the forest management work as planned. In the mean time, the local community is obliged to prepare working plan agreed by *Perhutani,* protect the forest resources in its working area and to support the programme works properly.

In the community based forest management programme, local government is also involved. In this case the local government functions as a facilitator to help in many ways so that the programme benefits both the local community and *Perhutani.* It is possible that the local government has the right to have a certain portion of forest products from the working area in the program, subject to the agreement by the parties involved. It is worth noting here that the partnership programme was able to reduce the illegal logging practice in a number of forest areas. The main constraint of this programme is the limited human resource, capable of facilitating the changes in the forest management policy. The progress has been slow due to the lack of trust from the local community resulted from the bad experiences in the past.

Improved practices in protected areas

In the past intensified management had led to environmentally unsound practices such as harvesting trees in so called protected areas such as river banks, followed by replanting the area using *Taungya* system. Consequently, protective function of the area is neglected. To improve the ecosystem along riversides function properly if area isl be reforested using species other than teak, particularly evergreen species, preferred by the fauna. It is expected that the area will function as corridors for fauna and the planted trees will increase the biodiversity of teak forest.

Forest certification

Ecolabel certificate has become necessary in every forest enterprise, since certified forest could provide an assurance for its sustainability. In the past, *Perhutani* obtained an ecolabel certificate for its total forest area. Then the certification was designated for the forests at district level. Six forest districts were awarded ecolabel certificates. Unfortunately, due to the economic and political crisis and the rampant illegal logging practices, the management became incapable to contain them. It turned out that ecolabel certificates possessed by five forest districts were suspended and only one forest district has been able to maintain it.

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Current Status of Teak in Thailand

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ABSTRACT

Natural teak forests in Thailand decreased from 2,324,300 ha in 1954 to about 150,000 ha in 2000, mostly due to the demand for agricultural land and constructional wood by the increasing human population. Plantations could hardly keep pace with deforestation. Up to 2000, both private and public sectors in Thailand could establish only 836,000 ha of teak plantations, as reported by FAO. Thailand, therefore, has to import natural teak wood from overseas, especially from Myanmar, Lao P.D.R. and Indonesia, on an average of about 2 billion Baht annually. However, small logs from teak plantations can be used for furniture, carving, general construction, household utensils, toys, etc. domestic consumption as well as for export. Recently, the Forest Industry Organization of Thailand achieved 2 FSC certificates for its teak plantations and is still trying to get additional certificates to manage teak plantations sustainably. Information on teak improvement, research and development programmes in the country is discussed in the paper, pointing out the constraints in teak plantation establishment.

Keywords: Teak plantations, Thailand, research and development

NATURAL TEAK FORESTS

Thailand was once a major teak exporting country. In 1954, teak in Thailand occurred naturally in the North, stretching from 14° to 20° 31´N latitudes and between 97° 30´– 104° – 30´E longitudes, from about 100–900 m elevation, covering an area of approximately 2,324,300 ha. However, because of the increasing population pressure, high demand of agricultural lands, wood for general construction and wood-based industries, deforestation during 1970s and 1980s was extremely high, causing disappearance of natural teak-bearing forests. In 1996, the Forest Resources Assessment Division of the Royal Forest Department of Thailand tried to enumerate the existing teak-bearing natural forests in the North, and the result are as given in Table 1

However, the survey was confined to the major protected areas where teak is predominantly the major species. Teak may also be found in other national parks and/or wildlife sanctuaries, as well as

Table 1. Natural teak-bearing forests in North Thailand

Locations	Area
Jae Sorn National Park, Lampang	768.80 ha
Mae Yom National Park, Lampang-Phrae	8,679.80 ha
Mae Yuam National Park, Mae Hong Son	2,312.21 ha
Doi Inthanon National Park, Chiang Mai	659.84 ha
Mae Ping National Park, Lamphun	1,525.35 ha
Klong Laan-Klong Wang Chao, Kamphaeng Phet	4,590.73 ha
Umphang Wildlife Sanctuary, Tak	8,771.50 ha
Mae Wong National Park, Kamphaeng Phet - Nakhon Sawan	9,597.62 ha
Total	**36,905.85** ha

in the national forest reserves. It is estimated that, in total, Thailand may have natural teak-bearing forests of about 160,000 ha (Gavinlertvatana, 1995). These areas may be partly illegally encroached and the real natural teak-bearing forests should not exceed 150,000 ha. Since January 1989, after the complete ban on forest concession in Thailand and the current conservation attitudes of the public since 1990, forest encroachment gradually decreased to some level of satisfaction, and the predicted 150,000 ha of teak-bearing forests is expected to exist. Nevertheless, it is also anticipated that density of teak trees within these areas may be lessened due to illegal felling, as the price of teak wood still increases, year after year and the government could not supervise all the l areas thoroughly with limited resources. In 2001, the Royal Forest Department reported on teak wood production as given in Table 2.

Table 2. Teak-wood production in Thailand ('000m^3)

Year	By license	Confiscated
1997	0.1	12.8
1998	0.1	11.9
1999	0.1	10.6
2000	0.01	10.17
2001	0.02	7.96

The data support the above statement clearly that encroachments into natural teak-bearing forests is reduced in the last 5 years as indicated by the declining figures of confiscated teakwood. As far as this trend continues, it is optismistically hoped that, teak bearing forests may be kept untouched in the near future. But enrichment planting may be necessary to replace the illegal felling trees with younger generations of the species. The current government grassroot economic development plan may be an important tool which contributed to forest conservation through the provision of employment opportunities to the villagers, instead of encroaching into the forested areas, and work in the new small to medium enterprises (SME), as initiated by the government.

TEAK PLANTATIONS

Teak plantation in Thailand started since 1906, by applying the *Taungya* system with modifications to suit well with the surrounding circumstances, both economically and socially. Previously, teak plantations were established by the government, especially by the Royal Forest Department; and of late, by the State enterprises, such as the Forest Industry Organization (FIO) and the Thai Plywood Company (TPC), whose teak plantations were established for business and/or industry. Until 1990s, the private sector participated strongly in teak plantation establishment with partial support from the government both, in terms of finance and technology. From 1994 to 2000, the Royal Forest Department has already assisted private sector to establish teak plantations upto about 100,000 ha. Prior to 1994, farmers created their own teak plantations without supports from the government and it is estimated that private sector in Thailand may have already established teak plantations probably upto 200,000 ha. FAO (2000) reported that Thailand possess teak plantations upto 836,000 ha. This figure includes plantations established by both State and private sectors.

There are certain problems occurring in old teak plantations established by the Royal Forest Department; like illegal logging and the invasion of the teak beehole borer (*Xyleutes ceramicus*), whose lavae bore into teak stems and damage as well as devalue the wood from plantations. Apart from these, after 6 years, the government provided no additional fund for maintenance and thus attracted illegal loggers to encroach such the plantations. Thinning and pruning are also ignored which affected greatly, the growth and yield. Without maintenance cost, teak plantations established by the Royal Forest Department were left unmanaged and unmonitored. Unfortunately, there is no clear picture on the exact area of teak plantations under the supervision of regional forest offices in Thailand. No information is available on the status and quality of these plantations. It is thus impossible for the public sector to manage its teak plantaions sustainably, and of course, quality timber production is still a big question in Thailand. Alternately, the State enterprises (FIO and TPC) have their own management schemes to maintain and manage their plantations properly and effectively. Since last decade; these two enterprises started to fell their old teak plantations for commercial purposes. The FIO could even get FSC certification for its teak plantations, who has also applied for additional certificates to demonstrate that their teak plantations have been sustainably managed.

The private sector, on the other hand, suffered initially with their teak plantations. Without recognizing the important role of management regimes, plantations were not subjected to thinning, probably due to the lack of market for small lumbers and the enactment of the Forest Plantation Act B.E. 2535 (1992), which along with the existing Forestry Act B.E. 2484 (1941), prevented the private sector to fell, sell, and process their teak logs freely. Recently, when a market was opened to use the small teak logs from thinning for log-cabin construction, private sector has put more attention to their teak plantations again.

Still there are some constraints on private teak plantations, especially on growth and marketing. Some farmers did not realize the effects of planting materials on growth and used planting stocks of unknown sources which were slow growing. While many companies tried to use superior planting materials from *in-vitro* culture, which resulted in high investment cost, to increase the yield per unit area. They still are unhappy with the legal problems they are facing. However, recently, the related forestry acts have been revised and amended by the government, and it is anticipated that such constraints may be minimized, so that private forest plantation can be more attractive.

TEAKWOOD MARKETING AND UTILIZATION

Since January 1989, Thailand completely banned all terrestrial forest concessions, and thereafter, had to import raw material (wood) from overseas to supply to the wood-based industries. However, some State enterprises and private companies who have their own plantations, survived from their resources. The Royal Forest Department (2001) reported on teak wood import and export, as given in Table 3.It indicates that Thailand lost its foreign exchange enormously, every year, for teakwood consumption. Teak-wood imported into Thailand is mainly from Myanmar, and partly from Indonesia and Lao P.D.R. in terms of both logs and sawn timber. They are used for general construction and for furniture manufacturing. Teak exportation from Thailand is mainly as "re-export" of the products after processing and manufacturing items, such as furnitures. Fluctuation of the values of the exporting products depends greatly on the types and quality of products. Since last 2 decades, production of teakwood seemed to decline and has been substituted by rubberwood *Hevea brasiliensis*), which becames more promising.

Teak wood is commonly used for carving, furniture manufacturing, general construction, toys, house-hold utensils production, etc. The local products of the FIO teak plantations are mostly used for domestic consumption with less quantity used to make value-added products for export. However, the FIO itself runs a business producing prefabricated round teak log cabins for sale at reasonable price, which is of interest to riches in the Kingdom. This product is also for export, as reported by the FIO.

Research and development in teak

In collaboration with the Royal Danish Government, Thailand has established the Teak Improvement Centre (TIC) in Lampang, since 1965, with following objectives (Keiding, 1965)

1. Improve the quality of teak in terms of growth

Table 3. Teak wood (log and sawn timber) import and export *(Currency exchange rate 40 Baht = 1 USD)*

Item	1997		1998		1999		2000		2001	
	cu.m	'000 B	cu.m	'000 B	cu.m	'000 B	cu.m	'000 B	cu.m	'000 B
Import	80,488	1,348,397	39,720	917,397	110,796	2,075,781	94,82	2,001,889	91,62	2,090,169
Export	4,698	462,105	4,866	474,505	7,008	616,977	36,887	573,553	26,214	644,310

rate, stem form, wood quality and resistance to pests and diseases through breeding programmes.

2. Produce genetically superior seed by the establishment of seed production areas and seed orchards.
3. Develop nursery and plantation techniques suitable for large scale planting programmes.
4. Conduct research supporting tree improvement, seed procurement and planting programmes.
5. Since then, notable results of this centre were obtained as follows :

- 480 elite trees were selected (Gavinlertvatana, 1995) for further multiplication and propagation. Out of this, 357 plus trees have been vegetatively reproduced for clone banks and clonal seed orchards establishment (Sumantakul and Sangkul, 1995).
- Seeds of selected trees were collected for progeny trials, as well as for seedling seed orchards establishment.
- Both local and international provenance trials have been established and studied for their appropriateness to suit with different conditions and sites.
- About 1,120 ha of seed production areas have been established and maintained for immediate seed production. However, seed productivity of these SPA is rather low, ie. about 10 kg/ha only (Meekaew, 1992).
- 1,831.20 ha of seed orchards were established and maintained. However, their seed productivity is low, ie. about 70 kg/ha (Meekaew, 1992).
- Annually, about 20 tonnes of genetically improved seeds can be harvested from the SPA and seed orchard, which is still far less from the yearly demand of approximately 150-200 tonnes.
- Controlled pollination in teak has been successfully developed for breeding programmes. The outputs from this are still under-way.
- Vegetative propagation techniques have been developed. Buds are commonly used for cloning; tissue-culture technique was developed in 1987 (Kaosa-ard and Apavatjrut, 1997), which became commercial in 1992. Annually, about 500,000 plantlets are produced for afforestation (Gavinlertvatana, 1995).
- Rooted cuttings from both mature trees and seedlings in seed orchards have been successfully developed since 1993; it is now possible to apply this technique to tackle problems in quality seed deficiency.
- Saturated polymer and drip irritation have been applied for teak plantation establishment to make it possible to plant teak trees all the year round, as well as to increase growth.
- Insect pests have been studied to find out suitable methods of control, both chemically and by biocontrol techniques.
- Small teak timber from thinning for specific utilization is still under study.
- Hundreds of research results on teak have been published in Proceedings of Annual Forestry Conferences in Thailand, as well as in other scientific/forestry journals of regional and global status.

ISSUES RELATED TO QUALITY TEAK TIMBER PRODUCTION

As the theme of the conference focused particularly to quality timber production. It is still unclear to many participants on such the word 'quality timber'. Some issues should be highlighted as follows:

1. What is the meaning of 'quality timber'? Is it a timber from natural forest or from teak plantation? Is the timber for general processing, or for specific purposes? Quality timber may mean the large timber for processing with less or no knotty wood, round, long, less buttress and less sapwood. If so, quality timber may be only ideal material as it is hardly possible to afford such the timber.
2. Criteria to classify the 'quality timber' are not yet stipulated. What should be such the criteria?
3. The quality timber is for whom? Is it for producers (tree farmers), for the manufacturers, or for end-users. We may need different criteria to classify the quality timber for these target groups.
4. As far as there is no clear status of teak forests or plantations, it is likely impossible to manage the resources sustainably. Current status of teak resources in each country is thus urgently required as the baseline information for planning.

CONCLUSIONS

Teak in natural forests of Thailand is decreasing continuously and the remaining natural teak-bearing forests are to be conserved satisfactorily. Teak stand density is being decreased at alarming rate, probably due to illegal cutting for domestic consumption and for other purposes. On the other hand, teak in forest plantations increased since 1993 after the government for Thailand promoted private sector to invest in this business through the provision of subsidy for private forestation. However, the enactment of the Forest Plantation Act B.E. 2535 is an obstacle for private forestation promotion. Tendency for teak plantation establishment is likely to increase when the act is revised and amended. The State enterprise, especially the Forest Industry Organization, played an important role in teak plantation establishment and utilization. Thailand has to import teak-wood from neighboring countries after logging ban since 1989, and wood deficiency is still a major concern among the wood-based industries. Private forestation thus can be an alternative to solve the problems.

Thailand has established the Teak Improvement Centre in Lampang since 1965. Many achievements have been made for teak plantation establishment, especially using genetically improved materials. Techniques to propagate teak vegetatively have been developed and commercialized, and are at present used for superior clonal multiplication.

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Quality Timber Products of Teak from Sustainable Forest Management pp 73-79

Growing Teak in Malaysia

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ABSTRACT

There is an enduring global demand for teak wood because of its outstanding appearance and durability. Yet, supply of the timber is diminishing and there is an increasing reliance on plantation timber to fill the gap. Growth rates of teak are modest, generally averaging less than 10m3 ha-1 yr-1, except where exaggerated claims are made about the potential performance of plantations. This discourages significant investments in plantation development and research and development to support the activity. However, if systematic research efforts are put into the improvement of the species, better yield and improved quality timber is achievable, as in the case of many other plantation species around the world. While, there has been a lot of interest generated by private sector investors in Malaysia to go into forest plantations, there is a need to find out if at all any genuine efforts have been made by these investors to pursue their efforts to success. The other major area of concern is that, if the interest is genuine and if the investors are moving into such plantation programmes, is there sufficiently good quality planting material of teak available at reasonable price for such ventures? The paper, therefore, attempts to look at the state of teak plantations in Malaysia and the research and other efforts that have been carried out till date, to support establishment of teak plantations in the country.

Keywords: Demand and supply, Malaysia, teak, private plantations

INTRODUCTION

Teak (*Tectona grandis*) is a unique species, undoubtedly one of the world's premier appearance grade timber, having the additional utilization benefits of workability, stability and durability. It enjoys a global reputation and demand. In addition, it is amenable to plantation cultivation and is planted on four continents. On a global basis, it ranks among the top five tropical hardwood species based on plantation area established.

Cultivation of teak in Malaysia is relatively a new enterprise. The total area planted to date is estimated to be approximately 4000 hectares. For a long time, it was widely believed that teak grew best only in the drier states in the north of Peninsular Malaysia and hence was not promoted in other parts of the country which are hotter and wetter. However, results from 3-8 years trials now indicate that they are equally as well suited to the production of teak as in the north, and this has generated considerable interest in the establishment of teak plantations on a large scale.

The establishment of teak plantations in Malaysia is being actively promoted by the Department of Forestry, the Forest Research Institute of Malaysia (FRIM), the Federal Land Development Authorities (FELDA, FELCRA, RISDA, etc), other government agencies and the private sector. These commercial planting programs aim to achieve mean annual increments of eight cubic meters per hectare per year or more. Developments are occurring on an industrial plantation scale (>100 ha) as well as on small holdings. The latter activity is being vigorously promoted as an enterprise requiring low labour inputs but with potentially high returns.

ECOLOGICAL REQUIREMENTS OF TEAK

Teak can survive on a large variety of soils, however it develops best on well drained and fertile soils, especially on volcanic substrata such as igneous and metamorphic soils or on alluvial soils of various origins. The optimum soil pH is between 6.5-7.5 and the calcium content of the soil is an important factor. The deficiency of this mineral in the soil results in stunted growth of teak (Kaosa-ard, 1981). From the early experience of growing teak in Malaysia, Wyatt-Smith (1957), reported that teak is rather flexible to soil requirements as it grows on a variety of soils of different geological formations. However, the quality of growth depends on depth, structure, porosity, drainage and moisture holding capacity of the soils. In general, the findings indicate that deep soils with free draining properties are most desired for growing teak. Optimum rainfall for teak ranges between 1250 and 3750 mm/year; however, for the production of good quality timber, the species requires a dry season of at least 4 months with less than 60 mm precipitation (Kaosa-ard, 1981). Teak grows best when the minimum monthly temperature is above 13°C and the maximum monthly temperature is below 40°C

EXPERIENCE WITH TEAK IN MALAYSIA

Teak cultivation in Malaysia is relatively new when compared to neighbouring countries like India, Myanmar, Thailand and Indonesia. Even though the first teak plantations in Peninsular Malaysia was established in 1909, the total acreage of teak plantations in Malaysia is still very small. In the early years it was believed that teak only thrives best in the drier zones like in the states of Kedah and Perlis and hence was not seriously promoted to the other parts of Malaysia. Table 2 gives the areas and

Table 2. Details of teak plantations in Peninsular Malaysia

State	Forest reserve/ Name of agency	Area (Ha)	Year of establishment
Perak	Chikus	20.00	1989
	Bintang Hijau	45.00	1984
	Maju Aik Sdn Bhd, Trolak	45.00	1993-1996
Negeri Sembilan	Kenaboi	90.80	1980-1988
Kelantan	Temangan	81.00	1983
	Jeli	30.00	1983
	Chabang Tongkat	0.04	1986
Perlis	Mata Ayer	3.12	1953-1958
		128.83	1960-1969
		64.29	1980-1989
		145.00	1990-1992
Kedah	Bukit Berangin	626.30	1985-1990
	Chebar Besar	23.00	1987-1988
	Gunung Raya	40.00	1985
	Bukit Enggang	31.63	1953-1957
		76.00	1983-1986
	Rimba Teloi	43.60	1985-1986
	Bukit Perak	19.00	1989
	Terenas	54.80	1985
	Chebar Kecil	24.00	1988
Sabah	Sejati	320.00	1992
	Boonrich, Telupid	470.00	1993
	Balung, Tawau	180.00	1994
	Banggi Island	100.00	1996
	Tabung Haji	300.00	1998-2002
Malaysia	Private sector and smallholders	1036.59	1998-2001
	Total	**3998.00**	

hectarages in Malaysia where teak is now grown.

EFFECTS OF HIGH RAINFALL ON GROWTH PERFORMANCE

Various small plot studies in Perak (Lenggong-rainfall 2800mm), Selangor (Kuala Selangor rainfall, 2500mm), Kepong (FRIM-rainfall 2600mm and Johore (Yong Peng-rainfall, 2700mm) over the last 3-8 years have shown that teak can thrive equally well if not better on wet and hotter regions around the country. Furthermore the early growth performance of the trees in these regions have also been remarkable. This has sparked off the interest to promote teak on a large scale within Malaysia. A report by Kondas (1995) from the teak growing areas in India showed that teak responds very well in terms of growth and girth increment in areas were the trees receives sufficient moisture at least for most part of the year when compared to those growing in the monsoonal areas.

PERFORMANCE OF TEAK

(Data based on trees from Mata Air Station in Perlis)

Height growth	: 4 m in the first year
Diameter growth	: 1.5-2 cm (per year)
DBH at 15 years	: 25-35 cm
Total height at 15 years	: 22-25 meters
Clear bole at 15 years	: 12 meters
Volume per tree at 15 years	: 0.50 m^3

GROWTH PERFORMANCE ON SOME SOILS IN PENINSULAR MALAYSIA

Unmanaged teak stands

Based on the information from Table 3, it can been observed that soil types have a significant influence on teak growth if left unmanaged. Penambang series (riverine soils) and Serdang series (sandstone derived soils) was observed to have better growth when compared to shallow and moderately deep stony soils of shales of Kuah series and Batu Lapan series, respectively. Laterite soils of Gajah Mati series and Pokok Sena series have been observed to drastically reduce the growth of teak crops by 30 per cent in compari-son to the Penambang series and Serdang series.

Based on the details in Table 3, it would seem clear that teak cannot do well on laterite, compacted and shallow sub-soils if unattended after planting. However, for rubber plantations upon adequate preparation of such soil types through ploughing etc., and through good silvicultural practices, good yield of latex have been achieved. Hence, if intensive management practices and good fertilization programmes can be followed, teak would probably do well in such soil types. These can be postulated form the young plantings as shown in Table 4.

New plantings under plantation management regimes

As part of trials to evaluate teak on various soil types and ecological conditions, small plots throughout the country have been set up for study. To reduce cost and to ensure that optimal silvicultural practices will be ensured, these trials have been carried out on small farmers plots. This arrangement has been termed as smart partnership because while the farmers benefit from free advise, good quality seedlings, agricultural input from FRIM and the returns from the harvesting of the final crop, FRIM in turn, gets the services of the smallholder in terms of labour to manage the plot and at the same time has also access to the growth

Table 3. Mature stand of teak - unmanaged

Soil series	Parent material	Year planted	Spacing(m)	Total height (m)	Diameter (m)
Serdang	Sandstone	1965	2.4 x 2.4	31.38	35.44
Penanbang	Alluvial	1966	2.4 x 2.4	31.34	34.60
Batu Lapan	Laterised Shale	1966	2.4 x 2.4	18.12	26.20
Kuah	Shale	1965	2.4 x 3.0	17.24	23.50
Gajah Mati	Laterite	1962	2.4 x 2.4	18.44	24.28
Pokok Sena	Laterite	1963	2.4 x 3.0	20.24	25.44

Source: Amir Husni, 1998

Table 4. Young teak stand - under plantation management regime

State	Soil series	Parent material	Crop age (month)	Spacing(m)	Mean height(m)	MAI height(m)	Mean DBH(cm)	MAI DBH (cm)
Selangor	Bernam	MarineClay	39	3 x 4	10.5	3.2	11.8	3.6
	Bernam	MarineClay	72	2.7 x 2.7	13.0	2.2	14.5	2.4
	Bernam	MarineClay	72	2.4 x 2.4	13.0	2.2	13.1	2.2
	Nerang	Shale	35	3 x 4	8.3	2.9	7.7	2.7
Pahang	Bungor	Shale	17	3 x 4	4.4	3.1	-	-
Kedah	Gajah Mati (lateritic)	Shale	72	3 x 3	12.5	2.1	12.8	2.1
Perlis	Resau	Alluvial	47	3 x 4	9.9	2.5	12.6	3.2
	Resau	Alluvial	44	3 x 4	8.5	2.3	9.5	2.6
	Resau	Alluvial	44	3 x 4	8.6	2.3	8.6	2.3

Seed source: FRIM, Perlis; *Data source*: Krishnapillay and Razak (unpublished)

data. Table 4 gives some of the early growth results on some of the soil types, It is interesting to note that growth results on some of the problematic soils appear to be good. Monitoring of these plots will be continued until the crop is harvested.

ADOPTION SCHEME (SMART PARTNERSHIP)

As mentioned earlier the concept of smart-partnership has become very successful for the furtherance of knowledge on the growth of teak under various conditions on the farmers field. This concept has been further extended to the other species that are presently also being promoted for forest plantations, namely Azardichta excelsa. To date we have a total of 39 smallholders participating in the programme (Table 5)

Table 5. Showing the number of participants on the Adoption Scheme

No of participants	Crop	Area [ha]
31	Teak	68.16
2	Sentang	5.6
6	Teak and Sentang	14.4

Source: FRIM (unpublished)

AVAILABILITY OF PLANTING MATERIALS

Teak plants can either be raised using seeds, vegetative tissues (stumps, branch cuttings etc.) and through tissue culture. Plants raised from seeds collected at random tend to show fairly wide variability in its growth. Seeds, however, are very important to maintain a broad genetic base. To obtain fairly uniform planting materials from seeds, it is important that seedling seed orchard or clonal seed orchards of good plus trees have to be raised to collect seed materials. On the other hand, vegetative propagation using cuttings and tissue culture techniques will ensure production of uniform planting materials of desired qualities.

At present the desired quality planting material of know genetic sources are not available in sufficient quantity. FRIM is currently working with some reliable commercial nurseries and plant propagators to produce large quantities of these quality plants to meet the needs.

RESEARCH AND DEVELOPMENT ON TEAK

FRIM at present is undertaking research on the following aspects of teak.

- **Tree improvement** - to make available elite planting materials for mass multiplication. To date seed and clonal orchards have been established
- **Tissue culture** - to develop large scale *in-vitro* propagation techniques for the production of uniform true to type plants for the plantation industry.
- **Genetic evaluation** and **finger-printing** of teak clones using isoenzyme and molecular markers.
- **Species site matching** - Detailed studies are ongoing

- **Silvicultural practices** - Planting trials relating to optimum thinning regime, fertilizer requirement and sound are being looked into.

INCENTIVES FOR FOREST PLANTATIONS

To hasten early development of forest plantations in Malaysia, incentive packages were introduced under the Promotion of Investment Act (PIA) 1986 and the Income Tax Act 1975 (Khaziah, 1992). Under the PIA 1986, the two incentives offered were pioneer status and an investment tax allowance. Those planting timber, rattan, and bamboo, which were designated promoted activities under the PIA 1986, were granted pioneer status. The Income Tax Act 1975 provided an agriculture allowance to those who invested in forest plantations.

The PIA 1986 (Malaysian Industrial Development Authority, 1986)

Pioneer Status (PS)

Before 11 January 1991, PS provided full exemption from income and development taxes for a period of 5 years. However, since 1 November 1991, tax relief has been in the form of a 70 per cent exemption from a company's statutory income. This means that a company granted PS would have to pay income tax of 35 per cent and development tax of 2 per cent on 30 per cent of its statutory income. Hence the company is taxed at a rate of 11per cent on its overall income. A company granted PS would be eligible for the 70 per cent exemption for a period of 5 years from the date of its first sale.

Investment Tax Allowance (ITA)

The ITA is in the form of an allowance of 60 per cent of the qualifying capital expenditure incurred within 5 years from the date of approval of the project. In the case of agriculture, the term qualifying capital expenditure has been expanded to include the following:

a. The cleaning and preparation of land
b. The planting of crops
c. The provision of irrigation or drainage systems
d. The provision of plant and machinery used in Malaysia for the purpose of crop cultivation, animal farming, aquaculture, inland or deep-sea fishing, and other agricultural or pastoral pursuits
e. The construction of access roads, including bridges
f. The construction or purchase of buildings (including those provided for the people's welfare or as their living accommodations) and structural improvements on land or other structures that are used for the purposes of crop cultivation, animal farming, aquaculture, inland fishing, and other agricultural or pastoral pursuits; provided that for the purposes of paragraphs (e) and (f) such roads, bridges, buildings, and structural improvements on land and other structures are on part of the land used for the purpose of such crop cultivation, animal farming, aquaculture, inland fishing and other agricultural or pastoral pursuits.

According to Khaziah (1992), the ITA is given as a deduction against statutory income. In any one year, the amount of deduction is limited to 70 per cent of statutory income for that year. Khaziah further noted that, even though it was supported by these two incentives, the private sector's involvement in forest plantation development, especially in Peninsular Malaysia, has not been encouraging. Passive involvement by the private sector in forest plantation projects is still partially the situation today. Another option that has been proposed to attract investors was to introduce 'group relief' under the ITA (Khaziah, 1992). Group relief in this context refers to offsetting losses with income from other profitable ventures of a company's subsidiaries.

There are three major types of risks involved in planting forest trees or commercial tree planting (CTP), namely:

- Physical risk
- Market risk
- Financial risk

Physical risk

Some of the major physical risks involved in CTP are the selection of the right species of tree to plant in certain types of soils, the growth rates of the tree, the physical properties of the timber required, the species' susceptibility to pests and diseases, the percentage of recovery from logs and the type of silvicultural regimes to follow. This list is not exhaustive and there are many more factors that are involved. In general, tree plantation is exposed to a higher risk of pest and disease infections than trees in the natural forest. This risk can be associated with the homogeneity of tree plantation. Fire is another major physical risk that is associated with CTP. Forest plantation fire outbreak is especially common during the dry season

Market risk

Unlike other agricultural projects where the final products are realized within a short period of time (from a few months to one to two years), CTP can only be harvested from 15 years or more depending on the final objective of the forest plantation. It would be difficult for the investor to change the species mid-way through the rotation if market preference change.

Financial risk

The financial risk is perhaps the single major factor that has prevented the large scale establishment of CTP. The high financial risk associated with CTP is due to the long gestation period and the payback period. The long gestation period means that investor has to set aside sufficient capital reserves for funding all the plantation activities from establishment to final harvest. This may span a period of 15 years or more depending on the species and the final objective. Many of those who have invested in CTP are currently facing cash flow problem.

The physical and market risks can be overcome through proper planning and implementation. However, the financial risks associated with long gestation period and the uncertainty of the final outcome has discouraged new investments in CTP. The current sets of incentives available for CTP have not addressed the cash flow problem adequately and as a result very few CTP have been set up.

Constraints of the incentive package

Almost all of the investors feel that the existing incentives for forest plantation are not only unattractive but also, if applied, would place the company concerned in a difficult position to sustain its yearly cash flow.

There are three main reasons, inclusive of the incentives, why private investors are not interested in investing on forest plantation projects.

1. The first is the issue of availability of land for the establishment of a forest plantation project. To make the project a profitable venture, most interested private entrepreneurs require a sufficient land size, not to mention that the land must be suitable for planting at a low premium charge and in a suitable location in relation to infrastructure. Such contiguous suitable land are difficult to come across.
2. Second is that funds or loans at a subsidized interest rate must be made available for the development of the plantation. Currently banks policy do not have provisions to fund projects on forest tree plantations.
3. Third is the issue of the incentive package itself, which is focused more on crops with a shorter rotation period than on crops planted under the forest plantation program is not attractive enough.

CONCLUSIONS

Based on the preceding discussion, especially with regard to constraints and weaknesses of the current incentives, the need to develop a more comprehensive package for forest plantation development or to conduct a revision of the incentives is more pressing than ever before. Other options that need to be considered for the development of forest plantation, for example, suggestions for additional incentives such as group relief need to be put in place

The need to hasten the forest plantation project is more evident than ever, especially with the decreasing trend in timber production from the natural forest. For instance, the timber production in Peninsular Malaysia has drastically declined from more than 12 million m^3 in the early 1990s to only 5 million m^3 from 1998 onward. A similar trend can also be observed for Sabah and Sarawak, where timber production dropped from 18 million m^3 and 8 million m^3 in the early 1990s to 14 million m^3 and 3 million m^3 in the year 2000, respectively. It is well known that the forest-based industries (FBIs) employed more than 300,000 workers in the year 2000; a majority of these workers were from rural communities. Hence the yearly declines in timber production will have a negative impact not only on the development of the existing FBIs but also on the social well-being of the workforce engaged in such industries. Therefore, it is imperative that more attention is given to the development of forest plantations, not only today but also in the years to come.

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Development of Teak Plantations in Ghana: Propagation, Processing, Utilization and Marketing

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ABSTRACT

The development of teak (*Tectona grandis* L.f.) plantations in Ghana is traced back to 1875. Since then, teak was grown as the most popular plantation species in the Country covering more than 50per cent of the total plantation forests, estimated to be about 150,000 hectares. The success of teak plantations in Ghana is dependent upon factors like ease of cultivation, fast growth, fire resistance, tolerance to wide range of soils and rainfall and superior wood quality. Artificial regeneration of teak in Ghana is by direct sowing, bag planting and stump planting. Beds of about 1.2 m width are used for seed broadcasting and the germinated seeds are potted in a mixture of sand and compost. The seedlings are transplanted at a spacing of 1.8m x 1.8m in savanna forests or at 2m x 2m in other forest zones. Thereafter, they are managed by singling, pruning and thinning until maturity, at about 30 years. Thinnings from 10 to 15-year-old plantations are used mainly as transmission poles, after pressure treatment with CCA preservative. Mature stems of over 20 years of age are processed into sawn timber which is exported to India at a price of 460 USD per m^3. Limited finished products like furniture and paneling and flooring materials are manufactured by local craftsmen for domestic uses. Demand for teak poles, sawn timber and finished products by far exceeds supply, making establishment of teak plantations a very viable venture. Past and present research in agroforestry, progeny testing and assessment of variations in quality and properties, which span over a period of 30 years, have been concluded. It is hoped that a new collaborative research programme, with four other partner countries, funded by the European Community, will improve the quality and productivity of future teak plantations in Ghana and the West African sub-region.

Keywords: Teak plantations, Ghana, artificial regeneration, utilization, research.

INTRODUCTION

Teak (*Tectonia grands* L.f.) is a large deciduous tree with an open crown, straight clear bole up to about 25 m and a diameter of up to 2.5 metres. It has a pale brown bark, which is sometimes fluted with shallow longitudinal grooves in young trees, cracked and scaly in matured ones with a thickness of 1-1.5 cm. It has simple broad leaves and inflorescence is terminal, forming a large pinnacle from the axils of upper leaves.

Teak is a semi-diffuse porous wood with medium to large solitary and 2-3 radial multiple pores of different sizes, of moderate frequency and usually with tyloses and gum inclusions. It has a paratracheal, vasicentric, with occasional aliform parenchyma. The rays are variable, very narrow to broad, about ¼ to ½ of the vessel diameter and of moderate frequency. The proportion of fibre tissue is high. Growth ring boundaries are demarcated by differences in vessel diameter, dark ground fibre tissue and marginal parenchyma cells. The cream sapwood of teak is 20 to 50 mm wide with golden brown, durable heartwood, which occasionally has streaks with distinct odour when wet. The grain is straight or slightly interlocked. Texture is medium to coarse with greasy feeling. Teak is a medium to high density wood with moderate to high strength. Teak seasoning is best done using air-drying and most of the teak processed in Ghana is dried this way to reduce seasoning defects. Though it can be kiln dried, care needs to be taken to avoid discoloration of the wood brought about by surface oxidation. Shrinkage and movement in service are low.

Teak is known to be relatively easy to saw and has desirable finishing qualities. It can be peeled on a rotary lathe to produce excellent rotary veneer but is normally sliced and used for face veneer in plywood manufacture. Although the heartwood is said to be one of the most naturally durable woods of the world, the sapwood is perishable and easily susceptible to rot, termite or borer attack.

HISTORY OF TEAK IN GHANA

Teak is indigenous to the South-East Asian region and grows naturally between latitudes of 10^0 N and 30^0 N, in countries like India, Thailand, Myanmar, Indonesia, Puerto Rico and Laos. It was introduced in Ghana, the then Gold Coast, by the German missionaries between 1875 and 1900, in the then Trans-Volta Togoland, now Volta region. The British colonial government also planted teak in the year 1905, in the then Ashanti region. In 1908, it was grown in small plantations by the Forestry Department in both the Savanna woodlands and the Closed Forest Zones on pilot basis and was later adopted as the main plantation timber species.

The timber industry in Ghana has until the last 10-15 years relied almost exclusively on the natural tropical moist forests for its wood supply. However, the high rate of deforestation and the increasing rate of population growth, industrialisation and high demand for poles for rural electrification projects gave indications that the natural forests could not meet the demand for wood perpectually. Therefore there was an urgent need to replenish resource base with short rotation timber species which have good wood qualities akin to the traditional species to satisfy both the quantitative and qualitative needs of the country. The choice of which species to grow was made from the three most important exotic species in Ghana: Cedrella (*Cedrella odorota*), Gmelina (*Gmelina arborea*) and Teak (*Tectonia grandis*), of which teak is by far the most widely cultivated. The wood industry today requires 4 million cubic metres of wood supply annually which by far outstrips allowable sustainable supply of only 1.2 million cubic metres. Many factors account for the adoption of teak as the favourite plantation species in Ghana. In addition to its relatively short rotation, the ability of teak to grow within wide vegetational zones, especially its capability to grow well in dry forest areas and the savanna, was a big deciding factor. Consequently, it is now grown in all regions of Ghana including the savanna regions of northern Ghana where its resistance to bush fire makes it the most preferred species for plantation. It could also be attributed to the strong reputation of its excellent wood quality that makes it one of the most valuable multi-purpose timbers of the world.

Teak plantations form over 50 per cent of the estimated 100,000 ha of productive plantations belonging to the Forests Services Division (FSD) of the Forestry Commission of Ghana. This is distributed in almost all the regions of the country as shown in Table 1. There are also about 70,000 ha of private plantations distributed in the ten regions of the country of which teak forms the major component.

Table 1. Government forest plantation with its teak component as of 1995

Region	Regional total (ha)	Percentage of teak
Upper East	1940.31	65%
Upper West	634.22	25%
Northern	1625.44	98%
Brong Ahafo	13554.8	62%
Western	6501.3	Not mentioned
Ashanti	16782.9	30%
Eastern	10169.1	8%
Central	Not mentioned	
Volta	1400 (Estimated)	Inventory being undertaken
Greater Accra	350 (Estimated)	"

Source: Forest Plantation Development Centre.

More recently, the government of Ghana has embarked on a massive reforestation programme with financial support from the European Union and other sources. Under this programme, the FSD has been commissioned to plant 20,000 ha in the year 2002 and 80,000 ha in 2003 and subsequent years. Most of this will be planted with teak. The

FSD provides the provenance and monitor the progress of the private farmers who are financed to undertake the project in addition to cultivating their own seasonal crops. FORIG provides superior seedlings and technical advice at a minimal cost to the farmers and private entrepreneurs.

TEAK AS PLANTATION CROP

Soil

The cultivation of teak as a plantation crop requires good soil. Soil textures could be light, medium or heavy. Subsoil textures of sandy, clay, loam and finer textures are considered wholly adequate and gravels of less than 10 per cent is acceptable (Keogh and Painstil, 2001). Teak grows well on porous sandstones but remains stunted on quartzite or hard-metamorphosed sandstone. It is also found on granites, schist and other metamorphic rocks. It grows on limestone where the rock has disintegrated to form a deep loam. The various soil types suitable for planting of teak are; acid soils, alfisols, alluvial soils; colluvial soils; ferralsols; gravelly soils lateritic soils; red soils; tropical soils; ultisols; vertisols (Keogh and Pentsil, 2001). The following preliminary values have been suggested for teak soils in West Africa (Class 1 stands) by Keogh and Paintsil (2001).

- over 150-160 pm P_1 (without $P_{occl.}$) in 0-10cm
- Ca/CECpH 7 (20-30cm) over 50 %
- Mg/ CECeff (0-10cm) over 15-20 %
- At least 15 ppm Mn (DPTA) in 0-10cm
- At least 2.0ppm Zn (EDTA) in 0-10cm

The required pH range is acid to neutral (Alexander *et al.*, 1987); but Keogh (2001) has stated that there is often no significant relationship between growth and pH in teak plantations. Teak is not a deep rooting plant and it tends to produce long lateral roots. Suitable depths of soil for planting teak are between 80 and 120 cm but soils of depth less than 50 cm is unsuitable (Keogh and Paintsil, 2001). The required soil qualities allow teak to be grown in almost all vegetational zones of Ghana and West Africa.

Regeneration of teak

Teak is insect pollinated and seed production starts after the fifth year. Artificial regeneration of teak in Ghana is done by direct sowing, bag planting and stump planting. Stump planting is the most common method used since stumps are easily produced and transferred from place to place whiles maintaining their viability. Moreover, they are easier and quicker to plant and subsequent growth is more rapid. Bag planting is also widely accepted though it is seen as more tedious and expensive. Direct sowing is the least favoured since it is characterized by high mortality and slow growth. Tissue-culture techniques are yet to be introduced in Ghana.

Fruits, containing one to four seeds are collected from the floor of the forest between January and March. In seed orchards the branches are shaken for the seeds to fall. Next to the genetic constitution, the moisture content and viability of the seed are the two important qualities of the seed that are considered. Moisture content of 11 to 13 per cent is deemed as adequate. The rate of natural germination of teak seed is low; (20 to 40 %) and sporadic; 10 to 60 days. (Gyimah *et al.*, 2001). Germination under nursery conditions is relatively low (25 to 35 %) and sporadic (between 10 and 90 days). The Forestry Research Institute of Ghana (FORIG) has developed teak seed orchards and has identified superior (plus) trees. Selection of superior trees for vegetative propagation is also made available from plots established in 1970 (Keogh and Penstil, 2001).

Seed preparation, germination, potting and transplanting

The calyx of fruits should be removed by rigorous rubbing and winnowing before storage. Fruit can be dry-stored in plastic bags and sealed tight for up to two years. Teak seeds are normally kept in sacks and stored in conditioned rooms protected from rodents for 1 to 2 years. They are also stored safely for one to two years under cold storage conditions. (Gyimah *et al.*, 2001) Seeds are soaked in water for three to four days followed by air drying for one day before sowing and daily water change (Gyimah *et al.*, 2001). Seeds should be soaked overnight in water and dried in the sun or in partial shade during the day. Repetition of the process for a week has been recommended for successful germination (Chacko *et al.*, 1991).

The beds should be narrow, about 1.2 m in width with varying lengths and loosened topsoil. Black soil and sand are added to the soil and mixed to promote better drainage and easier uprooting. There should be available water, which should not be stagnant, no standing trees and the site protected from grazing by fencing. On flat land, the longitudinal axis of the bed should be in East-West direction to prevent plants in the nursery from shading each other (Gyimah *et al.*, 2001). Beds on slopes should be along the contour (against the slope) to help reduce the risk of erosion.

Seeds are carefully broadcasted over the surface of the bed and soil is thinly spread over the seeds. A little shade is provided using palm fronds and the bed is watered twice in a day; mornings and late afternoons. Seedlings are then potted or transferred onto transplant beds, usually 8 to 12 weeks after sowing. The medium is prepared with topsoil or equal parts of sand and compost. Black polythene bags of 20 x 10 cm are perforated and filled to the brim with the soil ensuring that it can stand firm on its own. Transplant beds are prepared in the same way as the germination beds. Seedlings are ready to be transferred into individual pots or transplant beds when they have developed two true leaves. The soil in the pot and the transplant beds are all watered two hours before transplant and the germination bed is also watered for easier uprooting of seedlings. Seedlings with bent or badly formed roots are abandoned since they produce poor quality planting stock. Care needs to be taken to keep the roots intact, especially the taproot.

A hole is made in the center of the soil-filled watered pots and one seedling is planted in individual pots. The soil at the base is gently pressed to keep the seedling stable. The potted seedlings and the transplanted ones are shaded with 70 per cent palm fronds to protect the delicate leaves from excessive dehydration and heavy rains. After 7 to 10 days, the shade is reduced to about 30 per cent and fully removed after four weeks. Light watering of seedlings is done for the first eight weeks and thereafter only during the dry periods.

Pruning of the tap root is done to induce the plant to develop a strong compact root system when the seedlings have attained a height of 15 cm. The potted seedling is lifted off the ground and any protruding root is cut off. Potted seedlings are pruned every three to six weeks. For transplanted seedlings, a sharp knife is thrust into the soil diagonally to cut off the roots at about 15-20 cm length below the surface of the bed.

At the end of about three months, seedlings from the pots are ready to be transferred to the field. Seedlings grown on transplant beds are usually used for stump planting. Potted seedlings are not easily transferred in terms of cost and haulage but they have a higher survival rate. Stumps on the other hand are easily transferred but have a lower survival rate and are also subject to cutting errors. A process called 'hardening off' is employed to improve the chances of survival of the seedling in the field. This involves easing up on the watering of plants, removing the shade and then pruning the plants. This is done about a month to the date of transferring the seedlings to the field. Planting is done as close to the rainy season as possible to enable plants reach their full growing potential in the first year.

Site selection and preparation

In addition to securing good planting material, the next most important thing is the site for the propagation of the stock. The important parameters to be considered for the selection of site for stock propagation are the climate, slope and the soil as previously discussed.

Teak is tolerant of a wide range of climates but grows best in warm, moderately moist tropical conditions. (Kadambi, 1972). However, growth is highly correlated with rainfall and teak grows best in the wet evergreen and semi-deciduous forests of Ghana where rainfall exceeds 1200 mm a year. Below 1200 mm, as in the savanna, growth is slow. Teak also tolerates a wide variation in temperatures, which range from 0°C to 48°C, but the optimum range is between 16°C and 40°C which falls within the range of the temperature experienced in Ghana.

Ideally, teak should not be planted on steepy slopes of over 15 degrees. The thick canopy that is formed by the leaves makes it impossible for vegetation to grow beneath the tree making the land vulnerable to erosion especially on a sloping land. However, undulating ground may be superior to flat land as natural drainage is enhanced (Keogh and Pentsil, 2001).

The site for planting teak must be cleared of all vegetation especially to prevent competition for light with other plants as teak is a great demander of light. The topsoil needs to be loosened to break up to increase soil airspace and drainage. Waterlogged land must be drained.

The following guidelines are used for site preparation in Ghana.

- A planting distance of 1.8 x 1.8 m is recommended for savanna forest while 2 m x 2 m spacing is used in other forest zones.
- Ensure plants do not suffer dehydration or wilting during transportation or while waiting to be planted out therefore container stock has to be kept in shade and watered periodically.
- Avoid a prolonged period between arrival of the plants at the site and planting;
- Avoid planting damaged, very small or very large plants.

The use of fertilizer, though recommended, is barely used in Ghana because of financial cost.

Growth rate

The growth rate of teak in moist and dry semi-deciduous forest of Ghana is 8-10 m^3 /ha/annum at 25 years. This growth rate compares well with the rate of 5.5 to 66.4 m^3 /ha/annum reported for 25-year old stands in Indonesia (FAO). Height growth may be at rates between 3.0 and 5.0 m per year during the first 5 to 10 years. It is reported that a 45-year old teak stand at Bosomoa forest reserve in the transition zone of Ghana attained an average height of 31.0 m and a diameter of 43.0 cm. Growth and stem quality of trees in plantations can be improved up to 23 per cent and 17 per cent, respectively through proper selection of provenances or seed sources. For example using improved seeds can increase growth and volume production of plantations by 5 – 25 per cent (Keiding *et al.*, 1986).

Silviculture and management

Teak is a pronounced light demander intolerant of shade and requires complete light overhead. It is deciduous and shed its leaves in the dry season and the crown requires freedom on all sides for development. Teak is very sensitive to mutual competition and this is a limiting growth factor in drier sites. Teak produces a long thick taproot and this may or may not persist as the tree grows and develop numerous strong lateral roots. The seedlings are sensitive to suppression by weeds and cannot grow well without repeated weeding. The following silvicultural practices are needed in teak plantations to get the desired crop.

Singling by removal of recurrent multiple stems to ensure one dominant leader, should be done regularly. Competing leaders are removed at intervals of 3- 4 months during the first year. Some may also have to be cut during the second year.

Prunning of branches to prevent a large number of knots in the lower log of the tree at harvesting is also needed. Early pruning improves wood quality and increases merchantable height. If possible, pruning should be carried out just after most new leaves are produced during the rainy season and is best done after thinning. At least, 35-40 per cent of the total height in live teak crown must be left to prevent hindrance to growth.

Thinning to remove some of the trees to reduce the tree density of the stand, is an essential silvicultural practice in teak management. In Ghana, the first thinning is carried out when the stand is about 12 metres (top height) during which about 50 percent of the trees are removed. For all subsequent thinnings, basal area should be allowed to build up to 20 or 21m^2 /ha and thereafter 6 m^2/ha is removed at each thinning (Keogh and Paintsil, 2001). Although thinning and prunning are important silvilcultural needs in teak plantations, they have been ignored in many government and private plantations in Ghana until the current upsurge in the demand for teak poles and sawn logs. This has led to many poor quality stocks in these plantations. The Government policy of giving contracts to agencies to harvest marked trees for thinning has led to harvesting of unmarked trees meant for the final harvest due to poor monitoring. The new government policy is to sell all teak plantations through competitive bidding to private developers.

Hazards in plantations

Fires, erosion, wind, pest and diseases are natural hazards in teak plantations. Teak trees are seen in Ghana as being invulnerable to fires mainly because teak can recuperate and grow well after they have been burnt by fire. Young plants recover from fire as the root system survives and produces a new shoot system. Erosion is a big problem especially on sloping land where the shallow lateral roots are easily exposed when the soil is washed away. *T. grandis* is a moderately wind-firm tree because of its well-developed root system. Though teak is tolerant of wind, very high winds can destroy teak plantations. In exposed places, teak suffers from wind damage leading to branching (Troup, 1921).

Over 180 species of insects are reported to be associated with teak, most of which are minor pests. Those that cause serious damage are white grups in nurseries, sapling borers in young plantations, trunk borers in older plantations and two species of defoliators (Beeson, 1941; Sen and Thapa, 1981; Day *et al.*, 1994). Although diseases are not recognized as major problem in teak, some pathogens are of importance. In nurseries, bacterial wilt caused by *Pseudomonas* spp., leaf spots caused by *Phomopsis* and leaf rust caused by *Olivea* often cause serious problems (Sharma *et al.*, 1985; Balasundaran *et al.*, 1995). Fortunately, Ghana has not experienced any serious disease damage to teak plantations.

UTILISATION AND MARKETING

Utilisation

Teak is a versatile fire resistant tree which regenerates even after heavy fire. This property allows it to be planted as venue trees in towns and villages, homes and schools, and along roadsides in Ghana. It is also planted as live fencing for farm boundaries especially in fire prone areas where its fire resistance is invaluable in making it a permanent live boundary. Teak is recognized worldwide as the most important wood for furniture. It is widely used in shipbuilding, engineering structures, musical instruments and many other uses. All teak wood is inherently light grained and durable and is used for interior and exterior joinery, naval construction, staircases, flooring, cabinets, parquets and several others.

Perhaps the most remarkable and unique use of teak in Ghana is for transmission poles for which demand is more than 100,000 poles per annum. Thinnings from 10 to 15 year old teak plantations which are relatively straight with minimal knots and a minimum sapwood thickness of 15 mm are debarked, seasoned and pressure treated with copper-chrome-arsenate (CCA) preservative to a minimum retention of 24 kg/m^3 and a penetration depth of 15mm (Oteng-Amoako *et al.*, 2000). Treated teak poles are used for the Ghana government's ambitious rural electrification project which requires about 70,000 treated poles every year for extension of national electricity grid to rural areas. In addition, an estimated 30,000 to 50,000 poles are also used annually by private developers in the booming housing industry. Another 20,000 to 30,000 poles treated to CCA retention of 18 kg/m^3 are used for telephone poles, for which demand have more than quadrupled in the last 10 years. Because of the very high demand for teak poles, local farmers establish small teak plantations or practice taungya system with teak trees, with the sole aim of harvesting them after 10 to 15 years to sell to the pole industry.

Teak trees over 20 years are processed mainly with wood misers which are dotted in teak growing areas around the country . Processing with wood mizers gives a recovery rate of 25 to 40 per cent, as opposed to less than 20 per cent from existing traditional mills which are meant for processing large sized logs. Air dried lumber is either exported or further processed into various types of furniture, decorative doors and tongue and groove panels. It is also used for production of medium density domestic floorings in the housing industry.

Marketing

An estimated 50 per cent of all sawn teak logs are exported in the form of lumber or boules to mainly

India at export price between 420 to 460 USD per cubic metre. In fact, some of the mills with wood mizers are owned by Indian merchants who have within the last six years invaded Ghana in search of teak lumber for export to their home country. Over 50 wood mizer mills dotted around the country are in use in Ghana as compared to less than 10 in the early nineties. From 1997 to 2000, Ghana exported over 22,480 m^3, about 1.5 per cent of the total cummulative timber export for the period. In the year 2002 alone, 30,920 cubic metres of teak, or 30 per cent of total exports worth some 15 million Euros were exported. The export volume for only the first quarter of this year has reached 6,100 m^3 (25 % of total exports) worth some three million Euros. This trend is expected to increase as the cumulative export of 2,050 m^3 for March 2003 alone exceeds 1,964 m^3 for March 2002. The high demand for teak sawntimber has often resulted in malfeasance in the teak industry, which is currently under national investigation. Recently there has been agitation from furniture producers to ban export of teak sawntimber to encourage tertiary products of teak furniture for export. This is likely to increase local processing at the expense of sawntimber export if the Government yields to the demand.

RESEARCH AND DEVELOPMENT

The Forestry Research Institute of Ghana (FORIG) has the sole responsibility to undertake research in the forestry sector of the country. It is one of the 14 state institutions under the Council for Scientific and Industrial Research (CSIR). Teak research at FORIG spans over a period of more than 30 years and has greatly enhanced its propagation and utilization.

The Past

Past research on teak has concentrated on enhancing teak seed storage, pre-sowing treatment, germination rate and better methods of transplanting seedlings. Findings to date indicate that application of heat at 80°C for 4 hours before sowing enhances teak germination (FORIG Annual Report)

Progeny testing of teak to select good genotypes from the clonal seed orchard and the assessment of the growth performance of individual progenies is on going. The object is to remove undesirable clones from the open pollinated plants through planting of progeny from the orchard. The quality of teak wood in relation to provenance has also been undertaken to find the best sites for producing good quality teak wood.

Research on the influence of old sclerotic leaves on growth performance of teak has also been carried out. The photosynthetic properties of the leaves were studied in relation to leaf age and development to determine the stage at which leaves could be removed to open up the canopy. The removal of sclerotic leaves was found to be detrimental to stem volume and height growth and that nutrients absorbed from the leaves are important for growth of the plant (FORIG Annual Report).

Variation in internal structure of teak and its effect on wood density has been studied for teak trees grown in the wet evergreen, moist semi-deciduous and dry semi-deciduous forests of Ghana. Our findings show that teak from the dry semi-deciduous forest tends to be more ring porous with distinct but narrow growth rings demarcated by marginal parenchyma band, smaller vessels, thicker fiber wall and high volume of fibers. On the other hand teak from wet evergreen forest is more semi-ring porous (Oteng-Amoako, 1979). Inspite of presence of false rings which might have resulted from periodic bush fires of the dry semi-deciduous forests, the growth rings are mostly annual, possibly due to a single rainy season in the vegetational zone. This is in contrast to samples from the other two vegetational zones where two rings may be formed due to bi-modal nature of rainfall. The density of teak from dry semi-deciduous forest is about 10 per cent higher than that of the wet evergreen due to high proportion of late zone and thicker fiber walls.

The Present

A study on the performance of plantations of some exotic and indigenous tree species in Ghana, including teak, is ongoing. It involves comparison between performance of bare-rooted stumps, potted seedlings and spacing of plants. To date plots have been established in the dry semi-deciduous and moist semi-deciduous forest zones.

Research on teak agroforestry with cash crops like cocoyam, plantain and other tree species has also been initiated. The project involves inter-planting with various timber species and crops at different spacing to determine the effect of teak on growth. This is to ascertain the truth or otherwise of the notion that teak trees deplete the soil of nutrients and renders it unsuitable for cultivation of cash crops.

An economic analysis to determine the capital and labour input in establishment of teak plantations in different ecological zones has also been initiated.

For use of teak as transmission poles, research has concentrated on incidence and nature of transition (intermediate) wood in relation to transmission poles with narrow sapwood was initiated some five years ago. The research seeks to find how incidence of transition wood affect penetration and retention of CCA preservative and the enveloped protection in poles with narrow sapwood of less than 15 mm. Furthermore research on detection of decay in utility poles and application of appropriate non-destructive remedial methods to enhance their service life has also started. The findings from this research will assist in increasing the service life of utility poles from estimated 25 to 35 years.

The Future

Quite recently, an international research on improving quality of future teak stands and wood quality in West Africa, funded by the European Union, has been initiated. The project, which is a collaboration between three European (France, Italy and Denmark) and two West African (Ghana and Cote D'Ivoire) countries, has as its development objective to increase productivity and quality of future teak plantations in West Africa. This 5-year project will in no doubt improve the quality of future teak plantations in the West African subregion.

FUTURE OUTLOOK

The introduction of teak as an exotic plantation timber species in Ghana some 100 years ago has come to stay. Teak is now a common household name among Ghanaians. To the farmer and plantation developer, teak is the valuable tree that are e grown anywhere, anytime and harvested after 8-15 years and sold for 'big' money. To the average man on the street, teak is the tree that can be 'boiled' and then use for transmission poles. To the furniture maker and the timber exporter, teak is the 'only' tree, which is cultivated by man, harvested between 20-30 years and processed into sawntimber and high quality furniture either for export or local consumption. In the housing sector, teak is a well-sought timber for cladding, ceiling and flooring.

These diversified views attest to the fact that are cultivation, processing and utilization of teak are expected to increase for many years to come, particularly as traditional timber trees dwindle in volume and our demand for timber supply continue to outstrip that from the natural forest. The tree and wood quality of tomorrow's teak are expected to increase as gains from the EU sponsored international project are disseminated to various stakeholders.

The major caution however, is to guard against monoculture teak plantations to avoid possible pest infestation, which can spell doom for teak plantations in Ghana. Lessons have to be learnt from the experience of countries like Myanmar, Thailand and India where teak is indigenous and have been planted as a monoculture. It is therefore recommended that a shift is made from mono to mixed plantation.

While we in Ghana and in fact the West Africa subregion share the joy of having successfully promoted teak as an important exotic plantation species, it is about time that the same is done for some of the indigenous species. There is therefore an urgent need for our forest scientists to 'domesticate' Odum (*Milicia excelsa)*, Wawa (*Triplochitin scleroxylon)*, Emire (*Terminalia ivorensis*), Ofram (*Terminalia superba*) and Sapele (*Entandophragma cylindricum*) and others, as alternatives to teak.

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Teak in Brazil: Overview of Plantations, Know-how, Expertise and Market

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ABSTRACT

The paper describes the actual situation of teak plantations in Brazil, the technologies used in order to improve their productivity and local market development for first and second thinnings of teakwood. The advanced expertise in reforestation (mainly in pines and eucalypt forests), and the availability of fertile soil and manpower will make Brazil an important player in the teakwood market. A Brazilian and Dutch capital company namely *Floresteca* founded in 1994,, is the largest teak wood investor in Brazil, managing over 14,000 ha of teak plantations. All *Floresteca* plantations and sawn goods are certified by FSC (Forest Stewardship Council). The idea of presenting *Floresteca*'s enterprise in this paper is to demonstrate the expertise introduced in the company's teak plantations, improvement in management and the first and second thinnings, wood quality attained as well as the Brazilian vocation for teak. In order to achieve the presently accepted *Floresteca* competitive differential, its management investments in strategic sustainability, without disregarding environmental protection and development for which FSC certification, played a very important role.

Keywords: Teak plantations, certification, expertise, market development.

INTRODUCTION

Contrary to the thousand year's old history of teak in Asia, this wood producing species has been introduced in Brazil, less than 80 years ago. However, due to the existing teak plantation history and its good adaptability to the Brazilian climate and soil, teak reforestation in Brazil has increased at a very rapid pace.

Among many other native and exotic species, teak was first planted in Brazil in the early 20th century by Mr. Navarro de Andrade, a railway engineer looking after future supplies of sleepers and firewood. He was responsible also for the introduction of eucalyptus, now a days the principal raw material for the paper industry.

A local lumber company of European origin established in Cáceres, State of Mato Grosso, began tropical trial reforestation in the 1960s. Cáceres Florestal SA. planted several different wood producing trees, among them mahogany and teak. Only a few years were necessary to show teak superior qualities to the other planted species. It not only grew faster and showed straighter stems but also was more resistant to wildlife damage, draught and forest fires.

Cáceres Florestal planted 1.4 ha using for early plantations seeds imported from Trinidad and Tobago, a former British colony. T and T teak plantations were established between 1850 and 1920, using Tenaserim, Myanmar teak seeds.

During the last 50 years, Brazil invested heavily in forestation, introducing this new activity to private landowners, companies and big investors. While most of South Brazil existing plantations were established with fast growing tropical pine trees, elsewhere eucalyptus was chosen for its fast growth and the preference of the paper industry. Teak, the third exotic species, did not have such interest at the beginning as Pinus and Eucaliptus, due to its longterm return.

Total planted teak area now surpasses 45, 000 ha, making Brazil the largest teak reforestation country of South America. It is worthwhile to mention that most of the Brazilian teak forests have been planted within the last ten years. Nevertheless, teak round logs and sawn goods are being exported regularly to India, Europe and the USA.

WOOD QUALITY

A lighter golden color and a 600 km/m^3 specific weight characterize the Brazilian planted teak, due to the use of fertile soils and adequate climate. Interesting aspects since in the past few years there is an increasing demand for lighter color and lower weight woods in Europe and USA.

Teak plantations are favoured in Brazil because of:

- Availability of extensive tracks of unused private owned land,
- Inexistence of natural cataclysms such as earthquake, eruption, inundation, draught, snow, etc.
- Existing monsoon type climate in about 1/3 of its 8.5 million square kilometers area, which lies within following parameters:
  - Temperature: annual average between 22-27°C,
  - Rain: 1 500 to 2 500 mm annual precipitation
  - Dry season: May/June to October/November
  - Population: The largest part of its 180 million population is concentrated in the South-East of the country, closer to the Atlantic coast, leaving the inland more availability for agriculture and cattle raising.

FLORESTECA

The main purpose of Floresteca Agroflorestal Ltd., a Dutch/Brazilian company created in 1994, was to establish large and well managed teak plantations in the State Mato Grosso (Brazil), to produce and commerce second stage quality teak wood goods in a continuous and sustainable way. Floresteca has established already 17 thousand hectares of plantation teak, becoming the largest teak plantation within the Americas.

Balancing the interest of people, planet, profit and beleiving in the advantages of Brazil in teak production, Floresteca has more than 800 employees contibuiting for the management of its 12 teak projects in Mato Grosso.

All the plantations have been certified by the leading organisation SGS Forestry, accredited by the Forest Stewardship Council (FSC) since 1997. The FSC designation imposes high standards on the quality of the management and the social and ecological policy.

The certification raises the cost of operations as, however, Floresteca fully beleive that the relation cost/benefit of certification is worthwile for attending exigent markets such as Europe and USA.

Floresteca aims to expand planted area in the rate of 3 thousands hectares per year, with the final objective of 50 thousand hectares. Floresteca focuses on three main topics to develop its plantations:

- Genetics
- Management
- Climate/Soil

Genetic development

Investments in genetic material development and counting with partnerships worldwide, Floresteca has introduced different varieties of clones imported from all over the world. With a well managed infrastructure which is able to produce different varieties of seedlings per year and developing new technics of multiplication and introduction, Floresteca will improve significantly the forest´s productivity and quality.

Management

The Brazilian expertise in Pinus and Eucalyptus have given to Floresteca the possibility to adequate many technics into the teak forest management. The continuous search for mechanization of all process involved in the forest management have lower the cost of operations and diminuished the risk of labour accidents.

Soil preparation (leaving the soils as for agriculture use), constant prunnings, precise thinning schedule and the use of mechanization in the harvesting process have brought to Floresteca a modern forest management system for teak growing.

Climate/Soils

Having all plantations under the climate circumstances above described and the constant search for the best soils for teak purposes, Floresteca has taken the Brazilian natural advantages for increasing the forest productivity.

Regarding the three main topics above and Caceres Florestal experience, Floresteca aims to complete the cycle of its plantations within 20 to 25 years. The initial movements of Floresteca commercial development were partnerships with national and international furniture producers, and the export of logs to India and South-East Asia.

CONCLUSIONS

As mentioned in this paper, teak in Brazil is very promising. The host country has all natural and political carachteristics necessaries for the teak planted forest. The vocation of Brazil for the production of wood and management of forests are also a crucial advantaged for the birth of enterprises such as Floresteca. Also, decreasing availability of quality wood in the world, due the deforestation of tropical forests will drive the global society to search a sustainable way of producing quality wood. This will bring to Brazil a great opportunity of being a potential and powerfull player in the teak market.

Advancements in Management and Productivity of Teak in Central America

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ABSTRACT

Most recent advancements on growing teak in Central America in commercial scale reforestation programmes are presented. The interest of companies in opting for forestry certification has risen, particularly in the pursuit for better markets and valuation of indirect benefits such as carbon sequestration. With regard to doubts arisen on the quality of plantation wood from shorter rotation teak of 20-25 years, differences were observed in anatomical, physical and mechanical properties, workability and durability of products, in materials coming from Panama and Costa Rica. Similarly, anatomical structure, resistance to rot and preservation of 6-year-old plantation wood from Guatemala were determined. Acceptable results of wood quality have promoted greater industrial development using lower diameter teakwood for different final products. Small diameter logs or sawn lumber from early thinnings continues to be one of the major export items to markets in India. In Costa Rica, important results have been obtained in nursery production of root-led plants and in genetic improvement of plantations established with clonal material, by the effort of the newly established Genetic Improvement Co-operative. Trials have been conducted with new teak progeny materials brought from India, Indonesia, Thailand, Trinidad and Tobago and Tanzania. In terms of plantation growth and productivity, high differences were observed among plantations, ranging from 8 to 12 m^3/ha/year and 25 to 30 m^3/ha/year, in different sites and different zones. However, in several cases, initial growth was very high, even though it was drastically low afterwards with death or 'die-back' of trees, and this calls for further in-depth research.

Keywords: Short-rotation teak, potentials, genetic improvement, productivity.

INTRODUCTION

Forestry incentive programs, promoted and implemented widely in several countries of Latin America and particularly in Central America, have now become the major initial booster for the establishment of forest plantations through companies and private producers. The case of Chile stands out in South America, Mexico in North America, and in the specific instance of Central America, object of this study, forestry incentive programs stand out in Costa Rica, Panama, Guatemala, and more recently in Nicaragua and in El Salvador. In addition to the incentive programs, several private companies have initiated large-scale reforestation programs with teak in these countries.

Although some of these forestry incentive programs started somewhat more than 20 years ago, it can be said that in the case of Central America most of the plantation areas established on a commercial level have experienced their greatest momentum as of the decade of the 90s. In the case of Costa Rica, the government (MINAE-FONAFIFO), through its Forestry Incentive Program and more recently with the Payment for Environmental Services system (PES), has established from 1984 to date approximately some 155,000 ha out of which approximately 25,000 to 30,000 are estimated to have been established with teak.

In the case of Panama, forestry development has shown a very significant increase over the last decade, mainly with the establishment of plantation forests. This evolution has been favored by the enactment of Law 24 in 1992, which sets forth the incentives to reforestation. This brought about the direct benefit of some 50,000 ha having been reforested with forestry species until 2002, representing 1.6 per cent of total land surface suitable for forestry of the country (ANAM, SENADAF, 2001). Some 30,000 ha of teak are estimated to exist and of these some 18,000 ha correspond to plantations bigger than 10 ha (ANARAP-GTZ, 2003).

In Guatemala, the Forestry Incentive Program (INAB-PINFOR, 2002) is relatively new, having started 6 years ago. However, at present this is one of the strongest programs in Central America. To date some 34,000 ha of plantations are standing and nationwide there may be between 4,000 and 5,000 ha of teak. This species is one of the most important and of greatest interest in recent years. The program is for a term of 20 years (1997-2017) and its goal is to promote reforestation of some 280,000 ha, for which the government grants a total amount of US$1,450 per ha, apportioned over the first 6 years of the establishment of the plantation.

In the case of El Salvador, due primarily to the high population density, reforestation is small scale, mostly by small producers. Teak by tradition has been the priority species and the country possibly holds the longest teakwood trajectory in the Central American Region with the small-scale production of furniture and other products made with teakwood. Some 3,000 to 4,000 ha of teak are estimated to exist in the country. Recently this year, a new forestry incentives program, known under the name of Forestry Bonds, has been approved. Herewith, the government (FANTEL/MAG, 2003) expects to promote reforestation and management of existing plantations with private producers of some 16,900 ha containing different species, amongst which teak holds the greatest potential and is preference.

In Nicaragua, experiences with teak are mainly kept at the research level with small stands in different parts of the country. In several sites visited by this author throughout this year, areas were ascertained to exist in the country with favorable conditions and high potential for the establishment of teak plantations. Between 200 and 500 ha of teak are estimated to exist in small plantations. This year several private groups have begun to show interest in starting plantation forestry programs with teak. Same is the case of Precious Woods Company which has invested in purchase of land close to the border with Costa Rica to plant teak. The government of Nicaragua, through its Ministry of Agriculture (MAG-FOR), started a project (PROFOR) in 2001 for joint ventures through a fund set up by the World Bank in support of forestry sub-projects. Several of these subprojects have established small plantations of only teak and mixed with other species. For the year 2004, the government intends to strengthen these initiatives with the start of the new National Forestry Development Plan countrywide. Therein, forest plantations are one of the priorities and much interest exists among several organizations to become involved with this Plan in order to establish teak plantations.

Latin America including the Caribbean has no detailed information about the size of area planted with teak. However, the author estimates 150,000 to 200,000 ha of teak plantations to exist. The countries with the largest areas planted to teak purportedly are Brazil (40,000-50,000 ha) with a significant number of commercial plantations (approx. 20,000 ha) located in the State of Mato Grosso where teak was introduced some 30 years ago; Ecuador (8,000-12,000 ha); Venezuela (10,000-15,000 ha); Colombia (6,000-10,000 ha); Mexico (3,000-5,000 ha); and Trinidad and Tobago (10,000-15,000 ha). Commercial scale teak was introduced in Brazil following the research conducted by Cáceres Forestal S.A. in 1971 (CACERES, 1999), which has about 1500 ha of teak. Since 1996, CACERES exported teak goods to the US and Europe as well as India. At present Floresteca Agroflorestal and GoodWood have the largest teak project in Brazil. Teak in Trinidad and Tobago was introduced on an experimental basis in 1913 and on a commercial scale in 1926 (Ramnarine, 1994). At the end of 1991, there were about 9,400 ha of teak plantations ranging in age from 1 to 78 years. The author estimates some 75,000 ha of teak to exist in Central America, mostly located in Costa Rica and Panama. These would be ranging in age from 1 to 14 years.

GENETIC IMPROVEMENT

Some companies have developed tree-seed orchards, or have put into practice vegetative propagation or clonal production in Central America. Most plantations have been established with seed collected from certified seed stands growing near the Pacific Coast of Costa Rica. Seeds collected from these areas have also been distributed to other Central American countries. A few companies have purchased seed from countries such as Thailand, and Trinidad and Tobago. However, questions have been raised about the genetic pool of teak in Central America and about the potential significance of diversifying the germplasm.

Forest Genetic Improvement Co-operative

Certain major efforts towards genetic improvement in teak have been made in Central America, primarily over the last five years. These have addressed particularly progeny testing and more recently clonal reproduction. Among these efforts, the case of the first cooperative association for forest genetic improvement in Costa Rica (Murillo *et al.*, 2003), under the name GENFORES, which was started in late 2001 deserves special mention. Its mission is to promote the exploration, conservation, rational utilization, and improvement of the forest genetic resources. All member companies and organizations contribute resources to finance the operation and part of the applied research. A given genetic improvement program is developed for each member pursuant to their objectives and needs. The School of Forestry Engineering (EIFO in Spanish) of the Costa Rica Institute of Technology is the scientific body which directs the co-operative association. Through the co-operative association, research and development initiatives are promoted and further transferred to the member organizations. Mainly advisory service and training are given to the organizations in developing their own genetic improvement programs. The structure for the operation of the cooperative association includes the interaction among the Academia, State and the Production Sector.

The Foundation for the Development of the Central Volcanic Mountain Chain (known as FUNDECOR), was the first partner in 1998. Today other participant companies are Los Nacientes Group, ECOdirecta, EXPOMADERAS, Centro Agrícola Cantonal de Hojancha, CoopeAGRI, and BARCA, S.A. The Costa Rican State, through its Fondo Nacional de Financiamiento Forestal, FONAFIFO (National Fund for Forestry Financing), has contributed to GENFORES by support funding to small and medium forester organizations in joining the co-operative association. Member organizations share their genetic material, building a broader collective genetic base. A total of 180 plus trees and several seed tree stands exist for teak.

The TEC (Costa Rica Institute of Technology) has ample infrastructure to support the Program, both for the high altitude species (in Cartago) and lowland species (in San Carlos). Principal facilities in both venues include molecular biology and *in vitro* laboratory, greenhouses, nurseries, hydroponics greenhouses, clonal gardens, seed tree groves, seed bank and laboratories. Operating features of the co-operative association, breakthroughs and achievements, main publications, training activities, active species in genetic improvement, and clonal garden management are outstanding. In conclusion, this type of model with direct linkage between Academia, State, and Production Sector as an alliance is one of the basic factors that explain the quick advancement of this co-operative model adapted to the conditions of Costa Rica.

MANAGEMENT AND PRODUCTIVITY OF TEAK PLANTATIONS

Forestry Projects and investors in Central America urgently need relevant information on the growth and productivity of priority species used in reforestation, such as teak. Determining productivity at the end of the rotation is particularly necessary in the case of advanced aged trees over 20-25 years. Spatial competition among plantation trees is one of the decisive factors for adequate growth. One means of evaluating the effect of reduced competition is to monitor tree development.

Research was carried out on forest plantation dynamics (study of tree development through time), identifying the composition of crown biomass as an important indicator of competition within a stand, and the effect of this competition on other growth variables. The main objective of this study was to develop new site index curves and preliminary forest management proposals for *Tectona grandis* plantations to ensure high stand productivity.

The indirect environmental method gave results for *T. grandis* in so far that the variables that closely correlated with the index of site were hydric deficit, mean annual temperature, resistance to penetration, and content of Ca between 0-20 (cm) soil depth. Models were developed for different relationships among the variables, crown composition, crown structure, growth and productivity, using information from advanced aged teak plantations in Costa Rica.

The basis for stand growth simulation models included growth and productivity information obtained from plots measured in the field, results from stem analysis, and the relationships among crown composition, crown structure, and growth, and productivity. Eight scenarios are presented for each species, using intensive management criteria of a maximum basal area of 18, 20, 22 and 24 m^2/ha, and two initial plantation densities, i.e. 1111 and 816 trees/ha.

In the preliminary growth scenarios for teak in rotation periods between 25 and 28 years were evaluated with final densities of 97 to 125 trees/ha, average diameters of 45 to 50 cm, and total average heights of 30 to 34 m. The productivity at the end of the rotation varies between 10.2 and 13.3 m^3/ha/year, yielding a total volume of 270 to 380 m^3/ha.

The Pipe Model Theory was tested for *Tectona grandis*, confirming its use for advanced age trees of up to 46 years, evaluating the relationship between the sapwood area at the base of the tree (cm^2) and at the crown base (cm^2), with the foliage weight (kg).

Stem analysis on teak trees from dry zone plantations was carried out, using the clearly formed rings resulting from marked seasonality in the area. The evaluation of growth scenarios, based on reliable data for plantation growth in the country, was a useful tool to make predictions for plantation management over time. The scenarios allow for the anticipation of future productivity and yields, based on current and potential growth in terms of basal area in the site.

Tectona grandis is a species with medium to rapid growth that requires intensive management. This study seeks to contribute to management strategies for this species. Recommendations include reinforcing the results obtained with more data from advanced age plantations, particularly for those older than 20 years. During the last decade teak became one of the most important species in reforestation programs involving small holders and private companies in Central America for the production of sawntimber. Experiences from the different countries in Central America show that teak has high potential in terms of growth and yield. However, it is sensitive to site conditions and demands adequate maintenance during its early years. In humid areas of the Atlantic Coast of Costa Rica, soil drainage conditions and topography are critical to growth and productivity. Most plantations established during the last decade in Central and South America aim to produce saw timber for parquet and furniture on short rotations: 20 to 30 years for final harvest.

Currently, teak plantations with short rotations of 15 to 25 years are intensively promoted in countries like Malaysia and some Central American countries. However, the high growth variability in young stands, even within small areas, has created some controversy and doubts about productivity at final harvest. Gradually, private companies have become more aware about the need to establish and monitor permanent plots to generate more realistic information on growth and yield on their forest estates.

Teak silviculture in Central and South America still has to be improved, especially with regard to stand density management and frequency and intensity of thinning. Variability in growth brought on by differences in thinning regimes has provoked much of the debate on productivity projections and has made clear the need for permanent plots covering the wide range of height variability and different site conditions. Great variability in growth can be observed even over small areas. This substantial variability in growth of young teak stands has given rise to much controversy about realistic volume projections for final harvest. Large productivity differences are observed even in estates with similar site conditions.

Financial returns based on price and productivity projections are often far too high. An overestimation of volume projections and wood value from small diameter teak can place the success of entire plantation enterprises in high risk. These issues forced private companies to become more aware of the need for permanent plots for monitoring growth and yield in their own estates. The often highly optimistic claims of productivity and financial rate of return made by some promoters for investment in teak plantations mislead the public and investment institutions (FORSPA and TEAKNET, 1999). This is especially critical in the cases where companies have already sold their plantations to foreign investors on the basis of unrealistic growth projections. Thus, the need to generate better information on growth and yield has become more widely recognized in Central and South America.

More recent data collected in Panamá (Osorio and Ugalde, 2003) and Costa Rica (Pérez, Kaninen and Ugalde, 2003) show a more realistic estimation on growth and yield volume for teak plantations under short rotation with 20 and 25 years, as it is presented here. Results from research performed nationwide in Panama follow. This includes the measurement of 150 sites in different projects with teak plantations. Results were grouped and analyzed by age ranks. Table 1 shows the ranks for less than five years through to the ranks greater than 15 years of age, grouped into four categories. The number of plots between the ages 5 to 10 years is noticeable. This is due primarily to the fact that most of the area planted with teak in Panama was established in the years 1992 to 1997.

Most of the plots are observed to be 5 to 10 years of age. They show an average of 729 trees/ha, with a maximum of 1320 trees/ha and a minimum of 279 trees/ha. The number of trees per hectare by age ranks show no significant variation. However, these values are considered very high under each age rank condition. It is particularly necessary to point out that most of the plantations analyzed show strong crown competition, recession and poor crown development. This implies that, after the fifth year, plantations in Panama hold very high densities due to lack of thinnings, provoking negative consequences to tree growth, and in turn affecting future plantation productivity.

Mean Annual Increments in total height, DBH, basal area, and volume show that the mean annual increment for DBH with age ranks between 1 to 5 years is 2.9 cm/year, progressively diminishing by ageing to 1.6 cm/year. For ages between 5 and 10 years the mean annual increment in height varies between 2.7 m and 2.4 m, diminishing at age ranks greater than 10 years down to 1.2 m/year. The mean annual increment by volume is significantly high and remains with little variation for plantations

Table 1. Summary of Means for Teak by Age Rank in Panama

Age rank	No. of plots		Trees per hectare			Variance	MAI DBH (cm)	MAI Height (m)	MAI Basal area m^2/ha/year	MAI Vol. m^3/ha/year
	No.	%	Average	Min.	Max.					
< 5	35	23	822	394	896	224.1	2.9	2.7	2.6	15.8
5 – 10	94	63	729	279	1320	244.5	2.6	2.4	2.2	15.2
10 - 15	13	9	481	196	806	168.9	2.0	1.8	1.5	14.3
> 15	8	5	426	180	644	142.7	1.6	1.2	1.3	12.2

Source: Osorio and Ugalde, 2003.

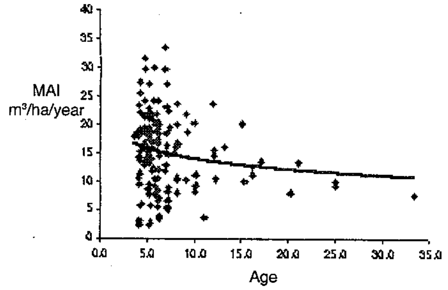

Figure 1. Trend between volume m^3/ha/year and age of teak plantations in Panama

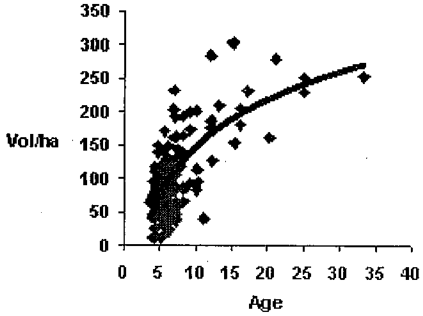

Figure 2. Trend between volume m^3/ha and age of teak plantations in Panama

from 15 to 34 years of age, with a rank between 9 to 12 m^3/ha/year.

Mean ranks of Figure 1 show the relationship between age in years and the mean annual increment in volume (m^3/ha/year) or the productivity of teak, expressing the trend of all mean annual increments of the plots evaluated. This graph shows the productivity and the yield trend in teak plantations established in Panama.

Significant variability is noticed to exist between years 5 to 10 and no relationship was found between lower ages and volumes since the level of dispersion shown by the graph is broader. Maximum volume of 34 m^3/ha/year and minimum of 2 m^3/ha/year was obtained, with an average of 19 m^3/ha/year. Dispersion of data for mean annual increment in volume in this case is not significant at the age ranks given. For ages above 10 years, the variability is low with a maximum of 20.2 m^3/ha/year, minimum of 3.65 m^3/ha/year and an average for these ages of 11.1 m^3/ha/year. This graph shows that for ages above 25 years productivity of up to 7.6 m^3/ha/year can be expected. Figure 2 shows the trends of teak productivity per hectare that can be expected in Panama up to the age of 33 years. The trend for data dispersion shows a curve with volume estimates of up to 250 m^3/ha/year in 33 years old plantations.

RELATIONSHIP OF HEARTWOOD AND SAPWOOD

This study was done (Verjans, and Ugalde, 2002) with the purpose of determining the type of relationship between, growth, age, and climate *vis-a-vis* the proportion of sapwood and heartwood in teak trees, 4 to 20 years old. Three growth ranges were determined: high (MAI DBH>3.01 cm/year), medium (1.51<MAI DBH<3.00 cm/year), and low (MAI DBH<1.51 cm/year). Also, 3 ranges for rainfall were used: A = (<1500 mm/year), B = (from 1501 to 2500 mm/year), and C = (>2500 mm/year). In total, 63 trees distributed among different growth and rainfall classes were felled and measured. The total volume was estimated in the same manner as for commercial volume, namely, logs 1 m long up to the tree apex.

Among the most relevant results, the relationship existing between DBH and volume of the heartwood stands out. For this relationship, the analysis allowed to select the following equation: V heartw.= -0.088 + 0.008*DBH (DBH in cm, the volume in m3, R2=0.78). This relationship enables to accurately estimate the volume of the heartwood in a standing plantation. Similarly, the relationship between the diameter of the heartwood and the diameter of the tree trunk at different heights was analyzed. Results were Diam. heartw. = -2,117 + 0,403 Diam (where both diameters are in cm, and R^2 = 0,89). This enables to estimate quite accurately the diameter of the heartwood at different tree heights.

The second part of the study was with the objective of verifying the influence of rainfall range on total tree volume, commercial volume, and total heartwood volume. The two methodologies to calculate the commercial volume are very similar (R^2 = 0,99). For this reason, the commercial volume calculated by logs was used. For the three types of estimated volumes no strong relationship with climate was found. This result could be explained partly by the fact that this study was done with individual trees in each plantation and not with average data from the plantations. For example, the study on growth of teak plantations in Panama (Osorio and Ugalde, 2003) indeed shows a relationship found between the ranges for rainfall and plantation growth. Such a study was performed jointly with the current study and on the same plantations.

The influence of growth classes on the same volumes also was analyzed, showing a positive correlation between high growth class and the three volumes. Accordingly, a high growth tree has more total volume, commercial volume, and more heartwood volume than a low growth tree, at the same age. However, results obtained on the basis of DBH showed no statistically significant difference. Yet, it is obvious that a low growth tree is going to need much more time than a high growth tree to achieve the same diameter and the same volumes.

ASSESSMENT OF STANDING TREE PLANTATIONS AND LOGS QUALITY

The need for woodlot evaluation and valuation, as well as log quality assessment has greatly felt in the Costa Rican forestry sector lately. Since the early 90's research approaches started in this direction (Murillo, 2003) which generated the first woodlot quality evaluation methodology. The principle of this methodology is based on the whole tree quality qualification or in the first four commercial logs (2.5 m length), in four quality categories: quality one or superior, quality two or acceptable, quality three or marginal, and quality four or not commercial. This methodology has been specially utilized in standing wood valuation and trading, for decision-making, harvesting priorities and industrial planning. This is especially useful in an early determination of expected plantation production goals. Some examples developed in the Dry Pacific and North Zone of Costa Rica with teak plantations are presented here. Finally, 3 indices developed in order to measure the quality state of a forest plantation, as well as to measure the progress of breeding programs in the near future, are also presented.

An unpublished report is available on the quality of logs from plantations in 25 reforestation projects, with an average age of 6 years, in the Nicoya Peninsula, Costa Rica. This would enable to know the quality of the wood in teak plantations established by different types of reforestation producers. The plantations registered a 62.3 per cent actual planted area, and from this about 80 per cent was covered with trees. Among the principal tree quality problems, branches competing with the apical dominance (26%), leaning trees (27%), and bole straightness (30%) were observed as most important. Forking was not found to be a serious problem (1.4%), as well as phytosanitary problems (6.7%). On an average, plantations registered qualities for codes 1 and 2, with 843 commercial logs/ha and 254 trees/ha. Also, 16 per cent of the projects contained more than 1200 commercial logs for quality codes 1 and 2 per hectare. The mean annual increment (MAI) of the commercial volume (DBH>10 cm debarked) for quality 1 and 2 trees was of 6.76 m^3/ha/year, yet 16 per cent of the projects registered a MAI over 12 m^3/ha/year. The general quality index for teak plantations before thinning was 3,04. It was concluded that more than 48 per cent of the teak plantations in this region of the country present acceptable quality. However, there is great potential for quality improvement through tree breeding and silvicultural programs.

TEAK WOOD TRADING

In latter years teak plantations have acquired greater interest in Central America and other countries of South America due to the appearance of a new market for the sale of small sized wood, from 6-10 years old plantations. Wood sold in several countries has been mainly coming from thinnings. This wood has been sold to traders who in turn ship it to India. In some cases the logs are transported to shipping ports located 300-400 km away from the plantations, thereby increasing costs and pressing sales prices downwards.

Most buyers from India purchase the wood from thinnings with the dimensions, penalties, and prices as given in Table 2.

Some experiences have shown that the effects of cubic conversion with the Hoppus formula, plus penalties the buyer specifies in estimating the volume of logs produces considerable shrinkage. In

Table 2. Details of wood purchased from thinnings.

	Long logs	Short logs
Length	8-11,80 mts	5,80 m
Allowance in length	10 cm	5 cm
Average Gross Diameter	17-22 cm	>25 cm
Measurement System	Hoppus -6 cm in circumference	
Price	US$150/m3 FOB	US$140/m3 FOB
Payment	Standby Letter of Credit	

logs of 16 to 24 cm diameters, this decrease may amount to 40-45 per cent of the actual volume. In some cases, this may reach up to 50 per cent, in relation to the volume of the cylinder that the logs may represent. For logs 25 to 35 cm in diameter the depletion is 35 per cent. And, for logs above 35 cm in diameter the shrinkage is approximately 30 per cent.

WOOD WORKABILITY AND PRESERVATION

Being known as to how a given species responds to different machining or milling operations is essential because in most cases these values determine the use of any wood. Workability tests were carried out at CIIBI in Costa Rica. Teak with three age ranges from two geographic regions, namely, Guapiles in Pococi, Limon Province, Costa Rica, and Port Armuelles, Chiriqui Province, Panama were used. The tests included shaving, sanding, boring, and lathe turning and machining. These tests were performed in compliance with ASTM-D-1666-93 Standard.

Among the most important conclusions and recommendations, the following are pointed out. The teak evaluated behaved from easy to moderately easy to shave. Rough grain and grain shear defects were most frequent. Said defects had degrees of severity that are classified from slight to moderate, and occasionally severe. The rough grain showed lower magnitudes for the tangential and oblique planes and tended to increase when teak pieces with radial plane cuts were shaved.

A tendency was observed of a greater free-from-defects area (FFDA) for teak from Costa Rica, possibly for being younger plantations subjected to some degree of management. In accordance with the results obtained for shaving, the hewing by removal for teak offers no major difficulties, given that this species is considered of easy removal and the temperature generated was not critical. The older teak (more dense) from Panama showed significantly higher shaving temperature magnitudes as well as greater removal difficulties.. On the whole, the teak analyzed qualifies as of good quality for sanding. In the boring tests, samples from all origins were classified as of very efficient penetration when a bit for metal was used (adapted for wood). The bit for wood had a deficient penetration. This is reasonable given that the intent of using this bit is to obtain an excellent quality perforation and not penetration efficiency. On the whole, the teak evaluated is considered to have good lathe turning and machining characteristics.

It is warranted to note that teakwood is highly abrasive and this impinges directly on greater wear of cutting tool edges. Hence, it is recommended to process this wood with carbon or tungsten-reinforced points and cutting edges, or the like.

In order to arrive at and study the final yield of 6 years old teakwood according to the quality of products obtained, the processes of sawing for lumber, re-sawing, and battening of a sample of 20 logs to obtain batten, flooring boards, and moldings were analyzed. The wood came from a 6 years old plantation located in the Atlantic Watershed of Guatemala.

After the respective processing of the logs, and classification of the products obtained, the yield or wood recovery factor (WRF) in the sawing process was 35 per cent for the batten, and 50 per cent for the flooring boards and moldings. Hence, the WRF for the global mix of products was 42 per cent. These are within the normal range of data reported for smaller diameter logs from forest plantations in Costa Rica. However, the yield for market ready acceptable product was 19 per cent for the batten and 34 per cent for the flooring boards and moldings with a global composite yield for all products of 26 per cent. The main defects to reject pieces were the presence of dead knots, live knots with bark included (pruning problems), and the pith included in the pieces evaluated.

In so far as the yields per product, the production of flooring boards and moldings would appear to be advantageous, given their higher yields. This follows suit with the actions of the major local industries striving to achieve the best usage of the raw material. These products (particularly the flooring boards) are widely accepted both in the local and international markets The average number of knots per piece and per face shows no significant differences for the batten and flooring. This is to say that most knots appear on both sides of the piece, giving no option to turn the piece over and accept one face before rejecting the piece entirely. So, a systematic pruning plan is required from the beginning of the plantation in order to produce first quality batten and flooring boards. This pruning plan prevents having wood knots, dead or alive with the bark included.

The spacing indicates that on an average a knot appears every 20cm. This suggests trees produce branches with this spacing. This reaffirms that the only way to obtain knot free wood in the first and second quality commercial logs is by doing systematic pruning. The most frequent was the dead knot. This could indicate that if pruning was done it was poorly executed. If pruning was not done, then self-pruning by the tree itself is adopted as a pruning system, which is not appropriate.

Given that a major proportion of the pieces were attacked by rot fungi, precautionary measures are advised from the moment the trees are felled. Also, keep in mind that most of the wood present in the logs evaluated was sapwood that has less natural durability and thus facilitates the action of fungi.

Another study was carried out on the Caribbean side of Costa Rica (Moya, 2002) to determine the change in specific gravity (Ow/Gv) in the radial direction from the pith to the bark of teak trees, as well as the influence of cambium age, growth rate and precipitation. Cross sections were cut at breast height (DBH) and growth rate, in terms of growth ring thickness, and specific gravity per ring, were recorded. Results showed that specific gravity increases from pith to bark and that it is affected by cambium age and growth rate, the former being the one that maximum influences this variable. On the other hand, precipitation rate did not significantly affect the specific gravity of wood in trees younger than 9 years. Another important result was that in intensively managed plantations the relationship between basic density and cambium age or growth rate decreases.

A study of teakwood was carried out (Arce, 2003) on the Pacific Coast of Costa Rica, in 10 years old forest plantations, under two densities and thinning intensities. The result demonstrates that the smaller plantation density favored hardwood production, although statistically significant difference doesn't exist. It also produces thicker branches and greater tapering (conicity) of the trunk. This study showed that characteristics such as specific basic weight, humidity content, volume contraction, and the radial and tangential contraction improve with greater density. The specific weight increases as age advances and diminishes from the base toward the tip. Meanwhile the humidity content decreases from the pith toward the periphery of the trunk and from the base toward the tip.

In an extensive literature review, the author pointed out that most physical properties of timber produced in short rotations differs little from that generated by mature plantations or naturally-grown teak. Wood properties from mature teak plantations growing in the Pacific Coast of Costa Rica were compared with wood from mature forests in India, Myanmar and Indonesia. Principal differences were related to natural durability and frequency of defects such as knots and shakes. The main limiting factor for the utilization of young teak could be the relatively small stem diameter (DBH) and hence smaller heartwood diameter

However, new technology for wood processing should allow for improved utilization of small diameter logs over time. An example of this trend can be found in Costa Rica where some private companies are employing new technology to process juvenile wood from second and third thinnings (minimum 12-14 cm dbh under bark) to produce parquet and furniture. In most countries wood from thinnings of plantations with long rotation periods has been used for poles, firewood and other minor products.

CARBON STORAGE ON TEAK PLANTATIONS

The last few years has seen great interest rising in valuing forest plantations in Central America, particularly from the viewpoint of the environmental services they contribute within the ecosystem. One of these indirect services is the quantification of the potential for carbon fixation or sequestering in teakwood plantations. This has generated special attention due to the eventual possibility of setting a value and negotiating the amount of carbon fixed as an indirect benefit (the environmental service) the plantations produce within the context of what is called Clean Development Mechanism (CDM). This pauses an option to reduce the increasing amounts of carbon dioxide released into the atmosphere.

The amount of carbon fixed by trees varies depending on the dimensions of trees. By the same token, age, climate condition, and the management given to the plantations influence tree dimensions. Total carbon in the ecosystem is dependent upon the amount and types of biomass that is quantified. This last aspect is where the various research results show great differences. Some studies only include certain components such as, for instance, the biomass produced by the trees as is aerial biomass (trunk, branches, foliage, fruit) or biomass inside the soil (thick and fine roots). Other studies include components in addition to trees such as the carbon stored in lower vegetation and leaf litter, and the carbon stored at different soil horizons. Accordingly, some research undertaken is presented here and results are compared with those from other regions.

In the case of Panama, a study was done to quantify the potential carbon stored in 20 years old teak plantations growing inside the Panama Canal Zone. Average daily temperature in this zone ranges between 23 and 30°C and annual precipitation varies between 2300 and 3000 mm, with a 4 months long dry season. Soils of these plantations were derived from sedimentary rocks of tertiary age, and soil textures tend to be loamy throughout the profile. From a sample of 192 trees, nine trees covering the range of sizes present in the four plantations were subsampled for harvesting to measure above and below ground biomass and tissue carbon concentrations. While DBH values of the nine excavated trees ranged between 16.9 and 43.8 cm, total tree dry biomass varied from 122 to 1365 kg. On an average, woody tissues (trunk, branches, twigs and coarse roots) made up 95 per cent of a tree´s mass. These woody tissues have significant higher carbon concentrations than the soft tissues, viz. leaves, flowers and fine roots (49.2 and 46.4%, respectively).

A regression analysis relating diameter at breast height (DBH) to total tree carbon storage was conducted to estimate plantation-level tree carbon storage, which averaged 120 t/ha. Litter, undergrowth and soil compartments were estimated to contain 3.4, 2.6, and 225 t C/ha, respectively. The soil carbon was a one-time measurement and not an estimate of soil C accumulation.

The biomass-weighted mean carbon concentration was 49.5 per cent, very close to the 50 per cent value often used for estimation of carbon storage from dry biomass data. The biomass and carbon which turned over yearly in the trees was small (5%) relative to their total biomass at 20 years of age, while long-lived woody tissue made up 95 per cent of the biomass. Karmacharya and Singh (1992), conducted a study in a dry tropical region (762 mm of annual rainfall, with an average of 55 rainy days) of Kerala, India, using 34 trees of teak plantations ranging 4, 14, and 30 years old. It was found that in later stages of development, though the more ephemeral tissues make up a small part of the trees' total standing biomass, the trees have shifted much of their production toward these tissues. At 30 years of age, 50 per cent of the trees' production went into woody parts and 50 per cent into softer-tissue parts which turnover rapidly, and at this age these plantations attained the level of biomass and net production found in uneven-age natural dry deciduous forests of the same region. This shows the relevance of monitoring and evaluating teak plantations throughout the rotation cycle. Leaves and twigs, though not storing carbon within the tree itself for long, they fall as litter, which can channel the portion of carbon not decayed directly to the atmosphere toward the soil carbon part. As a conclusion, research carried out in Panama, teak plantations have considerable mean carbon storage capacity, much greater than the abandoned pasture they were planted on.

CONCLUSIONS

At large, teakwood growing in Central America shows physical, mechanical, and workability characteristics with a high potential for the production of sawmill lumber and the manufacture of different products with greater value added, even from younger plantations. However, a very drastic difference should be noticed to exist in the quality of the wood coming from plantations younger than 10 years of age. This has a high percentage of sapwood, which can be called 'baby teak' as compared to the older wood more than 15 years old, where a higher percent of the volume is heartwood. This leads to the need for standards, wood quality classifications, as well as well differentiated marketing and trading procedures, in order not to create confusion or speculation with different qualities of wood.

Based on site and climatic conditions where teak is planted in Central America, it seems possible to manage plantations under middle and high site class with rotation periods between 22 to 26 years, and final densities of 95 to 130 trees/ha. Average diameters would reach 45 to 50 cm, and total average heights would be 28 to 34 m. Productivity at the end of the rotation could vary between 10 and 14 m^3/ha/year, yielding a total volume of 270 to 380 m^3/ha. However, the high growth variability in young stands, even within small areas, has created some controversy and doubts about productivity at final harvest.

In summary, it is indicated that, with the experience during the last decade in Central America, for the success of teak plantations the following aspects have to be considered.

Temperature: The limits are an average of 25 and 28 degree Celsius, classified as good. Outside of those temperatures, the species does not grow well.

Rainfall: Teak grows well between 1,250 and 2,500 mm/year. The species requires a 3 to 5 months dry period per year. Plantations established in humid to very humid sites with annual rainfall from 2,500 to 4,500 mm, and no clearly marked dry season, require special attention. This is due to the new experiences held with pests and diseases, causing serious problems to tree growth, especially limitations in achieving and maintaining good development of the root system. The latter brings about sudden death of the trees called 'die back'.

Elevation: In Central America, the best yields have been obtained under 600 meters above sea level.

Soils: Teak does well in sandy and slightly clayey, fertile, deep, well drain soils, with a neutral or slightly acid pH. In acid soils (pH < 5.5), prone to flooding during the rainy season, this species doesn't grow well.

Key limiting factors: It is not recommended to plant teak on steep slopes, compacted or shallow soils, and sites with high humidity and in heavy textures with acid soils.

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Teak in Trinidad and Tobago

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ABSTRACT

Teak was introduced in Trinidad in 1913 from seeds of Tennaserim, Myanmar origin. Plantations were established since that time to cover a total of about 9000 ha, ranging in age up to 90 years. Various methods of planting were tried in the early stages of introduction and by 1930, the species was raised in pure plantations. Teak is planted at a spacing of about 2m x 2m and thinned at periodic intervals based on height class. An economic rotation of 50 years is followed, and the coppices together with those regenerated during the first rotation, are used to form the second rotation crop. The tree reaches a height of 7 to 10 metres within 3 to 5 years. Volume increment varies from of 7 to 13 $m^3ha^{-1}yr^{-1}$ on best sites. Thinnings from the earlier plantings are sold to woodworkers. By 1958, an industry to market the teak thinnings was set up and by 1978, a State enterprise was established to harvest and market *al.*l the teak produced. This company was closed in 2001. The teak resources that are produced now are sold to local sawmills and woodworkers. The lumber from the thinnings and final fellings are sold to 250 furniture manufacturers who produce furniture for the local and regional markets. Challenges to management of plantations are high rates of soil loss, uncontrolled fires, theft and the poor performance of second rotation crop. The Forestry Division has conducted various research programmes in teak over the years, covering nursery studies, thinning, spacing, tree improvement and mensuration. At present, the Division is in the process of signing a memorandum of agreement with the University of the West Indies (UWI) for collaborative studies on problems related to teak management in Trinidad.

Keywords: Introduction in Trinidad, methods of planting, utilization, management.

INTRODUCTION

The country of Trinidad and Tobago consists of two main islands, Trinidad (4,828 km^2) and Tobago (ca. 300 km^2) and a number of small islets. Trinidad is traversed by three ranges of hills with its highest point in the northern range at 936 metres. These hills separate two areas of lowland terraces, alluvial plains and swamps. Tobago has a central ridge running for two thirds of the length of the island rising to 576 metres. The southern and western parts of the island are relatively flat. Trinidad and Tobago are structurally part of the South American continent to which they have been joined in recent geological times. The islands have a humid tropical climate with a distinct dry season from January to May.

Natural forests are mainly restricted to the hilly country of both islands but there are also significant areas of swamp forest in Trinidad and patches of lowland forest in less accessible areas in the lowlands. Recent Forestry Division documents estimate that 240,000 ha of land are under forest cover but much of this forest are classified as secondary.

State owned a forests cover of 192,000 ha of which 100,000 ha are designated as protected areas. The state-owned forests are composed of 35 legally proclaimed forest reserves and 8 unproclaimed forest reserves. Forest reserves are managed for protection, timber production or a combination of goods and services. In cases where these forests have been subjected to various interferences, conversion to plantations has been the alternative management option. In 2002, there were 15,000 ha of forest plantations comprising just over 9,000 ha of teak plantations, 4,000 ha of pine plantations and just over 2000 ha of mixed hardwood plantations.

HISTORICAL BACKGROUND

The Forestry Department (later Forestry Division) established the first experimental plantings of teak in 1913 at Quarry Road Plantations in the South and Mount Harris Plantations in the North of the country. Thereafter, small plantations were established regularly until 1928 when a definite planting programme of 28 ha per annum commenced. By 1940, plantations establishment reached 160 ha per annum, which was increased to 240 ha in 1953. By 1973, plantation establishment had peaked to 280 ha per annum, but declined in the 1990's to an average of 40 ha per annum.

Trinidad's genetic stock came from seeds imported from Tennaserim in Myanmar. Three seedlots were imported during the period 1913 to 1916 from the same seed source (Moore, 1966). Apart from these original plantings, all plantations established in Trinidad were from locally produced seeds, except for one experimental seed source obtained from India in 1936. The genetic base of the Trinidad plantations therefore has been extremely narrow but highly stable. It is considered a good seed source in the Caribbean and Latin American region.

PLANTATION ESTABLISHMENT AND MANAGEMENT

Early plantings

The early plantings of teak were done by direct sowing. The plantings were with a mixture of Cedar *(Cedrela mexicana)*, Cypre *(Cordia alliodora)*, Balata (*Manilkara bidentata*), Mahogany *(Swietenia macrophyla)*, Crappo *(Carapa guianensis)*, Poui *(Tabebuia serratifolia)* and Rubber *(Hevea brasiliensis)*. In 1915, a plot of pure teak was established in the Central Range Reserve at a spacing of 3 m x 3 m in an area of 2.2 hectares. By 1917, the 3½-year-old teak plantings established in 1913 started to produce seeds and it was anticipated that there would be no need for further import of seeds. By 1922, the pure stand, which was established in 1915, was also producing seeds. The seeds from this plot, together with seeds from the earlier plantings, were adequate for the Divisions planting needs.

Pure stands

Pure plantations of teak were first established on an experimental basis but later, as the growth was good, the Forestry Division planted teak as a single species in some of the coupes. It was also found that the shoot borer *Hypsipyla grandella* was damaging the cedar, mahogany and crappo plants and areas of the mixed plantations had to be replanted. Since teak was proving to be a vigorous growing, disease-free species, some of these older plantations that suffered the *Hypsipyla* attacks were replanted entirely with teak and excellent survival rates were obtained. Thereafter, the trend was towards the establishment of pure teak stands, instead of risking a setback by having to replant in these areas that were attacked in mixed plantations (Jhilmit, 1992).

This change to pure teak planting was gradual, but by 1918 the Forestry Division was planting coupes of pure teak in its regeneration programme. This practice continues till today (2003) and teak is still being planted as a monoculture. To date there are just over 9,000 ha of teak plantations scattered throughout the country in over 12 plantation centres ranging in age from 1 to 90 years with the age class distribution shown in Figure 1.

Taungya system in site preparation

The area to be planted is usually opened up for sale of salvageable timber to woodworkers, about 18-24 months prior to the year of planting. By the end of the third quarter of the year preceding the planting year, the coupe is divided into 0.4 ha compartments and rented to gardeners at a nominal fee.

The gardener proceeds to clear the 0.4 ha plot in preparation for planting. The Division undertakes to fell the unsaleable stems (exceeding 80 cm in diameter) to assist the Taungya gardener. By the end of April of the planting year, the land is completely cleared and left to dry for burning. The

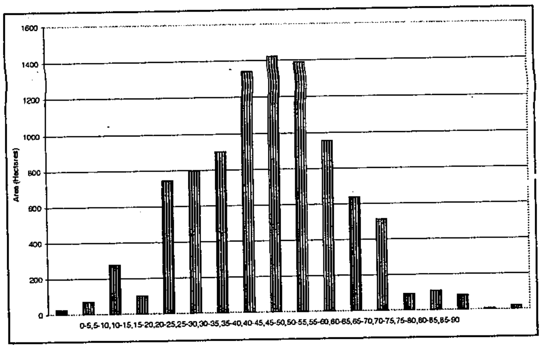

Figure 1. Teak age class distribution

entire area is protected by fire traces, which are cleared by the Forestry Division to prevent fires escaping into adjacent forests.

The coupe is burnt in May or June depending on the weather pattern that year. The gardener then proceeds to plant his crops on the freshly burnt land. If the burn was not clear, they would lop and form 'boucans' before planting. The Division also plants the teak crop around this time, depending on the weather.

The gardeners tend their crop as well as the teak stumps for the year or until they can reap their crops. By the time the gardeners have reaped their crops, the teak plants are firmly rooted and no further crop plantings are permitted. The gardeners can then move to another plot in next year's coupe. Table 1 shows the activities in the chronological sequence.

Table 1. Taungya system in Trinidad: Activities in chronological order.

Years	Activities
-2	Survey coupe open for general sales to woodworkers.
-1	Divide into 0.4 ha plots and distribute to Taungya gardeners.
0	Gardeners clear their own plots. Division fells overgrowns Burning and 'boucans'. Division plants teak. Gardeners reap crops.
1	Gardeners tend their crops and also the teak. Gardeners reap crops.
2	Teak is fully established and Division takes care of the teak.

Very often there are not enough Taungya gardeners to prepare the coupe. This could be so for a number of reasons such as poor accessibility to the site and praedial larceny. When Taungya gardeners are available they are accommodated and even allowed to cultivate more than the traditional 0.4 ha. However, it is not uncommon for the Division to prepare the entire coupe without a single Taungya gardener. In such cases, the Division employs daily paid labour to prepare the coupe.

Nursery production

Teak nursery production utilizes the concept of a 'flying' or temporary nursery that is located within or adjacent the area to be planted with teak. This method of producing teak planting material has worked efficiently and is currently in use.

The preparation for the production of the next year's teak planting begins in January of the year before planting. The nursery area is cleared of all vegetation and beds 1.2 m wide are formed along the contour of the site by digging drains, 12 cm deep. The beds are tilled to a depth of approximately 24 cm. The teak seeds are sown after the early June/July rains at spacing of not more than 5 cm x 2cm. The seeds germinate within three weeks and the nursery site is tended regularly to extract weeds. A fire trace is cleared for the ensuing dry season of the next January - June period. By June of the next year, the nursery stock would have been one year old and is then ready for planting. The teak seedlings are uprooted from the bed and a cutting comprising about 12 cm of root and 3 cm of shoot is used to make a stump plant. This stump plant is used to plant the crop. At this stage the stump plantings are 6 –20 mm in diameter and the length of the stump taken is approximately 15 cm. One hectare of teak nursery can produce stumps to plant 100 ha of land. Seeds are collected from seed orchards and from seed trees that have been identified in the various plantations.

Spacing

The early plantations of 1913 were established at a spacing of 10 ft. by 10 feet. Until 1918, various mixtures of teak with other local and valuable species were tried at various spacings varying from 6 ft x 6 ft to 20 ft by 10 ft. From 1918 to 1970, however, all plantations were established at a spacing of 6 ft by 6 ft (1.83 m by 1.83 m) in pure stands resulting in a density of 2,990 stem per hectare. After the production of the provisional yield tables for teak (Miller, 1969), spacing was changed to 7 ft by 7 ft (2.1 m by 2.1 m) resulting in a stand density of 2,200 stems per hectare and this spacing still holds.

Thinning regimes

Proper thinning in teak plantations shortens sawlog rotation and allows intermediate harvests, which commences as early as 3 to 4 years after plantation establishment and continues at regular intervals throughout the rotation in Trinidad. Up to 1970, teak, which was planted at 1.83m by 1.83m (6 ft by 6 ft), was thinned mechanically on the basis of age at five-year intervals up to 30 years and at 10 – year intervals up to age 50. Table 2 shows the thinning regimes used in Trinidad before and after 1970. It has been generally accepted that this regime has resulted in under-thinning (Lamb, 1955; Moore, 1966; Miller, 1969).

Moore (1966) carried out experimental heavy thinning in two stands located at Mount Harris plantations. A fifteen-year-old stand was subjected to experimental heavy thinning. Growth and form was good and the results stimulated further experimentation. In a five-year-old stand, stem numbers were reduced to 741 stems per ha instead of 1482. Response was rapid and the canopy closed within four years. At the age 10, the stand was further thinned to 346 stems per acre instead of 741. Growth under this heavy schedule was found to be excellent and the form of the trees was above average (Moore, 1966).

Miller (1969) produced Provisional Yield tables for teak and new thinning regimes were formulated based on results of these experimental thinnings and results from spacing and thinning studies. Three site classes were identified based on mean height of stands at age 50. These were identified as height class I (85 to 95 feet), height class II (75 to 85 ft) and height class III (65 to 75 ft). From 1970 this new thinning regime has been used to manage teak in Trinidad.

Growth and yield

Under optimum conditions, growth of the tree is rapid reaching a mean height of 7 to 10 metres within three to five years in Trinidad (Miller, 1969). Up to 20 years Mean MAI varies from 7 to $13m^3ha^{-1}yr^{-1}$ on the best quality sites (Miller, 1969). In comparison it is reported that in India, maximum mean annual increment in merchantable volume (top diameter e"5 cm over bark) (MAI) varies from $3.6m^3ha^{-1}yr^{-1}$ on the lowest sites to $15.6m^3ha^{-1}yr^{-1}$ on the highest sites (Anonymous, 1964). In Nigeria, Ola Adams (1990) observed that in 18 year old stands MAI varied from $9.8m^3ha^{-1}yr^{-1}$ 4m by 4m spacing to $15.9m^3ha^{-1}yr^{-1}$ in 2m by 2m spacing. Similar ranges up to 20 years have been observed in the Caribbean and South America (Weaver and Francis, 1990; Hase and Foelster, 1983) and Tanzania (Malende and Temu, 1990). However over a period of 50 years MAI varies from 4 to $8m^3ha^{-1}yr^{-1}$ on the best quality sites (Miller,

Table 2. Thinning regimes used in Trinidad before and after 1970.

	Before 1970		After 1970					
	All classes		Class I		Class II		Class III	
	Age	Residual stems	Age	Residual stems	Age	Residual stems	Age	Residual stems
	0	2990	0	2200	0	2200	0	2200
	5	1483	3	988	3.5	988	45	988
	10	741	7	494	9	494	12	494
	15	371	12	297	17	297	21	297
	20	247	18	185	25	185	31	185
	25	198	26	119	36	119		
	30	148	37	77				
	40	99						
	50	74						
Final felling	60		50		50		50	

1969). The main factors responsible for this variation in yield locally are variation in initial planting density, thinning regime and site productivity.

UTILIZATION AND PRODUCT DEVELOPMENT

Royalty rates

Up to 1990, Government heavily subsidized royalty rates for plantation grown teak despite the high cost of production. From 1975 to 1990, royalty rates were set at $11.09 per cubic metre. In 1990 the Cabinet of the Government of Trinidad and Tobago set royalty rates at $44.38 per cubic metre plus VAT based on recommendations of the Forestry Division.

In 1991, Nagle (1991) recommended an increase of royalty rates from $44.38 per cubic metre to a range varying from $300.00 to $465.00 per cubic metre to ensure an internal rate of return of 8 per cent on investment for site class II sites. Further Bothmer (1994) calculated that the cost of production was $85.56 per cubic metre and recommended that royalty rates be increased above this cost to cover the costs of production and ensure an adequate rate of return.

In 1997, the Conservator of Forests, influenced by the earlier recommendations, commenced selling teak to the sawmiling industry at $110.96 per cubic metre for thinnings of any age and final fellings at $221.92 per cubic metre. Ramnarine in 2001 combined the concepts of Nagle (1991) and Bothmer (1994) and also recommended new rates for teak based on varying the prices for thinning of different ages. Government accepted the recommendations in principle and since 2002 the Government has been selling standing teak from a royalty of $166.44 to $443.84 per cubic metre for teak above 18 years old as shown in Table 3. This royalty ensures that an internal rate of return above 6 per cent is obtained. For stands under 18 years old royalty still remains at $44.38 per cubic metre but this is expected to increase in the future.

Table 3. Royalty rates for Teak in Trinidad from 2002

Age	Price per m^3 (TT$)	Price per m^3 (US$)
<18	44.38	7.05
18-30	166.44	26.35
31-49	332.88	52.84
50+	443.84	70.45

Method of sale

Since 1997, before the closure of Tanteak in 2001, teak was made available to sawmillers, licensed loggers, furniture manufacturers and some entrepreneurs. From 1997 to 2001, the Conservator of Forests held monthly meetings and discussions with the Sawmillers Cooperative Society and fields were allocated to sawmillers based on requests from the membership.

Since 2002, fields to be thinned and clearfelled are allocated to sawmillers and woodworkers on a quota system. Each year fields to be thinned and or clearfelled are advertised for sale. Sawmillers are invited to indicate their interest in working a particular field. Based on locality, areas and logging equipment some sawmillers are able to harvest in any plantation while others are limited to plantations closer to their bases. Coupes to be clearfelled are subdivided into 5 ha units and coupes to be thinned are subdivided into 10 ha units. Units not worked in a given year are given priority the following year so that the thinning treatment takes place as close as possible to prevent variation in timing of thinning.

Tanteak

From 1940–57 teak was sold to licensees and other users of wood. As the volume of thinnings increased it was decided to centralize the processing and sale. In 1958, the Government opened the Brickfield Forest Industries whose main responsibility was to market teak thinnings. This industry worked well for 20 years and was expanded in 1978 by the formation of a state owned company, Trinidad and Tobago Forest Products Company Limited (TANTEAK) to accommodate the increased volume of teak from thinnings and final fellings. It had a monopoly up to 1997 on all raw materials from the teak plantations at a subsidized royalty rate of $44.38 TT per cubic metre. Despite this low royalty rate the company failed. For 23 years, its performance was consistently poor and finally in 2001 Tanteak was closed down.

Saw millers

There are 85 licensed sawmills in Trinidad and Tobago whose combined demand is over 100,000m^3 of raw materials per annum. They range in size from the typical sole entrepreneur family type enterprise to large companies. During the period when Tanteak had a monopoly on the teak resources, saw mills obtained their raw materials form private sources and imported logs from Guyana, and other Latin American countries. Now that Tanteak has been closed down, they are rising to the challenge and several of them are upgrading their mills, logging equipment, planing machinery and drying and seasoning facilities to increase their capacity to produce quality timber products for the domestic, regional and international markets.

Licensees

There are over 300 private loggers (wood workers) registered with the Forestry Division who have recently been allowed access to the teak resources. Within the last year already 60 of them have commenced purchasing teak, converting into boards and selling to furniture manufacturers and other private enterprise. Since 2002, a certain quantum is reserved for the licensees from the annual felling plan.

Furniture manufacturers

There are over 250 furniture manufacturers who are also seeking access to teak from the plantations. From 1997 to 2001, some furniture manufacturers sought and obtained teak fields. However, in 2002 Government decided that it was in the best interest of the industry to make the teak available to sawmillers and loggers who will then supply the furniture industry.

In Trinidad teak lumber is sold in a green state or partly air-dried. Very little probably less than 10 per cent is completely prepared for the manufacture of furniture and or immediate use. However, there are several operators who have commenced drying teak in kilns for immediate use in furniture and downstream processing.

Periodically, the manufacturers associations hold workshops and seminars to improve their members' ability to manufacture teak products to meet national and international standards. Very recently the Caribbean Business Services Ltd held a seminar for sawmillers, woodworkers and furniture manufacturers on how to properly kiln dry teak and other species destined for the international markets.

Market for teak timber products

Locally teak lumber is used for housing (flooring, ceiling, partition and rafters) household and office furniture, parquet tiles, yachting industry and souvenir and gifts. The market for teak lumber is limited only by the supply from state owned teak plantations. By far most of the teak lumber goes into the production of furniture.

There is a high demand for teak furniture locally, regionally and in niche markets in North America. These local furniture manufacturers are able to compete successfully in the local and regional markets. However, due to the inherent problems of plantation grown teak such as pith size, knots, sapwood, narrow boards and lighter colour the local manufacturers cannot compete in North America and European markets. There is a perception in the international markets that lighter coloured teak is of inferior quality to darker coloured teak even though studies reveal that plantation grown teak in Trinidad is as good as Burmese teak in terms of strength properties.

Even though Trinidad's teak cannot compete on the international markets, there is a high demand for teak locally and regionally and the volume of teak lumber is increasing annually as can be seen from Figures 2 and 3. Figure 2 shows the increase in historical yield from 1947 to 2002 and Table 4 shows the average yield by periodic intervals over the same period. Based on age class structure and sustained yield over the rotation a total of 32,000 cubic metres can be harvested annually.

Figure 3 shows the ratio of teak timber to the volume of natural forest species over a similar period. Table 4 shows ratio of teak harvest to natural forest harvest over the same period. By 1980, teak was the main species on the local market

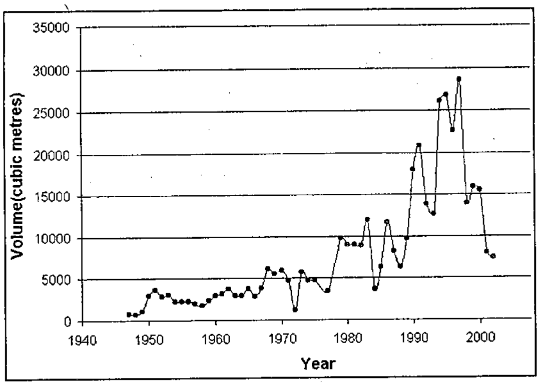

Figure 2. Harvest volume of teak from 1947 to 2002

and by 1990, it rose to be more than 50 per cent of the total volume of wood logged from the state's forests. Within the last 4 years, the volume harvested has reduced significantly from the peak of the 90's mainly due to the closure of Tanteak in 2001, but this is expected to increase in the near future.

MANAGEMENT CHALLENGES

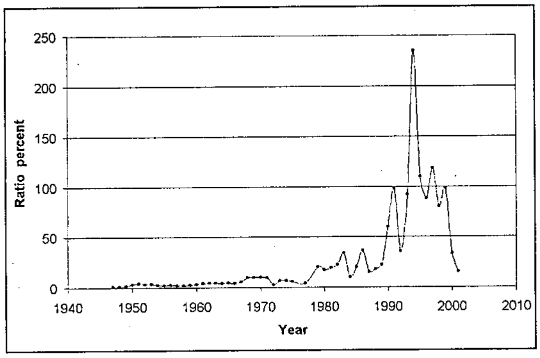

Figure 3. Ratio per cent of harvest volume of teak to natural forest species from 1947 to 2002

Table 4. Average periodic harvests from teak plantations from 1947 to 2002.

Period (years)	Average yield (cubic metres)
1947-1957	2174
1958-1968	3328
1969-1977	4517
1979-1988	6823
1989-1998	19322
1999-2002	11717

Table 5. Average periodic ratio of teak harvest volume to natural forest harvests from 1947 to 2002.

Period (years)	Average periodic ratio percent
1947-1957	2.4
1958-1968	4.4
1969-1977	6.8
1979-1988	21.3
1989-1998	94.1
1999-2002	39.8

The introduction of teak as a plantation species has been encouraged based on its relatively fast growth, higher yields than the indigenous tropical forest, which it replaces, relative ease of regeneration and management in plantations, and the high prices in the international markets (Keogh, 1979; 1982). This high economic return is obtained at a cost, for teak is not without its management difficulties. The major problems of teak management in Trinidad are the effects of uncontrolled fires, soil erosion, theft, and management of second rotation sites.

Fires

Even though teak is able to withstand fires better than most species, fire is a major cause of injury, especially in drier areas. Intense ground fires can kill three-year-old trees to the ground (Murray, 1961) but these are replaced by coppice shoots. However, on older trees the phloem and cambium can be injured, causing wounds, which are enlarged by succeeding fires resulting in secondary infection by other pathogens such as root rots. Sometimes the butt log may be destroyed or the entire tree may be killed. Fires also lead to increased surface erosion (Lamb, 1957; Murray, 1961; Moore, 1966; Bell, 1973).

Depending upon site quality, the teak canopy closes within 3–5 years based on an initial planting density of 2,200 stems ha^{-1}. This suppresses the establishment of an understorey of grasses and secondary species, which are essential for the prevention of erosion. Coppice regrowth from subsequent thinning operations further prevents adequate light from reaching the forest floor. Leaf fall within the dry season and frequent surface fires pose further problems for the establishment and growth of other species. Fires leave the soil surface bare for up to 10 months per annum exposing it to the sun and early rains in the rainy season prior to leaf flush. When in full leaf, the teak leaves which can be from 30 to 60 cm long collect and deposit large volumes of water on the bare soil which seal the soil surface, prevent perco-lation, increase surface runoff and erode the nutrient rich top soil. Several authors have expressed increasing concern over the rates of erosion in plantations (Lamb, 1957; Murray, 1961; Moore, 1966; Bell, 1973). Even as early as 1939, Marshall (1939) warned that fires pose the most serious threat to teak plantations.

Fires even alter the nutrient status of the soils. After a fire, nutrient levels in the upper soil horizons increase and with the onset of rains, nutrients are leached in the lower horizons with percolating water (Khare *et al.*, 1985). Fire protection measures, therefore, are essential to successful management of teak forests.

Each year during the fire season (December to May) the Division formulates a fire plan for the individual ranges. Officers and workers are rostered to provide fire protection to the plantation and natural forests between 10.00 am and 6.00 pm from March to May. Since the introduction of fire protection activities, the young plantations are being protected and the older plantations rarely burn except in very dry years.

Soils

In Trinidad, teak plantations have been established on a variety of soil types (Brown and Bally, 1968; 1970). The range in pH varies from 4.5 in sands to over 8 in calcareous clays. The soils are over 1m in depth with clay contents varying from a low of 12 per cent to a high of 97 per cent. Locally, soil studies have not been conducted to determine whether there are any correlations between soil types and growth and yield. From observations, however, it would appear that the teak grows well on a variety of soil types and moisture regimes. Best growth occurs in the calcareous clays on undulating terrain. Teak has been observed to be poorer on hilltops and sands, which are usually drier than on hillsides and valley bottoms. Impeded drainage in valley bottoms also shows poor growth.

It is documented that soils under teak deteriorates steadily through the processes of erosion (Murray, 1961). In pure teak plantations, which are burnt annually, a humus layer is absent and erosion can remove the soluble minerals. The removal of the entire A-horizon and parts of the B-horizon is common on the undulating slopes in heavy rainfall areas in Trinidad that are subjected to frequent fires (personal observation).

Gosden (1956) used a paired mini-watershed approach at the Brickfield plantations to quantify soil loss in a teak plantation compared to the natural forests. The watersheds were similar with respect to slope, soil type and area. Over a period of three years 173 tons of topsoil ha^{-1} was lost from the teak site with 153 tons being lost in one year. Using an average bulk density of $1.3 g/cm^3$ for clay to clay loam soils (Brady, 1974) this translates into a loss of 1.3 cm in depth of soil of which 1.18 cm was lost in one year. During thesame period only 2mm of soil was lost from the natural forest. Although this study did not continue for a longer period to reveal the magnitude of soil loss over the manage-ment period, the data suggests that teak plantations would lead to a change in the soil site complex. Although, this study did not quantify the loss of nutrients from the site it is quite possible that nutrient depletion occurs.

This steady reduction in soil quality can lead to yield reduction in existing stands and potential reduction in subsequent rotations. In India (Seth and Yadav, 1959) has reported depletion of calcium on first rotation sites and preliminary estimates in Venezuela by Hase and Foelster (1983) support such a decline. Since a positive growth relationship with calcium levels has been observed (Bhatia, 1956; Zech and Drechsel, 1990) it is expected that reduction in yield would result.

Theft

Forest officers are classified as civil servants and confined to work between 8 am to 4 pm, on weekdays. Outside of these hours and on weekends, the forests remain unprotected. During nights, weekends and public holidays thieves fell and remove valuable trees from the plantations. These trees are usually the better trees from the younger stands and trees earmarked for final felling. By far the greatest threat to sustainability is theft of trees selected for the final crop. With the advent of the mobile/portable sawmills these trees are converted into boards in the plantations and removed with relative ease.

At present, the Division has instituted measures to curb illicit logging. Each Conservancy has a dedicated patrol unit whose sole responsibility is to patrol the plantation and monitor movement of logs from the plantations to the sawmills. In addition, the Government is being approached to change the terms and conditions of employment of forest officers to ensure that the forests are protected on a 24-hour basis. Proposals for joint army and police patrols have been considered to assist curbing illicit logging. Additionally, the Sawmills and Forest Acts were amended in 1999 to make it more difficult to transport logs without permits, and to make the keeping records at sawmills more transparent.

Second rotation

Since 1982, the Division commenced felling of final crop trees at an economic rotation age of 50 years. To date just over 1,500 ha of plantations have been felled. All plantations, which have been clear felled, are being managed for a second rotation using coppices and natural regeneration.

Data collected from 39 plots in second rotations sites at Quarry Plantations reveal that at the time of clearfelling, there are sufficient trees per hectare to occupy the site at all locations. At a mean height of about 14 m, stand density after thinning on a first rotation Site Class II is approximately 494 stems ha^{-1} with a standing basal area of about 11.7 m^2 ha^{-1}. Data from second rotation sites compares well with the data obtained from first rotation sites at 9 and 17 years as shown in Table 6.

The ability to respond to thinning is dependent upon crown growth. The crowns of the coppices and natural regeneration established under the canopy of the final crop are usually narrow with minimal side branches. While lateral branches are needed to develop crowns, these are noticeably lacking on recently clearfelled stands. Due to the lack of side branches, the time required to respond to thinning in a second rotation stand would be longer than in a first rotation site. Even though recently clearfelled stands are comparable in mean diameter, standing basal area, mean height and volume to a younger stand on a first rotation, they are really responding at a slower rate. At this lower rate of response it will take longer to respond to thinning and therefore rotation will have to be extended. Alternatively, when stands are clearfelled log volume and size of logs would be much smaller if rotation is fixed at 50 years.

RESEARCH

Research conducted on teak in Trinidad within the recent past can be summarized as follows:

- Effect of stump size on survival and growth
- Grafting and budding studies
- Effect of time of seed collection on germination

Thinning experiment

In an eight year old coupe at Quarry Road

Table 6. Comparison of second rotation teak data in 1992 and 1998 in relation to with yield table for site class II at 9 and 17 years.

Variable	Second rotation		Millers yield table	
	1992	1998	Age 9	Age 17
Mean height (m)	14.0	17.4	14.9	18.3
Mean diameter (cm)	14.1	19.2	15.4	22.6
Standing basal area	10.89	11.91	19	11.7
Stand density	610	429	988	494
Standing volume	72	48	80	51
Rate of height growth (m yr^{-1})	0.57		0.43	
Rate of diameter growth (cm yr^{-1})	0.85		0.9	
Rate of basal area growth (m^2ha^{-1})	0.7		1	
Rate of volume growth (m^3ha^{-1})	4.05		8.35	

Plantations, a single experiment consisting of a control labelled A and four thinning regimes labelled B, C, D and E, with four replicates in a randomized block design was laid out in the year 1959. The total area of the experimental plot was 12.8 hectares. Each sub-plot measured 80 m by 80 m with a central assessment square of 40 m by 40 m and a surround of 20 m on either side. The experiment was measured at 8, 14, 16, 23, 32 and 40 years, since the plantation was established.

The plantation area was subjected to 50 per cent reduction in stem numbers when five years old. However, data were not collected on the area prior to year 8. Table 7 shows the thinning treatments, which were applied to the experimental site from age 8. At the time of first thinning in year 8, stem numbers were reduced in the treated plots between 741 and 371 stems per ha from treatment A to D with a constant reduction by 123 stems per ha as intensity increased. At year 16, stand density was reduced by a constant 123 stems per hectare across all treatments. At year 23, density was reduced by a similar factor of 123 stems per hectare over all treatments.

In summary, there were no differences in mean height within the treatments but the controls showed reduction in height growth. Mean diameter increased with decrease in density. There were no differences in total basal area and total volume production. At present the experiment is being assessed.

Spacing experiment

1n 1967, an experiment was laid down to determine the impacts of spacing and thinning on growth and productivity. A single experiment consisting of five initial planting densities, replicated in a randomized block design was laid out in the 1967 coupe at Morne Diablo Plantations. An area of 8 ha was subdivided into 20 plots of 0.4 ha each. The plots were subdivided into 4 blocks and 5 treatments were allocated at random in each block. Each sub-plot was 64 m by 64 m with a central assessment square of 40m by 40m and a surround of 12 m on either side. The treatments were 1.52 by 1.52m (A), 2.13 by 2.13m (B), 2.74 by 2.74m (C), 1.83 by 4.57m (D) and 3.66 by 3.66m (E). The experiment was thinned to specified densities at years 5 and 14 as shown in Table 8.

Table 7. Thinning regimes applied to teak at Quarry Road thinning experiment in Trinidad in terms of standing stems per hectare at years 8, 16 and 23

Age	A	B	C	D	E
0	2990	2990	2990	2990	2990
5	1495	1495	1495	1495	1495
8	1495	741	618	494	371
16	1495	618	494	371	247
23	1495	494	371	247	124

In summary, no differences were detected in mean height. However, total basal area and total volume increased with increased in density. The experiment is being assessed at present.

Tree improvement

On first rotation sites a tree improvement programme began with the selection of plus trees and seed stands. As the plantations increased in size over 100 plus trees were selected and evaluated through open pollinated one-parent progeny field trials. This led to the establishment of a clonal garden and a clonal seed orchard. This seed orchard has been supplying seeds for our local use. For export, seeds are collected from selected plus trees and seed stands. At present new seed stands and plus trees are being selected.

Table 8. Number of stems per ha at planting, after thinning at 5 and 14 years at Morne Diablo spacing experiment

Age	A 1.52*1.52m	B 2.13*2.13m	C 2.74*2.74m	D 1.83*4.57m	E 3.66*3.66m
0	4305	2197	1327	1198	746
5	1643	988	667	667	432
14	667	494	309	309	210
20	667	494	309	309	210

Forest mensuration

The establishment of permanent sample plots commenced in 1920 with the measurement of the original plantings that were established in 1913. To date there are fifty-four sample plots in first rotation sites and seventy-one plots in second rotation sites. Most of the sample plots on first rotation sites are located within the older plantations particularly at Quarry Road, Marac and Rochard Douglas Plantations. On second rotation sites sixteen plots are located within the Victoria plantations and thirty-nine at Quarry Road plantations. Although plantations at Morne Diablo and Catshill are as large as Quarry Road plantations sample plots were established in these locations within the last decade. In 1969 provisional yield tables were constructed using data from 37 sample plots (Miller, 1969). In 1994 data from these plots were used to construct site index curves, volume equations and a growth model for teak in Trinidad (Ramnarine, 1994). At present data from second rotation sites are being analysed.

POLICY INITIATIVE AND INCENTIVES

Private forestry incentives

Since 1998 the Government of Trinidad and Tobago began new initiatives and incentives to reverse the cycle of deforestation and degradation of private lands by encouraging reforestation and better land use practices. Although the necessary policies and institutional framework to allow for large-scale engagement of individuals and community groups were not in place, over 1000 farmers have already joined the programme.

As a result the Forestry Division administers this incentive programme for nature trails, perimeter fire tracing, Taungya land clearing and watershed rehabilitation. In addition rebates on vehicles and machinery and equipment used in the projects are available. To date over 1240 hectares of plantations have been established on private lands under this incentive scheme. While most of the plantations are of mixed species some teak plantations have also been established and maintained under this programme.

National reforestation programme

In a new policy initiative the Government has recently embarked on a massive reforestation project aimed at improving existing secondary and degraded forests on state lands and establishment of plantations of teak and other mixed hardwoods. At the same time this program will promote human development, enhance social and environmental conditions, improve social equity and harmony and increase the area and value of forest estate. The aim is to create meaningful long-term sustainable employment while addressing the issues of conservation and management of the forest estate. The project is envisaged to plant, maintain and protect 13,350 hectares over a period of 10 years.

Taungya

Since the early 1980's Government had offered an incentive to Taungya Gardeners of up to $300.00 per hectare. With the last 5 years government has now increased this incentive to $2,000.00 per hectare. Despite this increase there is a decline in the number of Taungya farmers who are willing to perform site preparation activities.

University of the West Indies cooperative research

Recently, after a week long workshop on Forestry hosted by the University of the West Indies along with the Forestry Division and other stakeholders, a working Group on teak was established to look at the problems of fires, soil erosion, understory vegetation and productivity on second rotation sites. The major objective of this group is to ensure that the plantations of teak are sustainably managed.

CONCLUSIONS

Trinidad and Tobago started the establishment of teak plantations since 1913 to the extent that today there are over 9,000 ha of teak plantations of varying age classes. The teak resources have been used internally to augment the supply of raw material from the natural forests. Teak is used mainly for furniture, doors, cupboards, paneling and flooring in Trinidad and Tobago. Attempts to source external markets have been met with limited success.

There are a number of issues relating to the management of teak. Challenges include, the management for future rotations, severe soil erosion, fires and the absence of an understorey cover. A teak working group has been established in collaboration with the University of the West Indies towards conducting research to provide answers for some of the challenges.

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Role of Teak (*Tectona grandis* L. f.) in Conserving the Biodiversity of Nepal

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ABSTRACT

Forests are one of the important natural resources of Nepal and about 90 per cent of the rural population depend on it. Furthermore, it is a major source of energy, fodder and timber. Various reports state that national forests are decreasing in quality and quantity, since early sixties. To overcome this, reforestation or afforestation had started, although it acquired momentum since early eighties when community forestry programme was started. As a result, a number of plantations have been raised, mainly in the mid-hills and Terai belts of the country so as to meet the demand of forest products. Many indigenous and exotic species have been used for planting, including teak, with high value for its timber and poles, apart from products like firewood, obtained from silvicultural operations during its rotation period. In Nepal, teak plantations were raised in 1960 at Chiliya in Rupandehi District. Over the forty years, teak covered only about 9.5 hectares. Private plantings of this species is minimum, scattered in the Terai and Bhabar regions. In constrast to this species, *Dalbergia sissoo* covers more than 49,000 hectares. This indicates that teak is not the preferred species for large scale plantations in Nepal. One of the reasons for this is the site requirements. Despite the promising growth of teak in some areas, it suppresses the undergrowth, not enriching species diversity. Also, farmers and communities prefer multi-purpose tree species like *Leucaena leucocephala, Guazuma ulmifolia* and *Cassia siamea*, the main reason being the long rotation period of teak. In terms of biodiversity conservation, the species acts as an important host for butterflies like *Hysipyla robusta*. Also, with wider spacing in plantations, various intercrops can be grown in the early stages which can support biodiversity.

Keywords: Teak plantations, Nepal, performance, biodiversity.

INTRODUCTION

Forests are one of the important natural resources of Nepal and about 90 per cent of the rural population depend on it. It provides various kinds of goods and services. Furthermore, it is a major source of energy, fodder and timber. Various reports state that national forests started to decrease in quality and quantity since early sixties and it is continued yet. To overcome this problem, reforestation or afforestation has started since that time, although it acquired momentum since early eighties when community forestry programmes started. As a result, a number of plantations have been raised, mainly in the mid-hills and Terai belts of the country so as to meet the demand of forest products.

Many indigenous and exotic species have been used for planting. Among the various tree species selected for plantation programmes, teak (*Tectona grandis*), an exotic species, is one. It is one of the important tree species because of its high value for timber and poles (Jackson, 1994). In addition to it, a lot of products like firewood, especially of branches, are obtained from silvicultural operations during its rotation period.

Table 1. Growth data of teak plantations in different locations

Location	Planting year	Area (ha)	Age (years)	Average height (m)	Periodic growth increment of height (m)	Average dbh (cm)	Periodic growth increment of dbh (cm)
Chiliya, Rupandehi	1960	7.28	14	15.2	1.1	23.1	1.7
Sagarnath, Sarlahi	1966	0.81	8	14.3	1.8	23.9	3
Solakpur, Parsa	1968	0.81	9	9.9	1.7	14	2.3
Shankarnagar, Rupandehi	1992	0.5	1.5	0.2	--	--	--
			2.5	2.3	0.9	--	--
			3.5	4.1	1.2	--	--
			4.5	--	--	6.7	1.5
			5.5	--	--	8.4	1.5
			6.5	9.2	1.4	9.9	1.5
			7.5	--	--	10.3	1.5
			8.5	--	--	12.6	1.5
			9.5	18.8*	2	13.9	1.5

TEAK PLANTATIONS/TRIALS IN NEPAL

Teak plantation began in 1960 in Chiliya, Rupandehi District (300 m). Over the forty years of plantation history in Nepal, teak covers little area (Table 1). Some block plantations have been established by Sagarnath and Ratuwa Mai Forestry Development Project in Sagarnath (260 m) and Ratuwa Mai (200 m), respectively in the Terai / Bhabar regions of Nepal. Private planting of this species is very minimal and are scattered throughout the Terai and Bhabar regions. In constrast with this species, *Dalbergia sissoo* covers more than 49,000 ha (DFRS, 2000). This indicates that teak is not a preferred species for large scale plantations in Nepal. One of the reasons for this is the site requirement. The sites required for its optimum growth is very limited. Table 1 indicates this scenario.

NATURAL REGENERATION UNDER TEAK FORESTS

Despite the promising growth of teak in some areas in the Terai/Bhabar regions of Nepal, it suppresses nearly all undergrowth in its plantations, mainly due to its heavy foliage leaving a bare floor with little but fallen leaves. Again, the species isn unsuitable for site amelioration. It has very minimal role in enriching species diversity in plantations although there has been reports that many species regenerate under teak forests (Kermode, 1944, 1946; Lamba, 1945).

ALTERNATE SPECIES TO TEAK FOR FARMERS AND COMMUNITIES

In the Terai/Bhabar plains of Nepal, people do keep livestock for agriculture and related activities. Farmers and communities have preferred some multi-purpose tree species. Among them, some are *Leucaena leucocephala, Guazuma ulmifolia* and *Cassia siamea*. One of the main reason for less preference in teak, in comparison to other species is the long rotation period, which is about 60 years Small farmers and communities are reluctant to wait for such a long period.

MANAGEMENT OF TEAK PLANTATIONS AND SPECIES OCCURRENCE

In terms of biodiversity conservation, teak acts as an important host plant for butterflies, namely *Hysipyla robusta*. In addition, with the adoption of wider spacing in plantations, various intercrops can be grown in the early age, which is beneficial for supporting biodiversity, including macro and microorganisms.

CONCLUSIONS

Teak, although not preferred by local communities of Nepal, is an important plantation species; it has a very significant role in biodiversity conservation, especially for butterflies.

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Quality Timber Products of Teak from Sustainable Forest Management pp 119-125

Teak in Sri Lanka: Resource Base, Issues and Challenges

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ABSTRACT

Sri Lanka lost its natural forest cover quite rapidly over the past four decades due to the problems associated with population increase. The Forest Department initiated its reforestation programme, about 100 years ago, to offset the denudation of natural forests of the country. Teak is by far the most popular species used in reforestation programs in Sri Lanka. Development of commercial teak plantations has been the responsibility of Forest Department until recently and the private sector involvement was not forthcoming due to the absence of a favourable business environment. Current National Forest Policy of the country has provided the policy and legal framework conducive to large scale private sector investments in forest plantation development. Apart from commercial teak plantations, home gardens play a major role in supplying teak to the domestic market. There is a great potential for increasing both the quality and quantity of Sri Lankan teak and the use of high quality planting materials for new plantation establishment. Improved management of existing teak resources is also vital to the growth of teak industry in the country.

Keywords: Teak, home gardens, private investment, National Forest Policy.

INTRODUCTION

Sri Lanka is a tropical island situated in the Indian Ocean with a population of 19 million people and a land area of 65,000 square kilometers. Topographically, the country consists of a highland area in the South-central part of the island which rises to about 2,500 m, and lowland plains which surround it. The climate is tropical and maritime.

Sri Lanka lost its forest cover rapidly over the past few decades from 44 per cent of the land area in 1956 to mere 23 per cent at present, mainly due to problems associated with population increase. Clearing of forest lands for agricultural schemes and new settlements, shifting cultivation and illegal timber extraction from natural forests are the main causes of deforestation.

Forest Department launched its reforestation program about 100 years ago in order to offset the denudation of natural forests of the country. Teak, Eucalyptus, Mahogany and Pines are the main species used in these plantations and teak has been, by far, the most popular plantation timber species. Establishment and management of forest plantations has been the responsibility of the Forest Department throughout this period and private sector involvement in commercial forest plantation development was commenced only during last five years. The new forest policy of 1995, coupled with the socio-economic changes in the country during last decade, paved way for investment by the private sector in commercial forest plantation development.

NATIONAL FOREST POLICY

The current National Forest Policy formulated in 1995 has three main objectives.

i. To conserve forest for posterity, with particular regard to bio-diversity, soils, water, and historical, cultural, religious, and aesthetic values
ii. To increase the tree cover and productivity of the

forests to meet the needs of present and future generations for forest products and services.

iii. To enhance the contribution of forestry to the welfare of the rural population, and strengthen the national economy, with special attention paid to equity in economic development.

The highest priority of the forest policy is given for conservation of remaining natural forests for environmental and socio-cultural benefits. It is planned to meet the demand for forest products and services from tree resources outside the natural forests, which include home gardens and forest plantations. The policy on management of private forests and tree resources along with the current policy on timber marketing and trade has encouraged the commercial forest plantation development in the country.

Policy on management of private forests and tree resources

i. Trees growing in homesteads and other agro-forestry systems will be promoted as the main strategy to supply wood and other forest products for meeting household and market needs.
ii. The establishment, management and harvesting of industrial forest plantations by local people, communities, industries, and others in the private sector, will be promoted
iii. The State will promote tree growing by local people, rural communities, NGOs and other non-State sector bodies for the protection of environmentally sensitive areas.

Policy on wood and non-wood forest products, industries and marketing

i. Greater responsibility will be given to local people, organized groups, cooperatives, industries, and other private bodies, in commercial production, industrial manufacturing and marketing
ii. Efficient forest product utilization, development of competitive forest industries based on sustainable wood sources and manufacture of value added products will be promoted
iii. The State will facilitate the harvesting and transport of forest products grown on private lands
iv. Effective measures to protect the forest and prevent illegal trade in wood, non-wood forest products and endangered species of flora and fauna will be instituted

FOREST RESOURCES OF SRI LANKA

The closed canopy forest cover of Sri Lanka at present is 23.9 per cent of the total land area. There are about 7 per cent open forests and 1 per cent forest plantations, as well. So, the total area under the forest cover is around 32 per cent at present (Table 1).

Table 1. Forest resources of Sri Lanka

Forest type	Extent (ha)	% of total land area
Montane forests	3,108	0.04
Sub-montane forests	68,838	1.04
Lowland rain forests	141,549	2.13
Moist monsoon forests	243,877	3.68
Dry monsoon forests	1,094,287	16.53
Riverine dry forests	22,411	0.33
Mangrooves	8,687	0.13
Sparse forests	463,842	7.01
Forest plantations	98600	1.50
Total	**2,145,199**	**32.39**

Forest plantations

Almost all the forest plantations in the country are managed by the Forest Department. There are about 5000 ha of forest plantations mainly *Eucalyptus* in the privatized tea estates that are managed by the respective plantation companies. Forest Department currently manages nearly 98,000 ha of forest plantations.

Table 2. Plantation resource base of the Forest Department

Species	Extent (ha)
Teak	38,400
Conifers	18,400
Eucalyptus (timber)	12,600
Mahogany	3,200
Eucalyptus and Acacia (fuelwood)	16,000
Mixed species	10,000
Total	**98,600**

Source: Forest Department, Sri Lanka.

TEAK PLANTATIONS IN SRI LANKA

Teak is an exotic species in Sri Lanka and was introduced by the Dutch during the 17th century. Several introductions were made subsequently from other countries in Asia including India, Thailand, Indonesia, and Myanmar. The first attempt by the Forest Department to establish teak plantations was during 1873 and 1875, in the eastern part of the country. There was a setback in teak plantation development during 1920s due to an adverse report stating that Sri Lanka is not suited to grow teak as a timber tree. However, the development of teak plantations on large scale was taken place during 1950 and 1970, mainly through the *Taungya* system. The extent planted grew from around 200 ha in 1900 to nearly 35000 ha in 1990.

Current status of teak resources

There are three main sources of teak in Sri Lanka

i. Commercial teak plantations managed by the State.
ii. Commercial Teak plantations managed by the private sector.
iii. Small scale teak planting in private lands especially in homegardens.

Commercial teak plantations managed by the State

There are about 35,000 ha of teak plantations in the country that are managed by the Forest Department. Almost all teak plantations are located in the dry and intermediate zones of the country. Some of these plantations were severely damaged by the cyclone in 1978. Damage by wild elephants has been a serious problem in most teak plantations in the dry zone and about 6000 ha have been affected to date. Another 4000 ha of teak plantations have subsequently been included in to the existing National Parks and Sanctuaries and hence not available for commercial management. Leaving out damaged plantations and those included in the National Park and Sanctuaries only about 17,000 ha have been allocated for commercial management at present.

Table 3. Distribution of State owned teak plantations

District	Extent (ha)
Anuradhapura	3013
Polonnaruwa	2515
Kurunegala and Puttalam	2090
Matale	4221
Monaragala and Ratnapura	1754
Hambantota	1901
Kandy	587
Kegalle	972
Total	**17053**

Most of these teak plantations were established during 1970-1980 period. As a result nearly 65 per cent of the present teak estate is at the rotation age or older. Figure 1 shows the age class distribution of teak plantations managed by the Forest Department

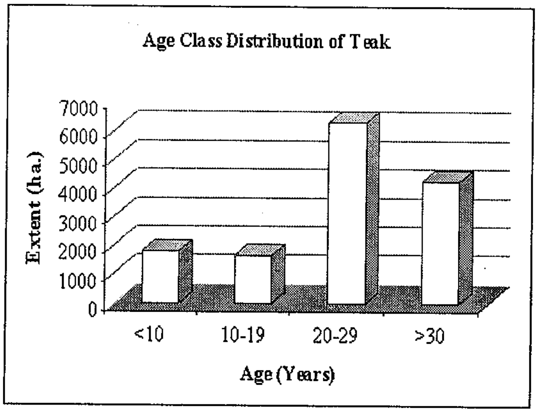

Figure 1. Age class distribution of teak plantations

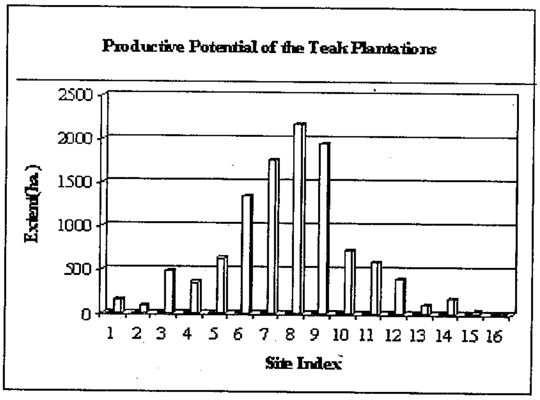

Figure 2. Production potential of teak plantations in Sri Lanka

The quality of teak plantations varies greatly depending on the location and past management practices. Figure 2 shows the extents by Site Index (height in metres at base age 15 years) indicating the production potential of existing teak plantations under commercial management.

The estimated standing volume in State owned teak plantations is around 1.8 million m^3, much of which is ready for harvest. As the majority of plantations are at the harvesting age the current average growth rate is around 2.0 m^3 /ha/year.

Commercial teak plantations managed by the private sector

Private sector involvement in commercial forest plantation development in Sri Lanka commenced recently. Several attempts made by the Forest Department during 1980s to attract private investments in commercial forest plantation development were not successful due to various reasons. With the legal frame work provided by the new National Forest Policy in 1995 and the changing socio- economic conditions in the country paved the way for private sector involvement in forest plantation development. As a result, the Forest Department was able to launch its own scheme called 'Private Sector Reforestation Program' in the year 2000. Under this scheme, it is planned to lease out 10,000 ha of barren lands belong to the State to the private sector for a period of 30 years for commercial plantation development. During last two years, 1200 ha have been leased out under this scheme and the entire area has been planted mainly with teak.

There are few private companies now in operation and dealing with the establishment of teak and Mahogany plantations. These companies are selling established block of plantations to individuals and keep maintaining them on their behalf till maturity.

Small scale teak growing in private lands

Sri Lanka meets 41 per cent of its national industrial timber demand from the home gardens. Teak is one of the main species grown in home gardens. According to a recent survey on trees in home gardens (Ariyadasa, 2002) there are about 3 million teak trees in all age classes in the home gardens. The following table (Table 4) shows the twelve most common tree species found in home gardens of Sri Lanka.

This survey was carried out in Grama Niladhari Divison (GN Division) level, which is the smallest administrate unit of Sri Lanka. The data were then compiled to the Divisional Secretariat Divison level (DS Division), which comprises of several hundreds of GN divisions.

Contribution of teak to the round wood supply

The total consumption of round wood (all species) in 1993 was estimated at 1.3 million cubic metres and almost all weres used for sawn wood production. In addition nearly 0.3 million m^3 of

Table 4. Common home garden species in the order of frequency of occurrence in Sri Lanka

Species name		Origin	Category	Total number of trees
Local	Botanical			
Coconut	*Cocos nucifera*	Planted	Timber and Food	38616649
Rubber	*Hevea brasiliensis*	Planted	Timber	17101488
Jak	*Artocarpus heterophyllus*	Planted	Timber and Food	10437142
Arecanut	*Areca catechu*	Planted	Food	9697944
Mahogany	*Swietenia macrophylla*	Planted	Timber	6410248
Alstonia	*Alstonia macrophylla*	Planted	Timber	5968286
Mango	*Mangifera indica*	Planted	Timber and Food	5607688
Albizzia_1	*Albizia molucana*	Planted	Timber	5607581
Eucalyptus	*Eucalyptus* spp.	Planted	Timber	4061191
Teak	***Tectona grandis***	**Planted**	**Timber**	**3293609**
Margosa	*Azadirachta indica*	Natural/Planted	Timber	3044932
Cashew	*Anacardium occidentale*	Planted	Timber and Food	3001240

poles were also consumed. The entire supply of round wood was from domestic sources and the imports of logs were negligible. The striking feature of the wood supply in Sri Lanka is that the majority of supply comes from sources outside the natural forests. Home gardens, Rubber and Coconut plantations and forest plantations are the main contributors of saw log supply (Tables 4 and 5).

Table 5. Projected wood production from home gardens and other sources in the year 2000

Supply source	Volume (m^3)	Percentage of total
Home gardens	570,000	42.4
Rubber plantations	256,000	19.0
Coconut plantations	202,000	15.0
Trees in tea estates	76,000	5.7
Other perennials	68,000	5.1
Roadside and settlements	4,000	0.3
Forest plantations	100,000	7.4
Imports	68,000	5.1
Total	1,344,000	100.0

Source: Forestry Sector Master Plan (1995)

The contribution of forest plantations to the total log supply is around 7 per cent and the share of teak is about 4 per cent or nearly 50,000 m^3 at present. There are about 3 million teak trees in home gardens and about 100,000 trees could be harvested annually. This will produce another 80,000 m^3 or 6 per cent of the total wood supply. Therefore, teak is accounted for nearly 10 per cent of the total wood supply of the country.

Marketing of plantation teak

The State Timber Corporation (STC) is the agency responsible for harvesting and marketing of timber from State plantations. They have the exclusive rights to harvest and market the teak from Forest Department plantations.

STC employs private contractors for harvesting operations and paid them according to the volume of logs they supplied to the STC depots. The STC sets rates for harvesting and transport based on the location and terrain of the plantations. STC sells logs from its depots through auctions. There are several depots around Colombo that hold weekly auctions. STC pays the stumpage to the central government which is around 60 per cent of the value of timber sold. Teak supplied by the State Timber Corporation during past 7 years is given in the Table 6. Nearly 98 per cent of the supply is from Forest Department plantations while the balance is mainly from home gardens.

Table 6. Supply of teak logs from Forest Department plantations during 1993-2002

Year	Log volume (m^3)
1993	7454
1994	9294
1995	10009
1996	11092
1997	11706
1998	17927
1999	16208
2000	15760
2001	37527
2002	30497

Source: State Timber Corporation

Depending on the market demand and quality of timber, STC has categorized all timber into 6 different classes, namely Super Luxury, Luxury, Special Class, Class I, Clsass II, and Class III. Teak is classified as a Super Luxury timber in the domestic market. All available teak sawlogs are presently consumed by the furniture industry.

Pricing of teak logs

Due to the monopoly it has over the plantation teak, the STC is the main supplier of teak to the local market. STC sets the sale price based on the mid girth of logs. The following table shows the current price of logs according to different girth classes. STC also uses 3 log grades; A,B, and C. Grade B logs sell for standard price while Grade A logs are marked up by 10-30 per cent on standard prices (Grade A-10, A-20, and A-30). Class C logs are sold 10-30 per cent below the standard price (Grade C-10, C-20, and C-30). Grade A and B logs are easy to sell while Grade C frequently fail to meet the set price (based on a discounted value of price for Grade B) and have to be re-auctioned. Nearly 50 per cent of the total log volume is Grade B while 20 and 30 per cents of the total volume fall in to Grade A and Grade B, respectively.

Table 7. Teak log prices of the State Timber Corporation - 2002 (US$ 1= Rs. 97.00)

Mid girth (in metres)	Price per m^3 (in Rupees)
1.50 and above	28800
1.42-1.48	26900
1.36-1.40	25000
1.30-1.34	23100
1.24-1.28	21600
1.18-1.22	20200
1.12-1.16	18800
1.06-1.10	17600
1.00-1.04	16400
0.94-0.98	15400
0.88-0.92	14400
0.82-0.86	14100
0.76-0.80	13700
0.70-0.74	13400
0.64-0.68	12400
0.58-0.62	10600
0.52-0.56	9600
0.48-0.50	8700
0.42-0.46	6800
Below 0.40	6400

Source: State Timber Corporation

Teak grown outside the State plantations, especially in home gardens, is marketed in the open market through small timber dealers and the prices are slightly lower than the STC prices. In the open market, home garden teak fetches slightly lower price than plantation grown timber mainly due to the higher portion of sap wood in logs.

International trade of timber

Sri Lanka imports about 5 per cent of its national demand of sawn timber annually. The following table shows the Imports and Export of sawn wood (of all species) during the period of 1985-97.

Sri Lanka imports only a negligible amount of high quality teak from Myanmar. There is no significant export of teak logs to other countries at present as the current forest policy emphasises on the export of value added products instead of logs. Teak furniture and artifacts are exported to several countries in small quantities at present.

PROCESSING OF TEAK

As mentioned before, all the teak saw logs are consumed by the furniture industry. There are about 4000 sawmills in the country. Most of these saw mills are small. The number of major industrial saw mills is around 400. There are about 680 furniture producers and they have their own sawmills. The capacity of sawmills varies greatly and can be anything between few cubic meters to 7000 cubic meters per year. However, the average output of the major sawmills is only about 750 m^3/year.

Most of these sawmills suffer from outdated technology resulting an average recovery as low as 40 per cent. The majority of sawmills are also not suited for utilizing small logs. These conditions obviously are not in favour of processing high valued teak.

FOREST CERTIFICATION

Forest certification in Sri Lanka is confined largely to certify Rubber plantations at present. According to the FSC records there are about 12,000 ha of rubber plantations with FSC certification to date. As the majority commercial Teak plantations belong to the state and export of Teak is quite limited at present, certification of Teak plantations has not taken place yet. However, the government has proposed to lease out state plantations to the private sector for long term management and pilot scale leasing out of 6000 ha will commence from year 2004. The private managers have the liberty to certify these plantations if they find certification would benefit the marketing of timber from their plantations.

Table 8. Sawn wood imports and exports during 1985-97 (m^3)

Import/Export	1985	1988	1990	1991	1993	1995	1997
Imports	38000	34800	27100	21500	28700	27500	62300
Exports	150	500	600	1300	150	290	20
Net trade	37850	34300	26400	20200	28550	27210	62280
Value of Imports US$	10.3	5.7	4.2	3.9	4.3	5.9	5.3

Source: External Trade Statistics (1985-97), Department of Customs.

CONCLUSIONS

Teak is by far the most popular timber species in Sri Lanka and accounted for nearly 10 per cent of the total industrial wood supply. Policy and legal frame work for the development of teak resources especially with the involvement of private sector, is in place with the current Forest Policy of the country. There is a room for improvement both the quality and quantity of Sri Lankan teak. The extent of teak plantations is expected to be increased with the private sector involvement in Teak plantation development. The quality of teak both in state and private plantations could be improved with the supply of high quality planting materials and adopting improved management practices.

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Teak in the European Union

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ABSTRACT

In the present European Union (EU) of 15 countries, furniture manufacture is the biggest wood-based industry (45%) followed by construction (18%), sawing, planing and impregnation (15%), wood-based panels (11%), packing cases (4%) and others (7%). Teak is used mainly for garden furniture, bathrooms, swimming pools and kitchens, parquetry and ship decks. Notwithstanding the increasing availability of temperate hardwoods, demand for teak is still firm. EU import of tropical timber as a whole is more or less stable. Processed products such as veneer and plywood, and the secondary processed products such as doors, parquetry and window frames are increasing their share at the expense of wood in the rough. Teak also follows the general trend of value being added outside the EU.

Keywords: Teakwood import, European Union, timber certification, quality hallmark

The patterns of wood use within the wood processing industry in the present EU of 15 countries are illustrated in Figure 1. It refers to all types of wood, including teak. It clearly shows that furniture is the biggest of these sectors.

Teak is mainly used in furniture for gardens, bathrooms, swimming pools and kitchens, as well as for parquetry and for ship decks. Notwithstanding the increasing availability of temperate climate hardwoods demand for teak is still firm.

EU import of tropical timber as a whole is more or less stable. Processed products as veneer and plywood, and the secondary - processed products such as doors, parquetry and window frames are increasing their share at the expense of wood in the rough. Teak also follows the general trend of value being added outside the EU.

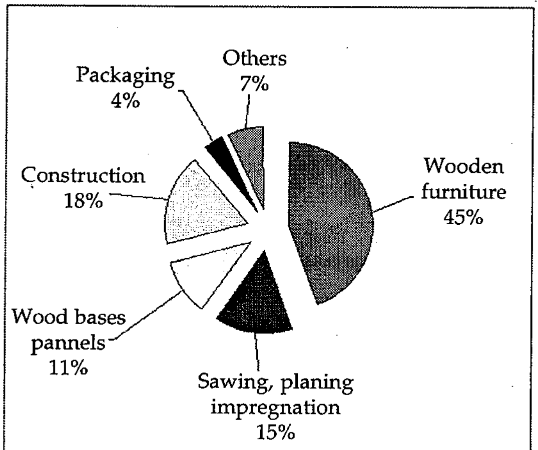

Fig.1. Shares of sectors within the processing industry of all types of wood (Source: CEI- bois, 2003)

All over the EU, there is a strong drive for quality standards to guarantee sustainable forest and plantation management, as well as user safety of end products. At EU level, directive 89/106/EEC governs building materials; focusing on: mechanical resistance, fire safety, hygiene, safety in use, noise protection, energy economy and heat retention. In addition, guarantees for products being produced in accordance with environmental and social standards for sustainability are covered by privately arranged quality hallmarks. All hallmarks require wood originating from sustainably managed forests or plantations. With processed products, the percentages of components originating from non-

Table 1. Imports of tropical timber products into the EU in 2000/2001 (adapted from , ITTO 2002 and Eurostat, 2000).

Timber Type	As % from own EU production	As total value in million Euro	Main importing EU countries
Logs	ca 1%	ca530	France
Sawn wood	3%	1500	Netherlands, Italy
Veneer	20%	300	Italy
Plywood	50%	1000	UK
Secondary processed wood products	10%	2000	Italy

sustainable sources can vary per hallmark. Main hallmarks on wood products in the EU are:

FSC : Forest Stewardship Council. Based on a worldwide certification system with global standards. It has no provisions for recognition of national or regional certification systems.

PEFC : Pan European Forest Certification. Adopted by a number of EU and non-EU countries in Europe. In principle it has also provisions for the recognition of other non-EU national and/or regional certification systems.

KEURHOUT : A Dutch label issued to wood products imported to the Netherlands that meet minimum sustainability standards. It allows for recognition of individual, national or regional certification systems.

Table 2. Relative values per 1000 kg of different timber products imported into the EU from developing countries. Logs = 100. (adapted from Eurostat 2000)

Logs	100
Sawn wood	290
Plywood	320
Continuously shaped wood	570
Veneer	650
Parquet panels and doors	900
Wooden frames	1500

At present in the EU, some 3 per cent of the total timber consumed is certified. It is believed that this will go up to 30 per cent in a few years from now. Therefore, demand for certified teak will increase at least tenfold in the coming years. It has already led a number of private investment funds to set up teak plantations with the intention to meet FSC certification requirements in Central and South America.

Status of Teak (*Tectona grandis* L. f.) Plantations in Bangladesh

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ABSTRACT

Teak (*Tectona grandis* L. f.), which belongs to the family Verbenaceae, is predominantly tropical or subtropical in distribution. It is a major plantation species in the tropical wet evergreen forests and in the tropical semi evergreen forests of Bangladesh. The establishment of teak plantations at Sitapahar (Chittagong hill tracts) in 1871 led to a new era of plantation forestry in Bangladesh. The total forest area of Bangladesh is 22, 41,793 ha of which hill forests cover 13, 61,670 ha. Up to 1980, 70 to 80 % of the plantations of the hill forests were with teak. Most of the teak plantations are located in Chittagong, Chittagong hill tracts, Cox's Bazar and Sylhet, which covered 23,740 ha, 1,43,981ha, 37,877 ha and 11,396 ha respectively. In total, teak plantations extending to an area of 2,16,994 ha in Bangladesh. Besides hill plantations, there are some block, roadside and homestead plantations of teak. They are under the ownership of private enterprises, industries, semi-autonomous corporations, farmers and small land holders. The rotation age followed for teak in Bangladesh is 60 years on all sites. The rate of return from teak plantations would increase if the rotation age is brought down. Between 20-30 years, the rate of return is the highest, and after 40 years, it comes down slowly. It is estimated that with 40 year rotation, return might be 6-15 instead of 3-10 per cent. Several biological organisms including insects, bacteria and fungi attack teak in nursery as well as in the field conditions. For development of teak forestry in Bangladesh, it is necessary to introduce modern forestry techniques such as introduction of mycorrhizal technology and identification of suitable mycorrhizal species for root colonization in order to enhance the growth of teak in nursery and plantation stages.

Keywords: Teak plantations, Bangladesh, plantation management, rotation age, mycorrhizal colonization

INTRODUCTION

Bangladesh lies on both sides of the Tropic of Cancer and the 90° E meridian, between 21°25' to 26°38'N latitude and in 88°18' to 92°40'E longitude. Total area of the country is about 147,570 km² of which about 11.3 million hectares (79%) is flood plains, 1.2 million (8.3%) hectares is terrace land and 1.8 million (12.6%) hectares is hilly area. The terrace lands occur in the central and North-West parts and the hills occur in the North, North- East and eastern parts of the country. The sediments in Bangladesh belong to the Recent, Plio-Pleistocene and Mio-Pliocene ages. The flood plains belong to the Recent, Barind and Madhupur tracts of the Plio-pleistocene and hills belong to the Mio-Pliocene ages (Tewari, 1992). The climate is relatively warm throughout the year. Sixteen per cent of the total land is under forests. During 1983-84, UNDP/FAO Global Environment Monitoring system reported that there is only 0.93 million hectares (6.5%) under tree cover. Over 20 years ending in 1980, the forest cover declined by 2.1 per cent annually and the annual deforestation rate is estimated to be about 8,000 hectares (FMP, 1993; Rahman, 1994).

During 1989-90's, forestry sector of Bangladesh contributed Tk. 12.6 billion, which is 2.6 per cent of its gross domestic product at constant prices. Present round wood demand is estimated as 13.2 million m^3, which includes logs, poles, pulpwood, fuel wood, and also totals about 0.12m^3 per capita. Fuel wood and logs are the major products, needed by about 62 and 34 per cents, respectively. In gross domestic product, government's development goal is considered as 5 per cent of its annual growth rate. To support this economic and development target, the nation will consume 16.5 million m^3 of wood annually by the year 2012, even at a low level of consumption (FMP, 1992).

Teak (*Tectona grandis* L. f.) belongs to the family Verbenaceae, which is predominantly tropical or subtropical in distribution. Teak plantations were established in Bangladesh in 1871, with seeds imported from Myanmar. Plantations were raised at Sitapahar, Kaptai and Chittagong. Till 1980, 70 to 80 per cent of the plantations of the hill forests were of Teak (Anderson, 1969; Slavicky, 1978; White, 1979; Howlader, 1982). Since then, teak has always been considered as the principal species in the plantation programmes of Bangladesh.

FOREST AREA AND FOREST TYPES OF BANGLADESH

The forests of Bangladesh are classified into three zones, namely Hill forests (in the greater districts of Chittagong, Chittagong hill tracts and Sylhet), Inland forests (central and northern zones) and Littoral forests (in the delta and coastal regions). The total area of these forests is 2241,793 ha, of which hill forests covers 1361,670 ha, inland forest 122,012 ha and littoral forests 758,111 hectares. But these lands are not under the control of Forest Department. Much of the land is under the occupation of encroachers and Sal forests are greatly affected by the encrochment problem. Since 1985, it was observed that encroachment and Jhum cultivation are on the increase in the Chittagong hill tracts (FMP 1992).

From an ecological point of view, Bangladesh forests are divided into five major forest types, namely tropical wet evergreen, tropical semievergreen, tropical moist deciduous, tropical freshwater swamps and the mangrove forests (Champion and Seth, 1968; Das, 1990). Tropical wet evergreen forests cover Sylhet (Lawachara), Chittagong Hill Tracts (Kaptai, Rangamati, and Mainimukh), Chittagong (Hazarikhil) and Cox's Bazar regions. Tropical semievergreen forests are in Sylhet (Longai, Baleshira), Chittagong (throughout), Cox's Bazar and Chittagong hill tracts and Dinajpur region. Tropical moist deciduous forests cover northern and central parts of Bangladesh (from Dhaka to Dinajpur and Comilla Sal forests). Tropical freshwater swamp forests cover valleys of lower Kassalong reserve of Chittagong hill tracts and the evergreen and moist deciduous forests are distributed in eastern Sylhet. Mangrove forests cover Sundarbans (Khulna, Bagerhat and Satkhira districts) Cox's Bazar, Chittagong (eastern shore of the Bay of Bengal, Chakaria Sundarban, delta of Matamuhuri river) and Teknaf to Patuakhali. However, teak is found as a major plantation species in the tropical wet evergreen forests and in the tropical semievergreen forests of Bangladesh. (Tewari, 1992)

MORPHOLOGY OF TEAK

Teak is a large deciduous tree up to 30 m high with deep and stout taproot system; bark is pale brown or gray. Leaves opposite, broadly elliptic, obovate, stellae-pubescent. Flowers are large, 60-90 cm long panicle, actinomorphic; calyx enlarged in fruit forming and becomes inflated; corolla pale white; stamens 5-6, alternate with corolla lobes; ovary with axile placentation. Drupe with thick shaggy exocarp of matted hairs, epicarp inflated, spongy; seeds1-4. Seedlings with sparsely to moderately branched lateral roots; first pair of leaves usually green, 6-9 pairs at second stage; hypocotyle and cotyledons epigeous; petioles 3-6 mm long, blade elliptic or ovate, epicotyls erect, glandular and hairy. Leaves decussate, veins prominent beneath, obovate oblong, young leaves red due to red cell sap in the epiderm. Flowers portentous and entomophilous. Pollen grains trizonicolpate, suboblate to oblate, spheroidal, ambi circular, apertures 3, colpate, tenuimarginate; exine sexinous, minutely reticulate. Embryo Solanad type, covered by 2-layers of endosperm cells when ripe; ovules anatropous; micropilar end of embryo sac much broader than chalazal end, degenerates in post-fertilization stages (Tewari, 1992).

PHENOLOGY

Teak is deciduous, shedding its leaves from November to January; new leaves appear from April to June. Flowering season varies from June to August or September. Fruit ripens during November to January and fall gradually (Tewari, 1992).

DISTRIBUTION

Natural distribution of teak is in South and South-East Asia. In India, the genus is known only by *Tectona grandis*. This species has worldwide reputation as paragon among timber trees. *Tectona hamiltoniana* Wall. is distributed in the dry zone of Myanmar. *T. philippensis* Benth. & Hook.f. is endemic to the Batangas and Mindoro (Iling Island) of Philippines, where it occurs on the dry exposed ridges (Troup, 1921). In South-East Asia, natural distribution of teak is from the Indian subcontinent through Myanmar and Thailand to Laos (about 73^0 to103^0 E longitude). In Myanmar, it occurs at 25.5^0 N and in India approximately at 9^0 N latitude. In South-East Asia vast area is also under teak plantation both within and outside its natural distribution range. Teak has also been introduced in different parts of the world outside its natural area of occurrence in South-east Asia (Bangladesh, Nepal, Pakistan, Sri lanka, Vietnam, Cambodia, Taiwan, Japan, etc.), Pacific (Australia, Fiji Isl., U.S. Pacific Isl.), East Africa (Tanzania, Sudan, Somalia, Zimbabwe, Uganda, Kenya, Malawi) West Africa (Senegal, Ginea, Ivory Coast, Ghana, Togo, Dahomey, Nigeria), South Africa, the Caribbean (Cuba, Puerto Rico, Panama, Honduras, West Indies, Jamaica, Nicaragua), South America (Brazil, Surinam, Colombia, Venezuela, Argentina) and Central America (Belizo, Costa Rico, El Salvador) regions(Hedegart, 1975; Keogh ,1979).

Bangladesh is very small country. There are not much variation in the teak growing regions in respect of rainfall, soil and slopes. Most of the teak plantations are observed in Chittagong, Chittagong hill tracts, Cox's Bazar and Sylhet. Temperature varies from 10.6^0C to37.4^0C. It can grow in gentle, steep, very steep slopes. Maximum rainfall is 5412 mm in Sylhet and minimum rainfall is 1836 mm in Chittagong hill tracts. In 1992, plantation areas of these regions are recorded. Chittagong, Chittagong hill tracts, Cox's Bazar and Sylhet regions covered 23740 ha, 143981 ha, 37877 ha and 11396 ha areas, respectively (Statistical Year Book, 1992; Agro-ecological Regions of Bangladesh, Report 2, 1998). There is also some block, road side and homestead plantations and office compound planting of teak available in Bangladesh. They are under the ownership of private enterprises, industries, semi-autonomous corporations, farmers and small holders. But the area of this type of teak plantations is not known. Tea gardens, tobacco companies and private persons have block teak plantations in Chittagong, Sylhet, Cox'sBazar, Jessore, Kustia and Mymenshing areas. Roads and Highways Department, Public Works Department, Water Development Board, Local Government, Engineering Department, etc. also have some block and roadside teak plantations in different parts of the country. Farmers throughout the country and settlers in the Chittagong hill tracts also plant teak in their homesteads.

PLANTATION HISTORY OF TEAK IN BANGLADESH

Initial attempts for raising forest plantations of teak started in 1871, in the Chittagong hill tracts using seeds brought from Myanmar. Since then, plantation forestry became a part of the overall clear felling silvicultural system. Until 1920, they remained confined to the Chittagong hill tracts. In 1921, plantation began in Chittagong, Cox's Bazar and Sylhet division. Total annual plantation rate never exceeded 400 hectares. Teak was the main species planted because of its high value. Teak was raised, prior to 1934, from nursery seedlings. From 1934, stump planting was introduced with satisfactory results. After 1950, even though teak continued to predominate, other species were planted on a sizeable scale. In 1974, the Forest Department began establishing plantations of fast growing species such as *Gmelina*. Slavicky (1978) reported that plantations up to 1981 (excluding pulpwood Division) was about 89.5 thousand hectares out of which about 62.7 thousand hectares was teak plantation and 54% of teak plantation was established during 1961-70. The proportion of Teak plantation up to 1978 in Cox' Bazar, Chittagong, Chittagong hill tracts (North), Chittagong hill tracts (South), Jhum control and Sylhet Forest Divisions were 28.7, 19.8, 14, 14, 11.5 and 12 per cents, respectively. The earliest teak plantation was raised in Chittagong hill tracts (South) Division in 1873, Chittagong and Cox's Bazar Forest Division in 1921, Sylhet in 1922 and in Chittagong hill tract (North) in 1941. Up to 1981, teak plantations below 15 years stood at about 44 per cent, while 15 to 30 year old plantation stood at 47 per cent of the total teak plantation (Rahman, 1982).

Till today, more than 80 per cent of the Chittagong Hill Tracts plantations are of teak. So far, teak plantations cover 216994 ha area in Bangladesh, which include felled, more than 120 years old, failed or poor plantations. Forest Resource Management Project (FRMP:1992-93 to 1999-2000) and Afforestation and Rehabilitation of Jhum families on the Unclassed State Forests and Reserved Forest lands of Chittagong hill tracts (3rd phase, 1995-96 to 1999-2000) were two schemes, which were implemented in teak growing areas. The first one was implemented by Cox'sBazar, Chittagong and Sylhet Forest Divisions and the second one by Chittagong Hill Tracts Forest Divisions.

PRODUCTIVITY

It is really difficult to assess the longterm production from the teak plantations of Bangladesh because of lack of required information regarding the site distribution on the one hand and the productivity from a particular set of site classes, on the other. There are many methods of measuring and expressing site quality, and the most common one is site index. Slavicky (1978), Kingstone (1979) and Dalmacio and Ahmed (1989) classified the sites from site index 10 to 40 with the interval of 5. They suggested that Bangladesh has very good and potential sites for growing Teak. Slavicky (1978) suggested that teak should be planted between site index 25 and 40. But this suggestion has never been followed. Even it is being planted in poor areas with site index 10. This is one of the reason for the poor status of teak plantations in Bangladesh.

The rotation of teak is 60 years in all sites. To reduce rotation length from 60 years to 20-45 years and to develop teak forests under multi-rotation system instead of single rotation system depending on yield and management objectives may be 40 years in Site Index 30, 25 years in Site Index 25, and a rotation of 35 years in Site Indices 35 and 40. For poles or small house posts, rotation may even be 20 years (Rahman, 1982). In Bangladesh, 40 years (long rotation) is the usual rotation for teak now a days. Recently, some plantations of teak are also raised with 18-year (medium) rotation for production of poles. But the proportion of plantation area under different rotations is not known.

There are limited data for teak plantations of Cox's Bazar Chittagong and Sylhet forest divisions, available from RIMS. The available data shows that more than 54 per cent (12912 ha out of 23732) of the plantations have less than an volume of 100m^3 per hectare. Even, at an age 40, out of 23732 ha plantation area surveyed,1041 ha falls under this lower most productivity class. Only about 8 per cent (1865) of the plantations fall under more than 300 m^3 /ha class. This shows the very poor condition of the plantations. De Milde and Ahmed (1985) also reported the same situation of teak plantations in Chittagong and Cox's Bazar forest divisions.

ECONOMIC ANALYSIS OF TEAK PLANTATIONS

Market price of teak varies from place to place. But there is a minimum government scheduled price. It is small all over Bangladesh and used only for auction depending on the basal area of log. But, practically this price also varies during real auction and is always higher than the government rate.

The rate of return from teak plantations less than 60 years age was calculated by Rahman (1982). It shows that, for site index 15, 20, 25, 30, 35 and 40, IRRs are 10, 16, 21, 26, 30 and 35 per cents, respectively under 30 per cent yield reduction. Under 50 per cent yield reduction, they are 4, 8, 12,16, 22 and 26 per cents, respectively. Considering the present stocking and growth, rate of return might be estimated at 3-10 per cent.

The rate of return from teak plantations would increase if the rotation period was less than 60 years. Rahman (1978) calculated marginal value growth per cent of plantations belonging to Site Index 25, between age 21-30, 31-40, 41-50, 51-60 and 61-70 years, which stood at 8, 4.5, 3.2, 1.7, and 0.01, respectively. Between 20-30 years, it is the highest, and after 40 years, it becomes very low. But, in poor sites, only poles can be produced at 30 years. For saw logs, 40 years would be more appropriate. But after 40 years, the costs far exceed the prices of available logs. Site Index 15 and Site Index 20, where MAIs are much lower than Site Index 25, would give different results. Rahman (1978) showed that the length of rotation of 60 years does not even satisfy maximum volume production criteria in all sites. It is estimated that with 40-year rotation, return per cent might be 6-15, instead of 3-10 per cent.

The economics of teak plantations can better be explained by comparing site productivity of Bangladesh with that of some other tropical countries. Keogh (1979) identified five site qualities of teak for tropical American region on the basis of top height of trees at 30 years. A comparative study of these figures with those as presented by Kingston (1979) reveals that the tropical American sites belonging to site classes (V and V can be compared with Bangladesh sites belonging to SI 35, SI 30, SI 25, SI 20 and SI 15, respectively.

Keogh (1979) suggests that, in these countries, most of the SQ (should be rejected economically. Millar (1969) considers that, it is very difficult to justify economically the establishment of teak in SQ (in Trinidad. Under the circumstances, there should be no teak plantation below Site Index 30 in Bangladesh.

PESTS AND DISEASES OF TEAK

The diseases of teak are mostly described from India and the Far East. So far, a few diseases have been recorded on teak planted in Africa, America and else where, away from its natural region of occurrence. Very little work on diseases of teak is reported from Bangladesh.

The association of *Alternaria sp., Aspergillus sp., Aspergillus niger, Aspergillus repens, Aspergillus rubben,* and *Penicillium sp.* were recorded from the fruit rots of teak (Fakir and Mian, 1974). *Pestalotia* sp. causing leaf spot (Mridha, 1975) in nursery, leaf rust caused by *Uredo tectonae* (Ahmed, 1952; Anonymous, 1966; Jalaluddin, 1970; Khan, 1951), root rot caused by *Polyporus* sp. (Khan, 1951) and to *Rhizoctonia solani* (Rahman, 1993a), seed rot due to *Aspergillus repens* (Fakir and Mian, 1974), seedling collar rot caused by *Fusarium* sp. (Anonymous, 1971; Rahman and Zethner, 1971a), bacterial wilt due to *Pseudomonas solanacearum* (Basak, 1992) and unclassified leaf diseases due to *Phyllosticta tectone* (Ishaque and Talukdar, 1967) were found in Bangladesh. Mistletoe due to *Dendrophthoe falcaae* (Rahman, 1990a), *Scurrula gracilifolia* (Alam, 1986a) and *Scurrula pulverulenta* (Alam, 1986a) also were found. Different types of wood decay fungi were reported from Bangladesh like *Daedalea zonata* (Rahman and Zethner, 1971b), *Irpex flavus* (Khan, 1952; FPRB, 1993), *Irpex cf. flavus* (Rahman and Zethner, 1971b), *Polyporus grammocephalus* (FPRB, 1993) and *Polyporus* sp. (Khan, 1951; FPRB, 1993).

Living teak trees harbour as many as 186 species of insects (Mathur 1960; Mathur and Singh 1960).Only two of them, *Hyblaea puera* Cramer (Hyblaeidae: Lepidoptera), commonly known as teak defoliator and *Eutectona machaeralis* Walker (*syn. Pyrausta machaeralis, Hapalia machaeralis,* Pyralidae: Lepidoptera), commonly known as teak skeletonizer, have been found to cause major defoliation of teak in Bangladesh (Baksha, 1990, 1993; Baksha and Islam, 1990). Epidemic infestations were reported to have occurred in 1970 (Zethner, 1970), 1979 and 1980 (Baksha 1990) and in 1990 (Baksha 1994). Teak is also attacked by a long horn bettle, *Dihammus cervinus* Hope (Cerambycidae: Coleoptera) near the base. This larvae is commonly known as Teak canker grub (Baksha, 1990).

MYCORRHIZAE

Arbuscular Mycorrhizal (AM) fungi, an ubiquitous soil borne Zygomycetous (Morton and Benny, 1990) fungi, are now being considered as biofertilizers in forestry management (Mridha *et al.*, 1995). They help the forest trees in up-taking nutrients, particularly Phosphorus, (Smith and Read, 1997), improve disease resistance and water relations, drought tolerance, etc. and thus accelerate the ability of them to compete for resources contributing to efficient recycling of nutrients. AM fungi association in the roots, mycorrhizal dependency and the biodiversity of AM fungi in the rhizosphere soils of teak were studied in India by many workers (Verma and

Jamaluddin, 1995). In Bangladesh, Rahman, *et al.*, (2000) studied the effect of pre-sowing treatments on the colonization of AM fungi in teak. Vertical distribution of AM fungi in the rhizosphere soils of teak was also studied (Rahman and Mridha, 2003). To observe the status of biodiversity of the arbuscular mycorrhizal colonization in the roots and spore population in the soils in nurseries and plantations in different parts of Bangladesh is urgently needed to utilize the Arbuscular Mycorrhizal technology in plantation programmes of teak in Bangladesh..

UTILIZATION

Tectona grandis is the most important and general-purpose wood in Bangladesh, suitable for almost all end uses. Teak wood is moderately heavy, strong and tough, very steady, hard, straight grained and coarse textured. It is the best timber in dimensional stability and has very low fibre saturation point and shrinkage. Teak wood is also moderately refractory to wood seasoning and can be seasoned free from defects with a little protection against rapid drying conditions. It is extremely durable and resistant to decay and termite attack, easy to work, gives smooth surface, good in carving, amenable to bending and can be finished to give very good gloss. It is excellent for furniture, joinery, cabinet making, decorative veneer, plywood and all sorts of construction works.

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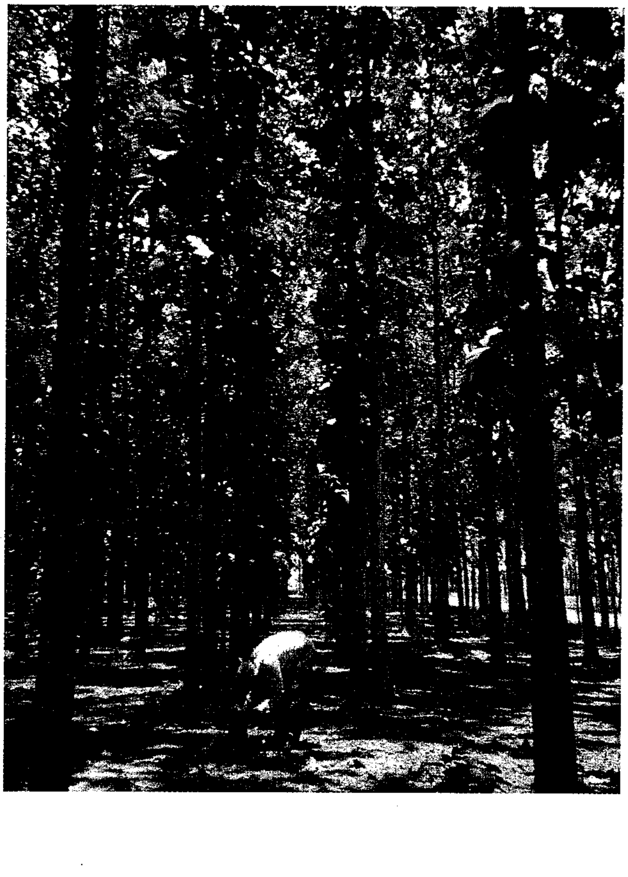
Sustainable Forest Management with Reference to Teak



Sustainable Management of Teak Forests in Myanmar

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ABSTRACT

Teak (*Tectona grandis* L. f.) from the natural forests has been a major source of foreign exchange for Myanmar for many years. After almost a century and a half of scientific and systematic management with the application of the Myanmar Selection System (MSS), the natural teak-bearing forests remain in comparatively good extent and status. However, due to the ever-increasing population and its demand for timber and land for agricultural purposes, forest degradation is being experienced with decreased production. The Myanmar Forest Policy 1995, stipulates that the natural forests of Myanmar will never be substituted by plantations. However, apart from the silvicultural treatments provided to assist natural regeneration, tree planting of moderate scale is also afforded to enrich the degraded areas, while larger plantations are established to replenish the depleted areas, as new wood capitals are being built up. The natural forests will continue to provide timber, especially premier teakwood , on a sustainable basis, while rendering protective functions to ensure ecological stability and biodiversity integrity with supportive services for cultivation, recreation and ecotourism. Due to the greater demand for timber, especially teak, a large share of the economic burden in forestry will be gradually shifted to plantations. With the application of time proven techniques and innovative modern methods, large-scale plantations are, therefore, being established on depleted forest lands, complementary to the main effort in natural forest management.

Keywords: Tectona grandis, Myanmar, sustainable natural forest management, annual allowable cut, plantation forestry, special teak plantations.

INTRODUCTION

In Myanmar, the forestry sector has contributed significantly to the country's total export earning and teak (*Tectona grandis* L. f.) from the natural forests, in particular, has been a major source of foreign exchange earnings for many years. After a century and a half of scientific and systematic management, the natural teak bearing forests of Myanmar are still in comparatively good extent and condition. However, due to unavoidable human interventions through shifting cultivation, agricultural expansion, illicit logging, etc. forest degradation is being experienced with decreasing production. Myanmar is, therefore, faced with the challenging task to restore its degraded forests and enhance the existing natural stock of teak not only by natural means but also artificial innovations. Teak as a plantation species, on the one hand, is a controversial issue as viewed from the ecological and biological standpoints, but on the other, when properly managed and provided with regular and timely silvicultural treatments has proved to be a species with high potential for commercial plantations in particularly suitable locations.

Sustainable development of natural teak forests, with the stabilization and promoting of their annual teak yield, is to be endeavoured as a national task. For the perpetual existence and enhancement of the values of natural teak bearing forests foresters, through different ages, have exerted great efforts by providing natural cultural treatments and establishment of teak plantations of different scales and objectives. However, the extent of natural teak forests is still reducing, the quality declining and the yield dropping leading away from the objectives of the efforts. Two obligations are realized with a view to reverse the situation and enhance the states of the natural forests. Firstly, effective protection and cultural treatments are further afforded for the existing natural forests together with the planting of teak on manageable scales in the natural forests to enrich the natural stock of teak without adversely effecting the existing ecological characteristics. Secondly, teak plantations have been established on an extensive scale in depleted areas to restore and replenish the natural forests while building up a new wood capital.

MANAGEMENT OF NATURAL TEAK FORESTS

Although the concept of sustained yield has been defined as early as 1792 and earlier forms of natural teak forest management actually started since the monarchial days it has been officially recorded that scientific forest management commenced back in 1856 when a well known management system was introduced by Dr. Dietrich Brandis. The management of natural teak forests in Myanmar was founded on this concept and had gradually evolved to what has eventually come to be known as the Myanmar Selection System (MSS). The MSS, an exploitation-cum-cultural system, has been the main silvicultural system practised in the management of natural teak bearing forests in Myanmar.

The system involves the adoption of a felling cycle of 30 years, prescription of exploitable sizes of trees, girdling of teak, selection marking of other hardwoods for felling, removal of less valuable trees interfering with the growth of teak, thinning of congested teak stands, enumeration of future yield trees and fixing of annual allowable cuts (AAC) for teak and other hardwoods.

Under the MSS, a Felling Series is divided into 30 blocks of approximately equal yield capacity. Each year, selection felling are carried out in one of these blocks and the whole forest is, therefore, worked over the felling cycle of 30 years. When felling becomes due, marketable trees that have attained fixed exploitable girth limits are selected for cutting. For teak, the girth varies with the type and status of the forests. In good (moist) teak forests, the girth limit at breast height is 73 cm dbh and in poor (dry) teak forests,it is 63 cm dbh. Exploitable limits are fixed at sizes beyond which trees are not expected to put on appreciable increment and their retention would only impede new regeneration. The fixed girth limit for other hardwoods other than teak varies with the species. However, it is not rigidly prescribed that all and only trees of the exploitable limits are selected for felling. Unhealthy trees that have not attained these exploitable sizes, but are marketable, are also selected for cutting if they are unlikely to survive during the subsequent felling cycle. If seed-bearers are scarce, a few high quality stems of and above the exploitable size maybe retained as seed trees. Trees left standing at the time of the selection are recorded, down to 39 cm dbh for teak, and10 cm dbh below the exploitable girth for other species. This provides a reliable basis for calculating the future yield.

Trees of exploitable size are selectively marked within the bounds of the Annual Allowable Cuts (AACs) carefully calculated for each Felling Series based on the principle of sustained yield management. Mature teak trees selected for exploitation are normally girdled and left standing for 3 years before being felled and extracted. This is to season the timber and make it floatable as logs are normally transported by floating down the steams and rivers. However, in more accessible areas, mature teak trees are sometimes also felled and extracted green.

The annual yield, or annual allowable cut (AAC), is determined from the following expression.

$$AAC = ARR + \frac{WS - \frac{1}{2} FC.ARR}{LP}$$

Where ARR=annual rate of recruitment

$$= \frac{\text{No. of trees within 1' girth class below exploitable girth limit}}{\text{Time of passage or number of years, required to pass into next girth class}}$$

WS = existing working stock (number of trees of exploitable girth and over)

FC = Felling cycle (30 years)

LP = Liquidation period

The AAC is revised periodically, in accordance with the existing stock. Before 1996, AAC for teak was prescribed at 609,500 m^3. The revised AAC is 409,062 m^3 with a reduction of about 200,000 m^3. However, the decrease in teak production is more than made up by the increased harvesting of other hardwoods which has always been, and is still being, underextracted. The current AAC for teak and other hardwoods are shown in Table (1).

Table 1. Annual allowable cuts

Tree species	No. of trees	Volume
Teak	124,213	409,062 cu.meters
Other hardwoods	1,795,424	3,236,071 cu.meters

Source: Planning and Statistics Division, Forest Department

CURRENT SITUATION IN NATURAL FOREST MANAGEMENT

In accordance with the prescriptions of the MSS, various kinds of silvicultural treatments such as improvement felling (IF) natural regeneration felling, thinnings in natural regeneration of teak (TNR), felling of 'nyaungbat' (ficus-bound teak tree), climber cutting, fire protection, etc. were carried out in order to improve the natural regeneration of teak, carefully protect the immature stock and assist it to attain a healthy maturity. The system is the best and only feasible way of working the multi-species complex teak bearing forests of Myanmar. It does not only laud itself well to work in a forest where there are close to a thousand tree species with only a few being extracted, but also achieve environmental harmony without causing ecological damage to the stand. However, the cultural and tending operations, in various degrees for a range of conditions, are essential and obligatory to assist the new regeneration brought about by the opening of the forests through extraction or other natural phenomena, i.e. mass bamboo flowering.

The enormous task to execute all these operations in the vast expanse of about 16.5 million hectares is a formidable and very difficult one, especially with limited staff and funds. Following the course of nature, natural stands which have been treated properly show that natural regeneration is capable of restocking the forest with more than double what it was after 30 years if efficiently assisted and controlled with sufficient amount of funds. The healthy state and regularity of stands can be attributed to the cultural operations given in the past. On the contrary it was observed that, in some insufficiently treated forest, for every yield tree extracted there remain only 1 to 5 trees of 40cm dbh and above in the forest while the norm at one time was that for every yield tree removed there should be at least 15 trees of and over 40cm dbh. It indicates that natural regeneration of teak is deficient even in the good teak forests if proper treatment is lacking or insufficient. The solution,

Table 2. Estimated volume of teak growing stock in 10 States and Divisions (1994-2001) Volume in m^3

States/ Divisions	Girth at breast height									Total
	2' 0" to 3' 11"(19-38 cm) dbh	4' 0" to 4' 11"(39 -47 cm) dbh	5' 0" to 5' 5"(48-52 cm) dbh	5' 6" to 5' 11"(53-57 cm) dbh	6' 0" to 6' 5"(58-62 cm) dbh	6' 6" to 6' 11"(63-67 cm) dbh	7' 0" to 7' 5"(68-72 cm) dbh	7' 6" to 7' 11"(73-77 cm) dbh	8' 0" + (78cm +) dbh	
Magway	372989	433529	232470	270118	255491	236730	164539	112573	314194	2392635
Mandalay	385470	385692	184892	200154	171866	139806	130339	111525	237094	1946841
Yangon	8002	2509	3657	4068	2678	1829	2661	2374	14170	41951
Shan	1378431	1364970	758050	636081	624022	418690	375293	276089	864308	6695934
Sagaing	2579682	2678758	1273375	1195800	1095259	1079408	817889	686335	1634370	13040926
Rakhine	84	168	-	-	-	471	499	-	-	1222
Kachin	711371	891889	566020	450238	456255	354624	232789	236059	616856	4516133
Chin	176303	125503	68058	43152	35678	42832	27876	18128	79160	616707
Bago	391276	380961	237671	202296	190341	139443	104371	61497	136018	1843874
Ayeyarwady	15000	6539	7108	5118	1742	7912	3498	4075	19003	70000
Total	**6018608**	**6270518**	**3331301**	**3007025**	**2833332**	**2421745**	**1859754**	**1508655**	**3915173**	**31166111**

Source: Planning and Statistics Division, Forest Department therefore, lies not in finding a replacement for the existing system, but rather, in seeing that as much of what have been prescribed are actually practised on the ground with adequate funds.

The volume of the growing stock of teak inventoried during 1994 to 2001 in the natural forests of 10 States and Divisions is shown in Table 2.

PROBLEMS IN FOREST MANAGEMENT AND POSSIBLE REMEDIES

Forest management in general, and teak management in particular, are faced with various constraints and problems. At present, timber extraction is concentrated only on a few species apart from teak, i.e. about 40 out of 460 species or different usable species available in the forests. This "creaming" of the forest, if not abated, might lead to the devaluation of the forests in the long run through the decrease of valuable species. The other main problems currently encountered are:

1. Encroachment in the forestland for agriculture, infrastructure, factories, and dwelling as the population increases.
2. Illicit cutting and logging of trees for commercial use.
3. Extension of pasture land for domestic animals.
4. Practicing of shifting cultivation.
5. Excessive utilization of firewood and charcoal for daily cooking and warming.

The Forest Department, adhering to the guidelines laid down by the Ministry of Forestry, is undertaking the following remedial measures to conserve the natural forests.

1. Timber harvesting is continuously being controlled and managed under MSS, as the system involves not only the exploitation of timber but also the cultural treatments in favour of better growth and natural regeneration of valuable species.
2. Application of the MSS is also favourable in that it causes the least disturbance on ecological and environmental conditions of the forestlands, and their biological diversity.
3. The adoption of a proper landuse policy is being planned for the effective and integrated utilization of the State land for the most benefit of the people with the least landuse conflicts.
4. To better affect the conservation of natural forests, forest reservation is being increased from 15 per cent of the total land area to 30 per cent. So far a permanent Forest Estate of 21 per cent of the total land area has been established.
5. Protection of the natural forests is better put to effect not only by legislative means but also through the participatory approach.
6. More community owned fuelwood plantations and forests are being established to ease pressure on the natural forest lands.
7. To reduce fuelwood utilization, wood fuel substitutes such as coal, agro-waste, etc. and fuel efficient stoves are being introduced and encouraged for use through educational programmes.
8. Increased utilization of previously lesser used species for specific purposes is being encouraged to conserve on the more valuable species such as teak.
9. Promotion of marketing without unnecessary increase in production is being afforded through down-stream processing and value added products.

PLANTATION FORESTRY

Apart from the production of uncomparable premier teak wood as naturally permitted within the bounds of the allowable cut based on the sustained yield concept and without detrimental effect on the conservation of the irreplaceable variety of diverse resources, the natural forests will continue their protective functions to ensure ecological stability, biodiversity richness, amelioration of weather condition, soil and water conservation, and services to facilitate cultivation, recreation and ecotourism.

It is clearly stated in the Forest Policy (1995) that natural forests in Myanmar will never be substituted by plantations. In fact, the Forest Department has been establishing forest plantations within the framework of this guide line. However, due to the decreasing supply from the natural forests and increasing demand for teak timber, it is anticipated that future teak production will come mainly from plantations and in Myanmar, a greater share of the economic burden in the forestry sector will have to be gradually shifted from the natural forests to plantations which are considered to be more economically viable in the light of an ever increasing demand for timber, especially teak.

BRIEF HISTORY OF TEAK PLANTATION IN MYANMAR

Plantation forestry is not really new to Myanmar and can be traced as far back as the year 1700 when teak was planted in the Paletwa area of the Chin State (FAO, 1956). In 1826, the formation of teak plantations was first recommended and, in 1841, rules drafted for the regulation of license for extraction of teak laid down that "for every tree felled and removed, five young teak trees of a proper size shall be planted by the license holder, or by Government at the expense of the former. However, concessionaires were not observing their bound obligations of establishing plantations as required by the law and only a little effort was made to carry out the rules.

The first recorded attempt at teak plantation by *taungya* method was made in 1856, the same year scientific forest management was introduced for the natural teak bearing forests of Myanmar. *Taungya* plantation was the idea conceived by Dr. Brandis during an excursion made in the Pegu (Bago) forests. The idea slowly caught up and the first large-scale teak plantations made in the Pyay Forest Division had attained a total area of 310 ha in 1868, and increased to 1370 ha by 1876. However, plantations in those days hardly exceeded 40 ha at one particular stretch and were established more with a view to increase the natural stock of teak rather than to create fully stock stands. They were practised to supplement or compensate for the natural regeneration of teak in the natural forests and were termed compensatory planting. In the concept of compensatory planting, silvicultural treatment, particularly thinning, was done up to the age of 40 years and after heavy thinning, planted areas were treated as natural forests and placed under the improvement felling schedules. When felling became due in accordance with the 30-year felling cycle of the MSS, marketable trees of exploitable size were selected for extraction as in all natural forests managed under this system.

By the turn of the century, the unsystematic ways in which plantation had been formed became the subject of considerable criticism and plantation forestry had its ups and downs in the following decades. It was not until the early seventies when Forest Department could successfully convince the higher authorities that 'for every forty tons of timber extracted from the forest, one acre of plantation should be established so as to make up for the exploitation of the past and build up a wood capital for the future'. A wood capital of 40 tons per acre was the merchantable volume of timber available at the rotation age of 80 years of teak plantation of average quality (Site Quality III).

ESTABLISHMENT OF TEAK PLANTATIONS IN MYANMAR

Extensive teak plantations in large blocks have been established since the early 1980's. It started with an annual target of 6200 ha in 1980 increasing gradually, and reached a peak of 14,745 ha in 1990 after which it slightly tapered down. The exact area to be planted each year is not rigidly fixed, but decided annually in accordance with the prevailing conditions and annual capacity of the States and Divisions giving them enough time for preparation before the planting season. The adoption of a 60-year rotation for normal teak plantations marked a significant change from the old procedures. It is expected that teak planted on locations with Site Quality II will reach about 46cm dbh at the rotation age. However, though teak planting is to be concentrated in good site classes for maximum production, its other objective is still to reclaim degraded or denuded teak natural habitats some of which may have reduced carrying capacity. Table 3. indicates teak plantation areas planted up annually up to 2002 in comparison with other species. It shows that the annual planting has increased from 135 ha in 1963 to 13,000 ha plus in the 1990's and 2000's.

SPECIAL TEAK PLANTATION PROGRAMME

Initiated by the Ministry of Forestry with the approval of the Government's Implantation Committee on special project, a special teak plantation programme was formulated by the Forest Department in 1998. Complementary to the extensive normal plantation scheme the special intensive programme is based on

Table 3. Teak plantations by year in Myanmar (in hectares)

Year	Teak	Others	Total	Year	Teak	Others	Total
1896-1941	36930	10237	47167	1983	11826	15785	27611
1948-1962	1230	692	1922	1984	11799	19017	30816
1963	135	606	741	1985	10839	25502	36341
1964	321	1312	1633	1986	10975	21971	32946
1965	773	1943	2716	1987	11554	20754	32308
1966	736	1717	2453	1988	11540	18376	29916
1967	1206	2272	3478	1989	10136	8593	18729
1968	1609	2177	3786	1990	14745	15953	30698
1969	1188	1691	2879	1991	14718	16316	31034
1970	1328	1881	3209	1992	13903	17682	31585
1971	1021	1751	2772	1993	10771	20239	31010
1972	745	2405	3150	1994	4709	18117	22826
1973	887	1836	2723	1995	9207	23231	32438
1974	859	1707	2566	1996	10874	21322	32196
1975	913	2161	3074	1997	12304	27586	39890
1976	1024	2101	3125	1998	14630	14019	28649
1977	1435	2186	3621	1999	14391	16323	30714
1978	1785	2519	4304	2000	12962	17732	30694
1979	2592	4139	6731	2001	12939	17817	30756
1980	6201	7294	13495	2002	13011	18304	31315
1981	8693	8554	17247	Total	319953	447545	767498
1982	10508	11727	22235	Percentage	42%	58%	100%

Source: Planning and Statistics Division, Forest Department, Myanmar

past experiences and within the context of international guidelines and conceptual framework on planted forests. It has been undertaken since with emphasis placed primarily on increasing timber production and overcoming the environmental impasse imposed by forest plantations.

The special teak plantation programme with a time span or rotation of 40 years is structured with a series of 8 consecutive phases. Each phase, with a duration of 5 years, accommodates 20 plantation centres. Felling-cum-Regeneration plan for the 5-year period is prepared for each centre and harvest by clear cutting, and replanting, will commence at the end of a rotation of 40 years. Each centre has an annual planting rate of 1000 acres (405 ha) and by the end of the first 5-year phase, a total of 100,000 acres (40,500 ha) would be planted up at the 20 plantation centres. A grand total of 800,000 acres (324,000 ha) of teak plantations would be established by the end of the 40-year rotation after which 20,000 acres (8100 ha) will be available annually for harvesting from the 20 centres.

The plantation centres are located in the natural teak habitats of the Sagaing, Mandalay, Bago (East and West), Magway, Yangon and Ayeyawady Divisions. The special teak plantation programme is peculiar in having characteristics like higher financial inputs, better care in the selection of planting sites, due attention to site preparation, use of superior genetic sources for planting, application of fertilizers where necessary and better soil working, pruning and a more determined protective effort against illegal human intervention, pests, diseases and the destruction of uncontrolled forest fires. Establishment of special teak plantations during the first 5-year phase (1998-99 to 2002-2003) is shown in the Table No 4.

The distribution of the plantations has been expanded from the original 20 to 31 centres as a modification and adjustment to the availability of required site quality, labour and to further minimize large scale monoculture effects.

To avoid environmental and ecological impasse blocks of single plantations are no larger than 250 acres (100 ha) with breaks of natural forests in between, or so arranged that adjacent blocks are planted alternately to avoid extensive clearing. Emphasis is also placed on interplanting of soil-improving and fast growing medium-sized trees as secondary storey to minimize monocultural effects

Table 4. Details of special teak plantations (1998-99 to 2002-2003) in Myanmar

Sr. No.	Division	Area establishment (Acres) 1998-99	1999-2000	2000-2001	2001-2002	2002-2003	Total
1.	Sagaing	1,000	1,000	1,000	2,000	2,000	7,000
2.	Mandalay	3,000	3,000	3,000	3,000	3,000	15,000
3.	Magway	4,000	4,000	4,000	3,000	3,000	18,000
4.	Bago (East and West)	9,000	9,000	9,000	9,000	9,000	45,000
5.	Yangon	1,000	1,000	1,000	1,000	1,000	5,000
6.	Ayeyawady	2,000	2,000	2,000	2,000	2,000	10,000
	Total	**20,000**	**20,000**	**20,000**	**20,000**	**20,000**	**100,000**

Source: Planning and Statistics Division, Forest Department, Myanmar

of teak plantation and also to meet the needs of the local communities. Community participation is also encouraged as the indigenous age-old but cosmopolitan and 'evergreen' *taungya* system is revitalized and promoted through provision of incentives such as adequate social welfare and loan credits for purchasing seeds and other basic needs.

To attain maximum production it has clearly been instructed that the special teak plantations are to be located on sites with quality level no less than site quality II/III. Provided that the plantations are established on ideal locations of site quality I/II the Forest Department estimated that, after the year 2038, a sustainable annual production from the annually available 20,000 acres of special teak plantation would be as high as 1.3 million cu.tons (1.8 million m^3).

This is an enormous quantitative improvement compared to the Annual Allowable Cut of 292,200 Cu.tonnes (409.062 m^3) for teak from the natural forests of the whole country. If locations of no less than site quality II/III are available as anticipated in accordance with the selection procedures, the realistic annual production estimated would still be anywhere between a conservative 408,500 Cu.tons (572,000 m^3) and a more ambitious figure of 664,300 Cu.tonnes (930,000 m^3). This does not even include the earlier returns that can be realized from the intermediate yields from thinnings.

GENERAL IMPROVEMENTS

Apart from quantitative improvement, a long standing concern about plantation teak is quality. Genetic heredity and environmental factors have great influence on the growth and quality of teak and in Myanmar, only teak of genuine genetic heredity are used as planting materials in their own natural habitats that have carried and produced teak wood of premier quality for many years. A rotation of 40 years is expected to give the plantation stocks enough maturity which to a large extent also dictates quality.

Other measures of improvement taken by the Forest Department are:

- Improved planting materials in the form of potted seedlings have generally replaced the traditional direct seed sowing and stump methods.
- Seed production areas (SPAs) are the back-bone of Myanmar teak improvement for the immediate future. The establishment of SPAs was initiated in early 1990 by the East Bago Yoma Project and revitalized by the Forest Department in 1996. Natural stands as well as plantation plots of at least Site Quality III, having a minimum area of 6 ha. with trees no younger than 15 years or older than 45 years, have been selected and converted to SPAs. To date about 2140 ha of SPAs have been established in Myanmar.
- Clonal seed orchards (CSOs) have been established with a view to facilitate the long term teak improvement objective. 33 clones were collected from selected plus-trees in the teak-bearing forests and set up in two CSOs in the Bago and Mandalay Divisions in 1981. A CSO of 34 ha was established in a research station in the Bago Yoma with a second, of 6 ha, located at a research station in Yamethin District, Mandalay Division. Seed collection from the CSOs and germination tests have been conducted by the Forest Research Institute. In addition, the Institute plans to develop more seed orchards with 60 clones as part of its

tree improvement programme and an expansion of clonal teak plantations based on seeds and cuttings of proven progenies from the two CSOs is being anticipated.

- The vegetative propagation methods commonly practised are the traditional as well as more recently developed methods of branch and bud-cuttings. Cuttings from selected mature teak trees are used for the establishment of CSOs and multiplication gardens. Appropriate techniques to produce large-scale cuttings from 6-month-old teak seedlings have also been developed and practised.
- Tissue culture, which had been attempted intermittently for many years due to its high cost and Myanmar's reliance on its seed supply from the natural forests, have finally been successful after a determined effort. However, further development of the method is necessary before a wide application is extended to the planting programmes. Tissue-cultured plantlets, at present, are planted out for experimental purposes only.
- Teak hedge or multiplication gardens, so far of small scale, are established in all the Divisions which are involved in the special teak plantation programme using vegetative cuttings from selected plus trees.

CONCLUSIONS

In Myanmar the state's economy, together with the social system, employment and economy of the rural communities, depends largely upon the natural teak bearing forests. Due to the economic requirements of the state, the extraction of teak and other hardwoods will continue well into the coming decades. Although a systematic harvesting plan has been formulated under the MSS there are problems and difficulties in adhering precisely to the cyclic regulation of the system. Furthermore, due to the increase in population and demand on forest products and land for agriculture, unauthorized human interventions in the forms of shifting cultivation, agricultural expansion, illicit logging, etc. have resulted in forest depletion and degradation with declining production, especially of teak.

Myanmar, in its effort to restore its degraded natural forests and enrich the existing ones, has two complementary obligations realized with a view to reverse and improve the situation. Effective protection and cultural treatments together with compensatory and enrichment plantings are being afforded within the natural forests to restore and enhance the natural stock of teak while teak plantations of extensive scale are being established in depleted natural teak habitats to replenish the natural forests and enlarge the wood capital. An increase in forest area under plantations may also reduce pressure on the natural forests and revive the opportunity to regulate precisely the felling cycle as prescribed in the management system.

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Malaysian Experiences in Timber Certification

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ABSTRACT

MTCC is an independent organisation established to operate a voluntary national timber certification scheme in Malaysia. It is governed by a Board of Trustees comprising of representatives from various stakeholder groups. The MTCC scheme began its operation in 2001, in a phased approach. The standard currently used for assessing Forest Management Units (FMUs) is the MC and I, which is based on the ITTO criteria and indicators. For the next phase, MTCC will use new standards developed through multi-stakeholder consultations using the Principles and Criteria of the Forest Stewardship Council (FSC) as the template. The standard for chain-of-custody certification is the *Requirements and Assessment Procedures for Chain-of-Custody Certification*. Two types of certificates are issued; currently three FMUs have been awarded the *Certificate for Forest Management*, while 29 companies have received the *Certificate for Chain-of-Custody*. By the end of June 2003, about 2,457 m^3 of MTCC-certified sawn timber have been exported. The external and internal challenges faced by MTCC in implementing the certification scheme as well as the main impacts of the scheme are highlighted. A significant area of Permanent Reserved Forests has now been independently assessed, providing valuable information about the current status of forest management, including aspects which need improvement. It is hoped that the phased approach taken will be accepted by the markets in order to encourage the efforts being made towards sustainable forest management in Malaysia.

Keywords: Malaysian timber certification, sustainable forest management, MTCC-MC and I-phased approach, consultation, stakeholders, challenges, impacts.

INTRODUCTION

The forest-based industries, in particular the timber industry, contribute significantly to the Malaysian economy and is a major source of foreign exchange apart from providing employment to about 337,000 employees. Timber exports from Malaysia reached USD 4.0 billion in 2002. In view of the importance of the export market to the timber industry, Malaysia's involvement with timber certification started in 1996 with a pilot study carried out in cooperation with the Keurhout Foundation in The Netherlands. The experience led to the formation of the Malaysian Timber Certification Council (MTCC) in 1999 as an independent organisation to develop and operate a voluntary national timber certification scheme in Malaysia. MTCC is governed by a Board of Trustees comprising representatives from the key stakeholder groups i.e. timber industry, non-governmental organisations (NGOs), academic and research institutions and government agencies.

OPERATION OF MTCC TIMBER CERTIFICATION SCHEME

The MTCC timber certification scheme began operation in October 2001 using a phased approach. The standard currently used for assessing Forest Management Units (FMUs) for the purpose of certification is the Malaysian Criteria, Indicators, Activities and Standards of Performance for Forest Management Certification (MC and I) which is based on the 1998 ITTO Criteria and Indicators for Sustainable Management of Natural Tropical Forests.

It contains the key elements for sustainable forest management covering economic, social, environmental and conservational aspects.

For the next phase of its certification scheme, MTCC will use a new standard that has been developed through multi-stakeholder consultations under the National Steering Committee (NSC), using the Principles and Criteria of the Forest Stewardship Council (FSC) as the template. The standard for chain-of-custody certification used by MTCC is the Requirements and Assessment Procedures for Chain-of-Custody Certification (RAP/COC).

Overview of MTCC Scheme

The MTCC timber certification scheme is summarised in Figure 1. As the timber certification body, MTCC receives and processes applications for certification, arranges for assessments to be carried out by its registered independent assessors, and decides on all such applications, based on the report of the assessors. The assessment report for forest management certification will be subject to a peer review process by qualified individuals who are registered with MTCC for this purpose. MTCC also provides an appeals procedure, should there be parties which are not satisfied with its decisions.

MTCC has established a Certification Committee which is responsible for considering assessment reports submitted by independent assessors on applicant FMUs and timber product manufacturers/exporters. Based on the recommendations of the assessors, the Certification Committee will make the decision whether the applicant merits the award of the MTCC certificate. Under the MTCC certification scheme, two types of certificates are issued. The

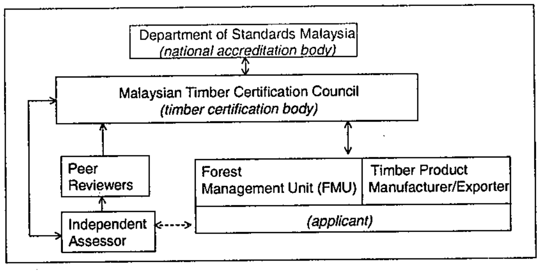

Figure 1. MTCC Timber certification scheme

Certificate for Forest Management is issued to FMUs which have complied with the requirements of the forest management standard (MC and I), while compliance with the chain-of-custody standard (RAP/COC) will qualify timber product manufacturers or exporters for the Certificate for Chain-of-Custody.

To date, three State FMUs (Pahang, Selangor and Terengganu) in Peninsular Malaysia covering a total of 2.31 million hectares of Permanent Reserved Forests have been awarded the Certificate for Forest Management. This Certificate provides the assurance that the Permanent Reserved Forests in these three State FMUs are sustainably managed to the requirements of the MCandI, and the timber is harvested legally. The remaining five timber producing State FMUs in Peninsular Malaysia (Johor, Kedah, Kelantan, Negeri Sembilan and Perak), which account for 2.50 million hectares of Permanent Reserved Forests, were first assessed in 2001 and 2002. These State FMUs have recently been re-assessed to verify the actions taken to address the Corrective Action Requests (CARs) issued during the assessments, and the results of the verification exercise are expected to be known soon. In addition, arrangements for a pre-assessment of an FMU in Sarawak are at the final stages.

As at July 2003, 29 timber companies have been awarded the Certificate for Chain-of-Custody. This Certificate provides the assurance to buyers that the MTCC certified timber products supplied by these companies originate from the certified State FMUs mentioned above. The MTCC certificates are valid for a period of five years. Certificate holders will be subject to regular surveillance visits by assessors during the period of validity, to ensure that they continue to comply to the requirements of the relevant standards.

EXPORT OF MTCC-CERTIFIED TIMBER PRODUCTS

Following the operation of the MTCC scheme, the first shipment of MTCC-certified timber was exported in July 2002, and by the end of June 2003, a total of 2,457 m^3 of MTCC-certified sawn timber have been exported to The Netherlands, Germany, Belgium and the United Kingdom.

As a result of promotion programmes for the MTCC certification scheme, a number of authorities and companies have shown interest in accepting MTCC-certified timber products. For example, the Danish Ministry of Environment and Energy has agreed to include the MTCC scheme as one of the accepted schemes in its guidelines for procurement of timber products while the Hamburg City authority is considering a conditional recognition of the MTCC scheme for the same purpose.

CHALLENGES

External challenges

Forests are complex and dynamic ecosystems which perform multiple functions. There are therefore many different viewpoints regarding what constitutes good or sustainable forest management. This has led to the establishment of a number of timber certification schemes or systems. The FSC scheme was the first scheme established in 1993 with support from the leading environmental NGOs [Worldwide Fund for Nature (WWF), Greenpeace, Friends of the Earth]. Currently a total of 36.6 million ha of forests world wide have been certified under the FSC scheme.

The other large scheme currently in operation is the Pan European Forest Certification (PEFC) scheme, which has certified a total of 46.6 million ha of forests in Europe. In such a situation with key markets, and a number of competing timber certification schemes, the national schemes, especially those from developing countries such as the MTCC scheme, face great difficulty in gaining acceptance in these markets.

This difficulty is further compounded by the formation of buyers' groups by private sector companies, such as importers, DIY stores and other retailers, in these markets for timber products. These buyers' groups have indicated their preference for purchasing FSC-certified timber. In addition, the public procurement policies of some national and sub-national governments in many key timber importing countries either disallow the use of tropical timber or accept only FSC-certified timber.

The existence of a number of certification schemes which use different sets of criteria and indicators has been a cause for concern and there are initiatives aimed at establishing an international framework for mutual recognition between credible certification schemes so as to reduce the potential for market confusion. However these initiatives have so far not made much progress.

Internal challenges

Within Malaysia, the different expectations and viewpoints among the various stakeholder groups on what is sustainable forest management has posed challenges to MTCC in its efforts to implement timber certification.

As a certification organisation, MTCC needs to use a forest management standard which is agreed among the main stakeholder groups in Malaysia related to forest management. These stakeholder groups are the forest managers, environmental organisations, timber industry associations, organisations representing local communities, workers' unions, academic/research organisations and government agencies. For this purpose, MTCC has initiated and coordinated efforts to develop such a standard, involving consultations among the stakeholders at regional and national levels. In this process, there has been misunderstandings on a few aspects, such as:

i. the relationship between MTCC and the standard which it is trying to develop through the multi-stakeholder consultation process;
ii. the fact that the performance standards should be discussed and agreed among the stakeholders, with MTCC being a neutral party; and
iii. that the requirements included in the standard should respect the laws of the country or state (under the Malaysian Constitution, forestry is under the jurisdiction of the State Governments).

This has unfortunately led to a boycott of the standard development process by some social NGOs representing the local communities, and their refusal to return to the process despite appeals made to them. These NGOs then alleged that the consultation process has ignored the interests of the local communities, and have circulated their allegations to seek international support and to criticize the MTCC scheme. Nevertheless, through the participation of other organisations which represent the local communities, the interests of these communities in relation to forest management have been taken into account in developing the standard.

IMPACTS OF TIMBER CERTIFICATION

Based on the experience gained from the assessments of FMUs in Malaysia, the following observations regarding the impacts of timber certification on forest management practices can be made:

i. **Need for holistic approach to forest management**: It is now generally recognised that forest managers have to take a more holistic and integrated approach towards forest management, so as to take into account the economic, environmental and social dimensions of forest management in a balanced manner. In the local context, the forest managers will have to look beyond fulfilling just the requirements of the forestry department. They will now have to consider the other aspects such as the monitoring of rare, endangered and threatened species of both forest flora and fauna, water quality, and the participation of NGOs and local communities in forest management, particularly at the planning stage.

ii. **Involvement of more stakeholders in forest management process**: As a consequence to recognising the need for a more holistic approach to forest management, there is increasing recognition on the part of the forest managers of the need to engage in consultations with a wider group of stakeholders in developing and implementing forest management plans. This is also reflected in the involvement of the various stakeholders in the regional and national-level consultations coordinated by MTCC to develop the *MCandI*, and similar efforts by the multi-stakeholder NSC in developing the new FSC-compatible *MCandI*.

iii. **Need for closer monitoring**: The assessments carried out have highlighted the need for closer monitoring by the forest managers to ensure that all regulations, guidelines and procedures are properly and effectively implemented according to approved plans, together with proper documentation.

iv. **Need for training**: The assessments have also pointed to the need for the forest managers and their field staff to be very familiar with the requirements of the *MCandI* and be able to demonstrate their compliance in the field, when an assessment is carried out by the independent assessor.

Timber certification also has impacts on research activities related to forest management since research is one of the key activities to generate the data and information needed to improve forest management practices once they have been translated into operational guidelines and procedures that can be used in the field.

The Corrective Action Requests (CARs) issued during the assessments of the FMUs so far provide an indication of the areas of non-compliance or those that would require further strengthening with more research inputs (Chew and Harnarinder, 2001) such as:

i. Cost-effective and practical technologies and techniques for reduced impact logging (RIL) have to be determined that can be applied in the field, especially for harvesting activities at higher altitudes or in steeper areas;

ii. Assessment of current harvesting prescriptions for protecting water quality;

iii. Cost-effective and practical methods to monitor water quality in logged-over forest areas have to be developed for use in the field;

iv. Procedures to identify endangered, rare and threatened species of forest flora and fauna, and cost-effective ways to monitor and protect them;

v. Research on the implementation of current prescriptions for sustained yield within predetermined harvest levels and cutting cycles has to be carried out to determine their efficacy in terms of meeting the set objectives under the management system.

vi. Procedures to monitor growth, composition and structure of residual forest stands. Issues pertaining to logging damage threshold levels, number, size and species of retention trees, impact of logging and other operations, and growth parameters have to be addressed so as to provide support to the concept of sustained-yield;

vii. Developing cost-effective and operational methods to monitor changes in forest biodiversity in logged-over areas; and

viii. Determining appropriate level of participation of local stakeholders in the forest planning and management processes. The current expectation is that the formulation of forest management plans requires the inputs of all stakeholders, particularly the NGOs and local communities living in the vicinity of the FMU. However, the translation of this expectation into pragmatic and cost-effective procedures may require appropriate research programmes.

CONCLUSIONS

With the assessment of all eight timber producing State FMUs in Peninsular Malaysia, a significant area of Permanent Reserved Forests has now been independently assessed under the MTCC certification scheme. These assessments have provided valuable information about the current status of forest management in Malaysia, including aspects which need improvement.

Nevertheless, in the current situation where a number of different timber certification schemes are operating in the market, national schemes such as MTCC and its certified products face challenges in gaining acceptance from the international market. MTCC has therefore taken action to overcome this challenge by cooperating with other schemes such as the FSC and PEFC, as well as supporting efforts towards establishing the mutual recognition framework. MTCC has in fact become a member of the PEFC Council since November 2002. In addition, MTCC has played an active role in the formation of an *Ad-Hoc* Working Group which is working towards the establishment of a Pan ASEAN timber certification scheme in order to encourage cooperation among certification schemes in ASEAN countries.

It is hoped that the phased approach taken by MTCC in implementing the Malaysian timber certification scheme can be accepted and supported by the markets which are looking for certified timber products, in order to encourage the efforts which are being made towards sustainable forest management in Malaysia.

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Certification and Labelling of Teak Wood Products with Special Reference to Opportunities and Challenges in India

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ABSTRACT

Certification and eco-labelling of wood products are hotly debated with the contentious issues in the current global wood trade and forest management scenario. In general, developed countries perceive that certified wood offers assurance to buyers not contributing to forest destruction or illegal logging, and to the forest industries for an opportunity not to be seen by the general public as the main cause of (forest) destruction by promoting responsible production and use of raw material resources. On the other hand, many developing countries regard certification as an impediment to trade and is an attempt by the developed countries to impose their views. Despite the endless arguments, apprehensions and doubts, forest certification is expanding, and the global Forest Stewardship Council (FSC) - the leading certification body - is implementing a strategic action plan to bring 30per cent of the world's forest under certification to FSC standards by 2007 and increase to 15per cent the share of the global roundwood market held by these forces. This, despite the fact that experience so far indicates that the original concept (of say, envisaging "green premiums" where consumers are expected to pay extra amounts to products from forests managed in an environmentally friendly manner) has evolved and shifted considerations. Mass markets for certified forest products are yet to emerge, but niche and regional markets have developed in the USA, Europe and Canada, and the demands are growing. India, being a member of the International Tropical Timber Organization (ITTO) and signatory to CBD and other International Conventions, has already developed criteria and Indicators (C and I) for sustainable forest management through the Bhopal-Indian Process (1988) which is being tested and evaluated. In this presentation, an attempt is made to examine the opportunities, constraints and apprehensions concerning timber certification and its labelling in India, with special reference to teak.

Keywords: Indian market, 'green' wood products

INTRODUCTION

Timber certification is a relatively new concept. Although doubts persist as to what it actually means, the general assumption is that a certified wood product is a guarantee that it has been produced in a sustainably managed forest. It is a trade related instrument originally aimed at enhancing market access and competitiveness of timber companies targeting especially the "green consumers" - a growing "niche" market segment. For Wood products to be "certified" under a globally accepted Forest certification scheme (eg. Forest Stewardship Council - FSC), tracking the wood from the retailer through the processing chain to its original certified source through each stage of production, distribution and to the point of sale is required. This verification process is known as Chain of Custody (COC) certification. COC requires that organizations establish a system that create a paper trail demonstrating certified materials are kept separate from non-certified and can be tracked to maintain their identity throughout the manufacturing and distribution processes. An assesser will assess the COC system before a certificate of compliance is issued. Apart from verifying the system of segregation (between certified and non-certified wood) in the organization, the assesser also verifies inventory, storage, labelling records from receiving of raw material until delivery of finished products. Organisation are subject to annual surveillance audit in order to ensure continuous system (Anon., 2003).

Labelling: Products originating from forests certified by accredited certification bodies are eligible to carry logos to indicate that they originated from a well managed forest. Accreditation is done by an accreditation authority, eg. FSC and is required to give certification bodies credibility with regard to their procedures and quality of assessment. Accreditation acts as a higher body that ensures that every certification body plays by defined rules to provide confidence in the market place. The accreditation body licenses or franchises certification bodies to operate provided they follow the defined rules. The main elements required for accreditation are:

i. Independence of the certification body;
ii. Certification procedure and
iii. Professional skills

All accredited certification bodies may operate internationally and carry out evaluations. Their performance is monitored by the accreditation authority (Anon., 2003).

In any analysis of the opportunities for production or promotion of trade in 'certified wood' in India in general and certified teak wood products in particular, it is important to examine the broader issues central to certification like Forest Certification (FC) itself, current certification processes, market outlook for wood and wood products, and the challenges wood faces and the concepts of sustainability and sustainable communities. This paper attempts to relate these and other relevant issues to the challenges in production of quality wood products of teak from sustainably managed forests.

FOREST CERTIFICATION

The broader issue central to timber certification is Certification of Forest itself. The Forest Certification (FC), even after a decade of its introduction, is a subject of intense and ongoing debate and many unresolved issues and ambiguities still exist. Worldwide, there are many FC schemes and considerable variation in assessment criteria and consultation. Examples include the global Forest Stewardship Council (FSC), the Regional (aiming to become global) Pan European Forest Certification Scheme (PEFC) and several National schemes like the Malaysian timber Certification Council (MTCC); Indonesian Eco-labelling Institute (IEI); the American Tree Farm System (ATFS), Sustainable Forestry Initiative (SFI), USA; the Canadian Stewards Association - CSA; and those found in Brazil, Ghana and forests covered by Keurhout declaration etc. Comparisons of different schemes can be found in Kanawski *et al.* (1999), Fletcher and Hansen (1999), Gray (2000), Palmer (2002), *etc.* The standards widely accepted for FC are those laid down by Forest Stewardship Council (FSC), an international body that introduced labelling schemes for forest and forest products to provide a guarantee that the products came from well managed forests. The FSC's principles and criteria (P and C) apply to all tropical, temperate and boreal forests. Many of these also apply to plantations and partially replanted forests. The P and C covers three main issues related to timber resources, forest ecosystems and social aspects. Due to diversity of forestry situations, and local needs, it is recognized that any international standard has to be adjusted to suit local situations. Efforts are being made to make such adjustments through national initiatives by all stakeholders and the certification body itself.

Despite diversity of opinions and a lack of, clear consenses on many issues, Forest Certification is expanding steadily. Certified forest area in 2002 is estimated to be 109 million ha. Worldwide, that is almost 'four times more than it was two years ago and twice the level of a year ago. (Eba' Atyi and Simula, 2002). However, the certified forest area is distributed unevenly. More than half is located in Europe and almost 40 per cent in North America. Developing countries account for no more than 8 per cent. It is to be noted that the imbalance has changed over time - for example in 1996, the share of developing countries in the total was 70 per cent. (Baharuddin and Simula, 1996). For many reasons, FC is much more difficult to achieve in natural forests in the tropics than in temperate forests and plantations. Tropical timber producers are concerned with aspects like the high standards of certification; inflexibility of these standards which tend to focus on the end results of Sustainable Forest Management (SFM) practices without recognizing the stages on the way to SFM; expected increase in production costs; illicit felling, difficult to meet market requirements; acceptability of the national certification schemes of developing countries in major certification demanding markets, etc. Certification is therefore, perceived as imposing a greater burden in tropical situations and the efforts to implement SFM are far from definitive.

Nevertheless, due to the support of organizations like ITTO (International Tropical Timber Organisation) which is committed to promote trade of tropical timber based on sustainably manged forests through its objective 2000, and other International bodies, tropical countries like Malaysia, Indonesia, Brazil are pursuing ahead with certification efforts, through National initiatives. India's initiative towards SFM is through its 'Bhopal-India Process, 1999' under which 8 criteria and 51 related indicators are identified, through a wide ranging stakeholder participated processes (IIFM, 1999).

In addition to the efforts to develop C and I at the National level, C and I also are developed for smaller units by other organizations (eg. C and I for the forest management unit level on several countries developed by the Center for International Forestry Research (CIFOR), including plantation forestry (for teak and Eucalyptus) in India (Sanker *et al.*, 2000).

CERTIFICATION PROCESSES

Under the FSC scheme, it may be noted that forest and timber certification is divided into forest management and 'chain of custody' as detailed above, and summarized in Table 1. The main phases of Forest Management and timber certification processes also depicted in Fig.1. The Forest Management scheme are aimed at ensuring that forest management practices meet a required set of standards set out by a certification programme, while the COC ensures that the wood sold in the market actually is sourced from 'well managed, certified forests'.

The main phases of Forest management and chain of custody certification processes are depicted in Fig. 1 and 2 Different labeling schemes may have different rules for allowing a label to be applied to the product.

In India, IMO Control Pvt. Ltd. (Institute for Market ecology) has been accredited by the FSC and SIS (Swiss Inspection Service) to issue FSC certificates for forest management and chain of custody. IMO was founded in 1989 and is accredited according to the European norms EN 45004 for inspection, EN 45011 (corresponding to ISO 65) for ecological products and according to the EEC regulation 2092/91. Through its office in Switzerland, Germany, Turkey, Bolivia, Egypt and India, IMO is active in over 50 countries. An independent body of representatives, of the authorities, consumers and producers supervise the activities of the Institute.

Table 1. Details of FSC scheme divided into forest management and chain of custody

Scope of Certification		Clients and requirements
FM	**Forest Management**	Forest owners, resource managers (concession); natural forests and plantations (older than 1994)
	Characteristics:	Sustainability of forest management, protection of species and habitats, acceptance of all social regulations, promotion of naturally established species and natural dynamics, non-use of specific types of pesticides or fertilizers.
COC	**Chain of Custody**	Sawmill, carpentry, joinery, chipboard industry, wood construction, production of furniture, cellulose, paper and cardboard, do-it-yourself, etc.
	Characteristics:	Separation and identification of certified material from uncertified, complete documentation of product flow, correct book keeping system, labeling according to FSC requirements.

Source: Institute for Market Ecology (IMO) Control

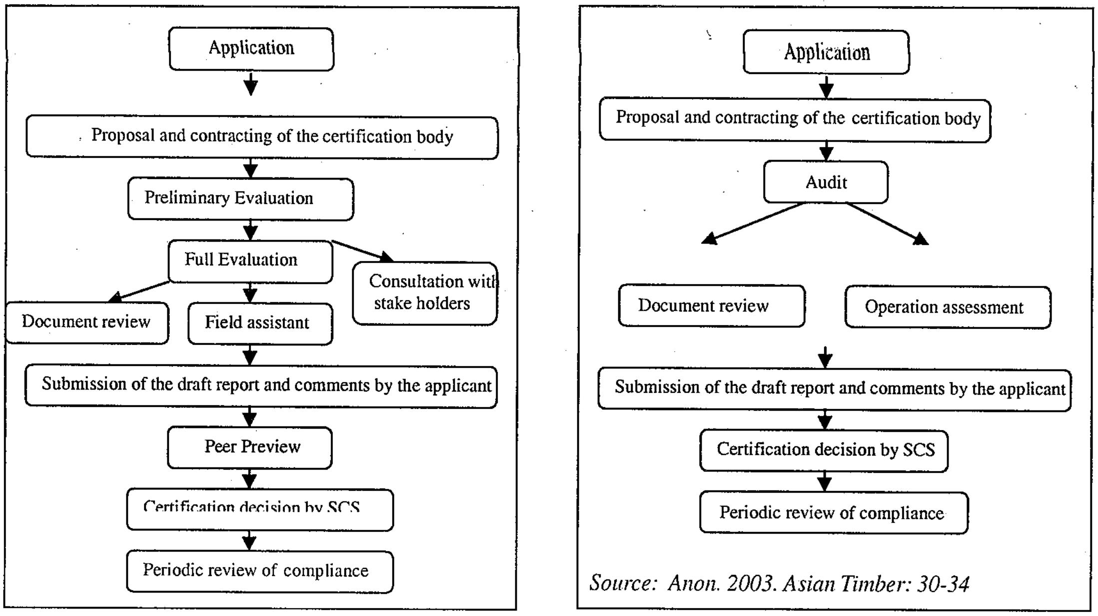

Figure 1. Main phases of forest management and timber certification process

Besides Forestry, IMO deals with certification in agriculture and textiles.

MARKET OUTLOOK FOR TIMBER AND CERTIFIED PRODUCTS

The market outlook for timber, in general appears to be favourable based on the growth in global production and consumption trend. In 2001, the world trade in timber comprising industrial round wood, sawn timber, wood-based panels together amounted to approximately US \$ 45.7 billion with an export volume of 300.3 million m^3. The two major developed regions namely, North America and Europe dominate the worlds' timber trade both in terms of exports and imports except plywood where developing countries such as Indonesia (31.5%) and Malaysia (15.7%) were dominant. FAO studies also indicate that the world timber trade has moved from upstream products (eg. logs) towards more downstream, value-added, processed timber products such as furniture and builders, carpentry and joinery products in the last decade. It is expected that world trade on these products will continue to grow annually at an impressive rate of 9 to 10 percent. In 2000, the world's total export of value added tropical timber products amounted to approximately US \$ 5.5 billion and is expected to increase to US \$ 6.6 billion by 2003. eighty per cent of these exports are currently contributed by the Asia-Pacific countries, while the balance is from Latin America (Dato Ismail, 2002).

MARKETS FROM CERTIFIED TIMBER AND LABELED TIMBER

Reliable estimates of total volume of timber available in the market from certified forest areas are not available. It is generally believed that only 5 per cent of wood from certified forests comes into market because of lack of chain of custody verification (Karl Buechal - In a presentation at Bangalore in 2002). Much of the current demand is from Europe, USA., Canada, Australia, New Zealand, etc. Major timber retailers promoting marketing of certified timber and timber products worldwide include Home Depot, Lewis and Nike in the USA, IKEA in Sweden, B and Q in the United Kingdom, OBI in Germany, Intergamma in the Netherlands, etc. Some of the companies like IKEA have begun operations in India. Indications are that, though not extensive at this stage, markets for certified timber are growing. It is however, a premium market aimed at increasing the base among green consumers who are willing to pay higher prices for environmentally friendly products. How much more these customers are willing to pay? A survey of consumers, architects and retailers by Ozanne *et al.*, (1999) indicated that some groups are willing to pay even upto 22 per cent of more for certified wood products. (Hock and Hay, 2003). This may not, however, always be the case.

COMPETITION FOR CERTIFIED WOOD

Certified wood in the market and indeed SFM compete not just with conventional market forces, (costs of certification, relatively low profitability, etc.) but with a whole set of other less tangible issues. While the SFM issue competes with an entire set of alternative land uses, the ultimate competition for timber markets whether certified or not certified, is from those who want to displace wood with non-wood materials. They seem to be more organized and gaining strength (Anon., 2002). Fortunately, there is currently a renewed interest in recognizing wood as the most ecological material we have and its other values are also being rediscovered. The different stakeholders involved in timber trade - producers, processors, manufacturers, retailers, need, therefore, to join strengths even while continuing to compete among each other and their efforts are needed to be better articulated to dispel the concerns of environmental groups and widen timber markets. New ways will have to be found to enhance the values of wood products. Innovations are needed at all steps to gain wider acceptability and consumer confidence.

Acceptance of certified wood and products from the same would be of paramount importance to sustain the SFM. However, quality and price are always important in formulating decisions for purchase of wood products. Certified timber consumers are not expected to pay 'premiums' if the quality of the products are not maintained.

OPPORTUNITIES FOR TEAK

Tropical countries have an opportunity to pursue markets for products from high value timber species their forests support. India has many such high value timbers, eg. Teak, Rosewood, Red sanders, Mahagony, Sandal, etc. The commodity fast grown timbers raised in the existing plantations which are projected to lead to 'regional gluts' are no substitutes for the tropical high value hardwood species.

'Among timbers, teak holds the place diamond maintains among precious stones, and gold among metals' (Sir Dietrich Brandis). It is clearly the most preferred timber species for production of high quality sawn wood and veneer. It has been found to be eminently suitable for multiple end-uses including construction, furniture and cabinet making, railway sleepers, decorative veneer, joinery boat/ship/ vehicle body building, mining, reconstituted products, handicrafts, toys, flooring, souvenirs etc. There is no end-use for which teak is not suitable (Bhat, 1999, 2000 a, b). In India, it is used as a reference species for end-use classification of a number of tropical hardwoods (Rajput and Gulati, 1983).

Teak is also the most preferred species in commercial plantations and in agro-forestry, farm forestry and social forestry besides the pulpwood/fuel wood species. Evidence available from different parts of the world, through recent research indicates that plantation grown teak is not inferior to naturally grown timber and new opportunities exist for development of value added products from fast growing teak plantations. However, to manufacture quality products that meet market standards, technological interventions are needed. Since the sapwood content is considerably high in timber harvested from short rotation plantations one of the main concerns is reduced natural durability for structural uses. Fortunately, teak does not offer diffculties either for air seasoning or kiln seasoning. Low recovery of sawn wood and veneer owing to growth stresses, small diameter, higher proportion of flutes and knots is another problem that needs to be overcome. Modified equipment for processing for sawn wood/veneer recovery from small diameter timber; portable processing units that can be operated at the felling/thinning sites (eg. small portable saw mills, solar kilns, preservation treatment plants, etc.) are suggested to facilitate supply of wood from farmers sites to the user groups (Damodaran and Xavier, 1992; Sivananda, 1992; Bhat, 2000). Further research is needed to address the problem of growth stresses. Aspects such as variations in strength properties, improvements of seasoning schedules, sawing techniques, developing quality standards/ grading rules for fast grown plantation teak are currently under various stages of investigations. In addition to the conventional uses, opportunities exist for production of value added products from finger-jointed and glulam structures, decorative veneers, cement-bounded particles boards, etc from relatively young (20-25 year old) teak.

An examination of the wood processing industry in India indicates that it is characterized by a large number of small scale units that are generally unorganized and disperse nature, with the exception of a few paper mills and panel product manufacturing units, which are in the large/medium scale sector. The pace of technology adoption and change in the user industry has also been extremely slow. Improvements are needed at all stages of operations - when wood is harvested, processed and utilized. For instance, even though, as much as 175 per cent rate of returns are indicated, if a monetary value is placed on the wood saved through prophylactic treatment alone, there is little evidence of this simple technique being adopted (Bajaj and Bhat, 1996). Studies have also shown that 'pressure treatments' enhance durability of a variety of timbers, many fold. Adoption of such simple and well proven treatment technologies have the potential to save a huge quantity of timber every year amounting to saving millions of well grown timber trees. This is in addition to other benefits such as reduction in investments, widening the choice of species for different end-uses, etc. However, the quantity of timber being treated in the country is negligible. Unfortunately, the potential of wood preservative technologies as an important tool for forest/tree conservation has never been fully realized in India (Satish Kumar, 1999). Reasons are many, but certainly a favourable operational regime for scientific processing, especially wood treatment, does not seem to exist. There is no legislation, no incentives or disincentives (for better or unscientific practices respectively) warranting a new wood use policy. There is also considerable scope to enchance the processing efficacy of saw mills and wood recovery rates by following simple improvements. The rate of return on investments in a programme of saw milling improvements appears to be as high as 120 per cent (Bajaj and Bhat, 1996).

Compounding the problem is the extremely weak, User-Researcher linkages, low level of technology development, technology absorption, virtually non-existent 'inter twinning' arrangements between R and D Institutes and Industry and lack of adequate market intelligence.

SUSTAINABILITY AND SUSTAINABLE COMMUNITIES

Central to the debate of certification is a comprehension of 'sustainability' itself. Definitions of sustainability are varied but include ecological, economic, social and ethical considerations and are more than a measurable concept. And the concepts and protocols are evolving. However, it is recognized that 'sustainable communities' are needed to make natural resource management sustainable. The concept of 'sustainable community' is one where all stakeholders, as partners in progress on the road to economic development, will be enabled to achieve not only 'sustainable production' but also 'sustainable use and consumption'. The agenda 21 of the Rio Earth Summit, the UN convention to combat desertification (CCD), the UN convention on Biological Diversity (CBD), the UN Frame work convention on climate change (UNFCC) and its Kyoto protocol, the Habiter Agenda adopted by the UN conference on Human Settlements in 1996, and the recently held World Summit at Johannesberg, suggested directly or indirectly, integrated planning and management of water, land, mineral and biota (including forest that land comprises) for sustainable development and use. Integrated approach facilitates utilization of human and natural resources in an optimal way.

Forests in India, like several other developing countries, are under immense pressure from a multiplicity of uses. Wood, despite the introduction of modern materials, continues to fulfill several key needs of the society. Its usage is both widespread and extensive. Contrary to the common but incorrect perception, its usage is ever increasing. The livelihood of several communities, especially the rural poor depend on the availability of wood. Fuel wood accounts for 70 per cent of the consumption of total wood harvested, but is not covered under SFM. Given the intensity of the resource requirements and the meager supplies of industrial wood, rational utilization of the resources emerges as an imperative and not an option. Unfortunately, the usage pattern of timber in India suggests that the current practice of utilisation are far from being scientific. The user Industry is far behind the R and D innovations that are taking place worldwide in the wood processing sectors.

Under the present FSC efforts what is certified is the quality of forest management and wood supply chain (chain of custody). This form of certification and labelling is unfortunately far short of covering the entire tree to Product chain and does not indicate whether sound practices are adopted in 'product manufacturing' that help reduce negative impacts. If the original goal of SFM is to install confidence in consumers that the wood and wood products they are buying are indeed the result of sound environmental practices, greater attention need to be paid to the 'manufacture and use' aspects. 'Production and use of wood that sustains it supply' is perhaps more appropriate, especially in the developing countries as the usage pattern is far from being scientific and is negatively impacting forest tree biodiversity. Promoting Sustainable resource use will be an important aspect that merits greater attention and recognition as a tool in advancing SFM. There exists an urgent need to develop and implement a proactive and vibrant strategy with a sharp focus on utilization. The situation calls for technological and policy interventions. Unfortunately, at present, there does not seem to be a favorable, operational requirement or the necessary policy support for achieving the rational utilization of Forest Products, which need to be reversed. Possibilities of developing C and I that take into account and place weightage on parameters that promote sustainable use need be examined and incorporated.

OTHER CERTIFICATION APPROACHES

Forest certification is not one operation, but is divided into three main activities: accreditation, standardization and certification per sec. All these disciplines are much older than forest certification itself and have well established standard rules, mostly drawn by the International Standards Organization (ISO). The World Trade Organization (WTO), accepts these rules of ISO and not creating unnecessary barriers to trade.

Certification can be based on two different approaches: System and Performance approaches. ISO 14001 (environmental management system) is the best known example of the system approach. Forest Stewardship Council (FSC) certification is the best known example of the 'Performance approach' applied to Forest management. While the system based approach ensures that a mechanism to reach certain objective is operational, the performance based approach indicates that these objectives are satisfactory and have been reached. The Brisbane International Conference on Certification and labelling (1996) recognized that forest management certification should include components of both concepts. The two concepts are not contradictory, but in fact, complementary. It is to be noted that principles of FSC accreditation already include some system elements (in its management plan, in Principle-7; legal compliance - principle 1) (Vallejo and Hauselmann, 2000).

Other certifications in the Certification of origin, the ISO quality management systems (ISO 9000 series); occupational Health and safety Management System (OHSAS, 18001), etc. are also relevant in this context. ISO 14001 is particularly significant in the context of Forest Certification as it includes the management system of forest companies as a part of environmental management. The Canadian Standard Association (CSA) has developed a forestry sector specific standard derived from 1S0 14001. This is only applicable to Canadian Forest Management.

The ISO (International Standards Organisation) recognizes 3 types of environmental labels and declarations, designed as Type I (Third Party Labelling); Type II (safety declaration, eg. ISO 14021) and Type III (Life cycle assessement, eg. ISO/TR-14025). Forest certification, although related to type I, only addresses one aspect of the Product life cycle. It is called a single issue label, not to be confused with type II, which is self declared. Thus FC does not fall into any of these categories. Recognition and incorporation of environmentally sound practices for manufacturing/processing are needed to be incorporated in the ongoing efforts.

It is to be recognized that the market for certified wood is a niche market. The consumers in this segment are quality and environmental conscious and constitute a elite group willing and capable of paying premium for high value end markets such as furniture, cabinets, flooring, mill work, etc. There may also be further market opportunities for products certified from schemes with even higher standards than the FSC provides, for example, under the 'organic banner'. The author is aware of similar efforts (for organic cultivation) of sandal, in India.

There appears to be a need, therefore to harmonize various efforts being carried out under different approaches - FSC certification for forest management, ISO certification for quality products and environmental management, organic farming etc, for production, value addition and marketing of quality teak wood products.

CONCLUSIONS

- Certified timber and eco-labelling are emerging concepts linked to the broader complex issue of certification of sustainable Forest Management (SFM). Many unresolved issues on what constitutes SFM, still remain and are hotly debated.
- Extent of certified forests is expanding. Trade in 'certified wood' however, continues to be in the premium markets and the demand is mostly from distributors (rather than consumers). Only a small portion of wood from sustainably managed forests comes into market because of lack of chain-of-custody verifications.
- While the market outlook for timber and especially down stream processed products is promising, the competition for timber, whether certified or not is from producers of a whole range of other non-wood materials, who appear to be better organised.
- To project wood as the most ecological material we have, wood industry needs a much higher level of articulation and linkages between SFM certification and certified products need to be strengthened.
- Opportunities for premium markets exist for quality wood products made from certified tropical hardwoods like teak. Technology upgradation and more importantly, technology absorption, which remains at a very low level are critical for development of value added, certified wood products.
- Pursuit of a strategy for expanding sustainably managed forests and widening certified and labelled wood markets, in tropical, developing countries calls for bold initiatives from existing practices.
- Sustainable communities are realized only when all the stakeholders, as partners in progress, are enabled to achieve 'sustainable production' as well as 'sustainable consumption'. The current pattern of utilization of timber in India is far from being scientific and is generally wasteful which needs to be reversed.
- Given the intense pressure on resources, rational utilization becomes an imperative rather than an option, and due weightage therefore needs to be given for elements including processing aimed at promoting better usage of timber while developing C and I. Forest products research Institutes need greater recognition from both Government and industry.
- The present timber certification does not address the entire tree to product chain. There exists a greater need to harmonize various certification schemes

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Are Intensive Teak Plantations in Agroforestry Practices Environmentally and Ethically Sound?

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ABSTRACT

Agroforestry and teak have generated high levels of enthusiasm in recent years, especially those concerned with tropical land-use systems. Although it is true that the scientific principles of agroforestry are only now being examined, and hence understood, the practice, in some form or other, has been in existence since very early times, especially with forest organizations growing teak under the *Taungya* system. However, the teak plantations established in the past have fallen short of their potential, and that a new approach is demanded for future programmes. The paper examines the possibilities of growing teak under various agroforestry systems, *viz.*, taungya, spatial agroforestry system (agrisilviculture system), silvopastoral system and home gardens. Possibilities of growing some suitable crops and grasses have also been examined. How the biophysical factors like light, water, nutrients and root behaviour play a role in increasing tree productivity has been discussed. Tree improvement activities for smallholder farmers, particularly in Chhattisgarh, are discussed. Moreover, a financial analysis of a small-scale teak improvement programme in Raipur, Chhattisgarh is described. The programme consisted of a seedling seed orchard, made up of ramets of plus-trees. The analysis demonstrated the annual planting rates between 31 ha per year (at 20% genetic gain in volume) to 125 ha per (at 5% genetic gain) over 30-year life of the orchard are economically justifiable. The results demonstrate that the tree improvement above the seed stand intensity be more widely adopted in support of smallholder tree planting. The implementation of such small scale, locally based programmes by community-based or locally oriented organizations may often be justifiable.

Keywords: Agrisilviculture system, financial analysis, seedling seed orchard, taungya system, tree improvement

INTRODUCTION

Teak (*Tectona grandis* L. f.) occupies a principal position in the timber economy of India and is regarded as the most important high-grade tropical hardwood timber entering the world market. However, due to increasing demand for teak wood and its versatility of end uses, there is a big gap between its supply and demand. Grainger (1988) reported that teak in 1980 constituted about 75 per cent of the area under high-grade tropical hardwoods or 11 per cent of the total area of tropical forest plantations. In 1990, teak constituted only 5 per cent of the reported total area under tropical plantations (Pandey, 1992). Although the figures are from different sources, this apparent drop in proportion of teak reflects a serious concern.

It is well known that most of the commercial timber species are difficult to grow in plantations as such species have evolved in highly competitive environments (Keogh, 1996). Fortunately teak is widely planted due to its ease of propagation, establishment and management. In 1980's the teak plantation got impetus when many industries, finance companies, real estate agencies and building promoters floated various schemes for investment. The reality today is that teak is no longer solely regarded as a species for large block plantations looked after (often ineffectively) by government agencies. It has become a species, which can be planted in large and small areas, by different organizations, people and individuals. In places where economic, social and environmental benefits accrue, they are planted.

It is true that generally plantations have not always been readily accepted within land-use patterns. One of the major reasons is that generally plantations are established as monoculture, which has its own drawbacks. Higher acceptability has been achieved on land where trees are introduced as an agroforestry component. This paper examines the potential alternative of establishing teak under agroforestry practices. However, before examining this aspect in detail, it is necessary to analyse the concept of agroforestry.

AGROFORESTRY

Agroforestry is a collective name for land-use systems in which woody perennials (trees, shrubs, etc.) are grown in association with herbaceous plants (crops, pastures) and/or livestock in a spatial arrangement, a rotation or both, and in which there are both ecological and economic interactions between the tree and non-tree components of the system. Its essential nature is that it covers combinations of trees with plants or animals, and that there must be interactions between the tree and non-tree parts of the system. It is the ecological interactions that are the most distinctive feature and which differentiate agroforestry from social forestry (forestry carried out by communities or individuals) although there is a large overlap (Nair, 1993).

Agroforestry is the traditional practice of growing trees on farms for the benefit of the farm family. It has been in use for at least 1300 years according to pollen records (Brookfield and Padoch, 1994), although tree domestication probably started much earlier (Simmonds, 1985). Agroforestry was brought from the realm of indigenous knowledge into the forefront of agricultural research two decades ago, and was promoted widely as a sustainability enhancing practice that combines the best attributes of forestry and agriculture (Bene *et al.*, 1977; Khosla and Puri, 1986). Growing trees along with crops and livestock was postulated to enhance crop yields, conserve soil and recycle nutrients while producing fuelwood, fodder, fruit and timber. Under certain circumstances herbaceous-layer productivity is lower under tree canopies (Somarriba, 1988; Puri *et al.*, 1994 b) whereas in other cases productivity is higher (Belsky *et al.*, 1989; Puri *et al.*, 1994 a). It is often suggested that the increased productivity under tree canopies is due to the ameliorating influence of shade in a hot, dry environment and increased soil fertility, while decreased soil productivity is due to shade and competitive interactions (Dye and Spear, 1982; Puri *et al.*, 1992).

The main components of agroforestry systems are trees and shrubs, crops, pastures and livestock, together with the environmental factors of climate, soils and landforms. Other components (e.g. bees, fish) occur in specialized systems. An agroforestry practice is a distinctive arrangement of components in space and time. An agroforestry system is a specific local example of a practice, characterized by environment, plant species and arrangement, management and social and economic functioning. There are hundreds, possibly thousands, of agroforestry systems but only some 20 distinct practices (Young, 1990). The important agroforestry practices are given in Table 1.

At the highest level, the classification is based on the components present: trees with crops, trees with pastures, practices in which the tree component is dominant and practices involving special components. The second level is based on the spatial and temporal arrangement of components. Rotational practices are those in which the associations between trees and crops takes place primarily over time, whilst spatial practices are those in which it is primarily a combination in space. Spatial systems are divided into mixed and zoned. In mixed spatial practices, the trees and herbaceous plants are grown in intimate mixtures, with the trees distributed over more or less the whole of the land area. In zoned spatial practices, the trees are either planted in some systematic arrangement, such as rows, or are grown on some element in the farm, such as boundaries or soil conservation structures. The third level of classification employs detailed spatial arrangement and functions as criteria.

Two key principles set agroforestry systems distinct from agricultural or forestry systems: competition and

Table 1. Classification of important agroforestry practices

I. MAINLY AGROSYLVICULTURAL (trees with crops)	
Rotational	
	·Shifting cultivation
	·Improved tree fallow
	·Taungya
Spatial mixed	
	·Tress on cropland
	·Plantation crop combinations
	·Multi-storey tree gardens
Spatial zoned	
	·Hedgerow intercropping (alley cropping)*
	·Boundary planting
	·Trees on erosion-control structures
	·Windbreaks and shelterbelts
	·Biomass transfer
II. MAINLY OR PARTLY SILVOPASTORAL (trees with pastures and livestock)	
Spatial mixed	
	·Trees on rangelands or pastures
	·Plantation crops with pastures
Spatial zoned	
	·Live fences*
	·Fodder banks*
III. TREE COMPONENT PREDOMINANT	
	·Woodlot with multipurpose management
	·Reclamation forestry leading to multiple use
IV.OTHER COMPONENTS	
	·Entomoforestry (trees with insects)*
	·Aqua forestry (trees with fisheries)

* Teak cannot be introduced in these agroforestry practices as per opinion of the author.

complexity. They in turn determine profitability and sustainability. How far teak meets these desired traits is the purpose of this paper. Evidences from direct experimental observations on teak under agroforestry systems are limited. However, an attempt has been made here by taking the results of agricultural and forest land-use and applying them to agroforestry. Nevertheless, teak was perhaps the first woody species used systematically and scientifically under taungya form of agroforestry practice.

TAUNGYA

Taungya is a Burmese word, which means temporary cultivation on hilly lands. The word is derived from *taung*, which means hill and *ya* meaning cultivation usually of a temporary character (Blanford, 1925). In 1856 when Dietrich Brandis was in Burma (then part of India), shifting cultivation was rampant and there were several court cases against the encroaching villagers. Brandis realized that shifting cultivation, which was so detrimental to the management of timber resources, could possibly be rendered useful to the development of forestry. Based on the well known German system of *waldfeldbau* which involves cultivation of agricultural crops in forests, and on the success of teak taungya plantations in Taungoo and Tharrawaddy Divisions, Brandis encouraged the concept of teak regeneration with the assistance of taungya (Blanford, 1925). Forest Department distributed teak and rice (*Oryza sativa*) seeds to farmers for sowing. This enabled teak plantations to be established cheaper and at the same time villagers no longer had to defend themselves in court for destroying the forests. Taungya fields were usually used for the intermediate cultivation of rice, tobacco and sesame in the valleys and for sugarcane, cotton and maize on the slopes. Thus a symbiotic agreement between the Forest Department and farmers developed.

Taungya is widely practised in tropical forestry with local variations in the system. The principle underlying the system of taungya is that in all cases temporary fertility of the forestland is used by the farmers for cultivation of agricultural crops. The advantages of taungya are manifold, ranging from higher yields of agricultural and tree crops, protection from soil erosion on slopes and regular employment for the local population. Above all it is regarded as a cheap means of transforming poor quality forests into a forest consisting of more valuable species.

Data on the tree-crop interactions under taungya are lacking. Hay (1924) reported the suppression of tree seedlings by sugarcane. Similarly, Rowbotham (1924) opined suppression of teak seedlings by rice in the first year, and Coster and Kardjowasono (1935) concluded that agricultural crops retard teak growth. Tapioca was found to be more harmful followed by dry paddy and groundnut. Root competition and shade were attributed to be main factors affecting growth of tree seedlings. In Kerala, experiments conducted in Palghat Division (Anonymous, 1947; 1949) indicated that many agricultural crops have no detrimental effect on teak growth. Hill rice, chillies, cotton, millets, tapioca, horse gram and ginger can be grown with teak without any loss in height increment. National Commission of Agriculture (1976) encouraged taungya in afforestation sites as it provides employment and increase productivity of agricultural crops. Alexander *et al.* (1980) reported changes in soil properties under taungya and envisaged changes due to disturbances caused to the soil in the form of pre-planting tillage, intercultivation operations, etc.

SILVOPASTORAL SYSTEM

It is a land-management system in which forests are managed for the production of wood as well as for rearing animals. Within this broad category several types of practices can be identified depending on the role of the tree (Nair, 1993). Since teak is not a fodder species, pastures can be raised in plantation areas. Animals graze on the herbaceous species. Only those grazing systems in which trees are present and play an interactive role in animal production (e.g. by providing shade to animals, promoting grass growth) can be considered as silvopastoral system. Nair and Jayson (1988) studied habitat utilization by large mammals in teak plantations of Parambikulam Wildlife Sanctuary, Kerala. Elephants showed preference for *Bambusa arundinacea* and *Brachiaria remota* (grass). Deer showed high preference of grasses like *Brachiaria remota, Mimosa pudica* and *Commelina* sp. However, for domestic animals grasses like *Cenchrus ciliaris, Setaria anceps, Chrysopogon fulvus, Stylosanthes hamata,* etc. can be grown under teak plantations.

HOMEGARDEN SYSTEM

In recent years teak has started encroaching the homestead areas. The state forest departments, which once monopolized planting of teak, are no longer so now. Farmers have started planting teak stumps on their own lands, especially in homegardens. In Madhya Pradesh, almost every homestead has at least a couple of teak trees. This is due to its versatile use and high price in the timber market. But more than its monetary value, by planting these trees in homesteads, the common man is unknowingly contributing to the upkeep of the environment, which is in no way quantifiable. Not only this contributes to our efforts in meeting the afforestation targets, but this also brings the forestry establishment closer to the people. Serious thought should be given to allow the people to own the teak trees planted by them in their own land.

SPATIAL AGROFORESTRY SYSTEMS

As mentioned earlier these systems are primarily a combination in space. The trees are either distributed over more or less the whole of the land area or are present in some systematic arrangement, such as, rows or on boundaries. In such agroforestry practices when plants grow in proximity to each other they interact either in positive ways (complementary) or in negative ways (competition). The biophysical bottom line of agroforestry is how to manage the interaction for light, water and nutrients between the tree and crop components. How these biophysical interactions can be promoted for the use of teak as an agroforestry species is discussed henceforth. However, prior to this, plant population and spacing is discussed as these affect biophysical interactions.

TREE POPULATION AND SPACING

Spacing and plant density for teak planting depend heavily on the desired final products such as fuelwood, posts, lumber, or a mixture of products at different times during the rotation. Traditional spacing for teak plantations varies between 1.5m x 1.5m and 4.6m x 4.6m, with some irregular spacing at 3m x 6m (Weaver, 1993). A 3m x 3m spacing in pure plantations is commonly used for timber production (Chaves and William, 1991). In India, the most commonly adopted spacing is 2m x 2m. Under these high-density espacement, teak is good for production of fuelwood, posts or timber (after desired thinning from time to time). Crops (particularly rhizomatous, like ginger, turmeric, etc.) can be grown for 2-3 years initially. However, if crops are to be grown for longer duration, a wider spacing is to be adopted.

Arifin (1983) tested a spacing of 3m x 1m, 3m x 2m, 4m x 2m, 5m x 2m, 6m x 2m, and 6m x 1m for an intercrop trial in Indonesia. Food crops could be grown successfully for longer duration in a wider spaced plantations. However, low branched stem of teak was commonly observed in wider espacements. Dagar *et al.* (1995) studied the effect of six-year-old teak trees (planted at 6m x 6m) on Kharif (May to October) and Rabi (November to April) crops grown in between the rows. The crops grown were rice, pearl millet and sorghum (Kharif season) and bar seem, wheat, mustard, lentil and gram (Rabi season).

The performance of various intercrops is shown in Table 2. As is evident there is reduction in yield of grain and straw when compared with controls. Highest reduction of 75 per cent was of rice grain and of sorghum straw (fresh weight). Barseem and gram can be grown reasonably well with teak. As the arable crops were irrigated frequently, trees could get sufficient moisture for their growth. In rice-barseem and rice-wheat rotations the availability of moisture was maximum because both these crops required more irrigation, hence the average increase in growth and girth in teak was maximum in these rotations (Table 3). Even the dry biomass was maximum in trees grown in association with crops. Rice-barseem rotation yielded almost two times more biomass when compared to fallow system. It can be concluded from these studies that with an increase in spacing annual crops can be grown in association with teak. Agronomical practices followed for growing of crops will enhance growth of trees and ultimately its productivity. Competition between trees and crop plants can also be minimized by selecting crops, which compete less with teak trees (e.g. rice-barseem or rice wheat rotation).

BIOPHYSICAL CONCEPTS

Light

Squire *et al.* (1987) found that when water is not limiting the dry matter (W) produced is linearly related to the total intercepted radiation and is represented by $W = Sfe\ dt$

Where, S = total radiation (mean of daily totals) MJ/m^2

f = the fraction of mean daily insulation intercepted by the canopy

Table 2. Yield and straw biomass (t/ha) of different crops interplanted with teak (Source Dagar *et al.,* 1995)

Crop	Control (without plantation)			With teak		
	Grain	Straw		Grain	Straw	
		Fresh wt.	Dry wt.		Fresh wt.	Dry wt.
Rice	5.2	-	17.8	1.3 (75)	-	5.6 (69)
Barseem	-	96.2	12.6	-	68.1 (29)	9.3 (26)
Wheat	4.1	-	5.3	2.0 (51)	-	2.1 (60)
Pearl millet (fodder)	-	20.0	4.9	-	8.8 (56)	2.2 (55)
Mustard	2.1	-	7.7	0.9 (57)	-	2.8 (64)
Lentil	1.6	-	5.2	0.8 (52)	-	2.5 (69)
Sorghum (fodder)	-	13.8	4.0	-	3.7 (75)	1.0 (70)
Gram	1.6	-	2.7	1.3 (19)	-	2.1 (22)

Note: The values in the parentheses are the percentage reductions in yield /biomass over the control.

Table 3. Performance of tree species with different crop rotation (Source Dagar *et al.,* 1995)

Crop rotation	Initial height (m)	Increase in height (m) after 2 yrs.	Initial girth(cm) at 1.37 m	Increase in girth (cm) after 2 yrs.	Increase in dry biomass (kg)
Rice-barseem	6.49	2.12	34.5	21.3	62.8
Rice-wheat	6.51	2.19	33.7	19.3	56.9
Pearl millet-mustard	6.18	1.92	34.7	15.1	48.5
Pearl millet-lentil	7.12	1.62	35.6	18.4	54.3
Sorghum-gram	6.23	1.67	31.4	15.5	45.7
Fallow	6.33	0.98	35.7	11.5	33.9

e = the amount of dry matter formed per unit of intercepted radiation (g /MJ)

t = the duration of crop growth in days

The value of S varies from 12 to 30 MJ/m^2 in the tropics (Ong, 1993). The leaf area of vegetation determines f at any time and f can be related to leaf area index. Intercropping will increase total interception of solar radiation compared to sole tree or crop system. This is probably the most important reason for higher productivity in intercropping. These positive interactions for light provide a physiological basis for the management strategies of mixed canopies for agrforestry interventions. The first strategy is to adopt temporal sharing concept by pruning the tress so that crops can intercept most of the solar radiation during their growth period and allow the tree to regrow after removal of the crop. Another strategy can also be adopted whereby the tree canopy is allowed to intercept radiation during the early part of the season when the crop canopy is too open to intercept more than a small fraction of incident solar radiation. Once the crop canopy becomes nearly closed, the trees are pruned. However, in case teak is planted densely, the pruning may not be a solution to crop growth. In such instances, thinning is recommended as per the silvicultural requirements for teak. It should also be always kept in mind that teak is a light demanding species and requires complete overhead light and ample growing space for proper development (Ryan, 1982).

Nutrients and water

Competition for nutrients and water between tree and crop depends on uptake demand of both components, as well as the relative distribution of the root system. Studies of nutrient cycling in soils below teak plantations are available (Egunjobi, 1974). Nearly 70 per cent of the litter fall in a teak stand is between December and March and more than 90 per cent of the plant nutrients (N, P, K, Ca, Mg and Na) were found in the leaf litter alone. Various fertilizer trials have concluded that teak growth can be increased by fertilization (Chaves and William, 1991). Similarly, growth of teak is enhanced if plantations are irrigated. However, the use of these resources (nutrients and moisture) is dependent upon the root system distribution.

In agroforestry systems, trees and crops are targeted on the assumption that crop and tree roots take up water and nutrients from different depths, hence minimizing competition (Huck, 1983; Puri *et al.*, 1994c). This is assumed on the basis that the root system of herbaceous and tree species are distributed differently in the soil profile, giving the tree species access to nutrients and water unavailable to the herbaceous crops.

Several studies are available on teak rooting systems. Troup (1921) reported that teak produces a long and thick tap root. It may persist or disappear, but in either instance, numerous strong lateral roots are formed (White, 1991). Because teak roots are sensitive to oxygen deficiencies, they often remain shallow (Murray, 1961). Ngampongsai (1973) studied the depth, diameter, length, and distribution of teak roots from numerous trees between ages 1 and 20 and showed that, with age, the rate of root growth declined and both lateral and vertical roots were concentrated in the top 30 cm of soil. In another study, the lateral and vertical distribution of fine root mass under teak between 2 and 20 years was examined (Singh and Srivastava, 1984). Bulk of the live roots (fine) were found between 10 and 30 cm depth.

The distribution of roots indicates that some of the primary and lateral roots reach deep soil levels, while the bulk of the roots are present in upper soil profile. Most of the fine roots are present in the top 10 to 30 cm of soil and this provides the plant an easy access to moisture and nutrients, while the primary roots, which go much deeper, help in extracting moisture and nutrients from there. Root competition between crop and tree species can therefore be expected when they are intercropped. It is emphasized that in order to alleviate the competition between trees and crops, hoeing and tilling may be practised prior to planting the crops. Root exclusion mechanism, such as trenching, may also be practised.

TREE IMPROVEMENT AND FINANCIAL ANALYSIS

In recent years there has been increasing interest in strategies for smallholder tree improvement. Small-scale, locally based approaches to tree improvement by or for smallholders would appear to have advantages over large-scale, centralized programmes, e.g., it is easier to take into account local differences in species preferences, environment and ideotypes; farmers can be involved or take charge of the process more easily; overall genetic diversity may be enhanced; costs are likely to be lower because of short distances from base to field sites. Many studies have demonstrated the potential or realized profitability of industrial-scale tree improvement (e.g., Willan, 1988; Zobel and Talbert, 1984). However, such studies have not been reported for small-scale, locally based activities in support of small to modest planting programmes. This section addresses this issue, taking as an example of teak improvement programme taken up by Indira Gandhi Agricultural University (IGAU) in Chhattisgarh region.

Since the late 1970s, farming activity, which historically consisted of production of cattle and, to a lesser extent, staple crops has been increasingly supplemented by plantation forestry. Initially, farmers' interest in tree planting appears to have been largely a result of declining productivity of profitability of traditional activities. More recently, however, farmers appear to be increasingly accepting tree planting as a 'mainstream' activity undertaken in expectation of income from the final product rather than from government incentives.

In the mid-1990s IGAU initiated tree improvement activities in Chhattisgarh. Currently, the programme concentrates on teak, and consists of three main components: seed stands, progeny tests of plus-tree material, and a pilot programme of vegetative propagation and clonal testing. Selected germplasm (at present available only from seed stands) will be supplied by IGAU to smallholder farmers through the existing seed and plant distribution system.

The aim of the study was to financially analyze the programme based on the seedling seed orchards. After defining what activities the programme would consist of and when they would be carried out, costs were estimated, mostly from actual cost data collected over many years. Gross returns were then estimated for various genetic gain scenarios. Both costs and returns were discounted or compounded to the base year using standard formulae. Following this, the break-even annual planting area was calculated, i.e., the annual area of improved plantations that must be planted in each year of orchard life in order to produce enough gain to justify the costs of the programme (i.e., to give internal rates of return equal to the discount rate or net present value of zero). A real interest rate of 5 per cent was used throughout. The year of trial establishment was taken as the base year for compounding and discounting purpose.

Description of the programme

The programme begins with the selection, on stem straightness and growth criteria, of 20 plus-trees within local teak plantations. The trial has 15 randomized complete blocks, three trees per plot, 2 m x 2 m spacing. The trial is maintained according to local practice, and measured in years before thinning. Seed production is assumed to start in the 10th year in seedling seed orchards. All activities that, in the absence of a tree improvement programme, would be unnecessary to secure (unimproved) seed supplies were costed (Table 4). An overhead of 15% was allowed to cover administrative costs and maintenance/depreciation of infrastructure.

Returns from the programme

The forecasting of yield increase due to genetic improvement is perhaps the most problematic element in the financial analysis of tree improvement (Friedman, 1992). In the present programme, as in most other programmes that have been analyzed, data on realized genetic gain are not available. In addition, there are little reliable data on which to base estimates of current productivity, and in any case such historical data would be of dubious relevance as, due to inexperience, many plantations have been established on unsuitable sites and have received poor management, particularly as regards thinning. Rather than attempt to forest gain, it was decided to make calculations for genetic gains in volume from 5-20%, applied to a plantation programme with the following mean characteristics: rotation length 30 years, with MAI of 4 m^3/ha/yr and half of the total cumulative volume removed in thinnings. We consider that these assumed parameters are justified,

Table 4. Present value costs at 5% discount rate of seedling seed orchard in a teak improvement programme in IGAU, Chhattisgarh.

Activity	Year	Total actual cost ($US)	Present value ($US)	Notes/assumptions
Plus-tree selection @$22/tree	-1	523	556	Two to three trees selected/day
Seed collection @$20/tree	-1	466	496	Five trees/day, two visits/tree
Nursery costs	-1	194	199	
Establishment @ $702/ha	0-1	1404	1416	Includes soil sampling, site clearance, planting, replanting, etc.
Maintenance @ $433/ha (average of first 2yrs)	0-4	2098	1976	Includes fertilization, watering, spot and general cleaning, stump pruning, firebreak
Measurement, analysis	3-5	936	808	
Conversion to seed orchard (genetic thinning) $232/ha	5-7	394	332	
Subtotal			5783	
15% overhead			867.45	
Total			6650.45	

as there is little doubt that, due to accumulated experience, future plantation management and site selection will improve substantially with respect to past practice. Timber prices were based on current prices of around $25/m^3$. These were halved in order to reflect the approximate expected costs of harvesting and transport, as actual stumpage values were unavailable. All thinnings were assumed to be non-commercial.

The break-even annual planting programme required under the base scenario is from 31ha (at 20% improvement) to 125 ha (at 5% improvement) (Table 5). Evidently, an effective (i.e., one capable of achieving genetic gains of at least around 10%) teak improvement programme of the type analyzed would be amply justified by the current planting programme of around 100 ha. It is, in any case, probable that programme returns have been underestimated : neither returns from decreased cleaning costs (due to faster early growth nor possible income from second (commercial) thinnings have been considered.

Evidently, such returns will only be available to organizations in a position to make the necessary investment, i.e., with the capacity to divert part of existing funds and manpower into tree improvement activities over a period of around 30 years. Where such flexibility does not exist, it is doubtful whether a programme of the sort described here could be implemented, except as a special project funded by national or extra national agencies.

Broadly speaking, the findings of the present study are likely to be applicable to other parts of the country. Todate, tree improvement for smallholders has been characterized by the establishment of seed stands as 'interim' seed sources. Due, in part, to a general perception that higher-level activities are only justifiable when annual planting rates are in thousands of hectares, rather than tens or hundreds, there has been a reluctance to enter into higher-level activities, even of the simple sort reported here. The results of the present study suggest that this reluctance is unjustified. At the same time, however, it should be emphasized that the present analysis establishes only the financial feasibility of programmes of this type. Their wider feasibility will depend on, among other factors, the degree of commitment, training and awareness of local personnel, and the presence of organizations able to fulfill the catalytic and supporting functions.

The results of the study indicate that small-scale, locally based tree improvement programmes of the type described here are financially justified for annual planting programmes of the scale being undertaken by many farmers' organizations and other community-based groups. Providing that programmes can

Table 5. Results of break-even financial analysis of a teak improvement program in IGAU, Chhattisgarh (base scenario and sensitivity analysis)*

Assumptions	Marginal yield increase due to programme (%) 5	10	15	20
	Break-even annual planting requirement (ha)**			
Base scenario	125	62	41	31
Orchard life of 30 years	110	55	37	28
25% increase in stumpage or unimproved MAI	100	50	33	25
25% decrease in stumpage or unimproved MAI	166	83	55	42
4 year seed production delay	152	76	51	38
Only one trial planted	60	30	20	15

At 5% discount rate; ** i.e. the annual planting rate at which internal rate of return = the discount rate and net present value = zero

be designed and implemented so as to allow gains of around 20%, these should be justifiable even for planting programmes as low as 31 ha per year. However, even tree improvement programmes producing gains in the order of 5% are readily justifiable for modest (around 125 ha) annual planting programmes of even medium-value species. It is therefore recommended, when possible, that tree improvement activities beyond the seed stand level be implemented as a routine element of such planting programmes.

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An Appraisal of Teak Farmers' Woodlots in Sri Lanka and the Relevant Management Strategies

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ABSTRACT

Teak is widely grown in the dry and intermediate agro-ecological zones of the island Sri Lanka, characterized by reddish brown soil and prominent rains during the Northeast monsoon. Teak stands covering an area of about 19,451 ha were established under the *taungya* system by peasants on land leased for three years period, a practice that lasted till the latter part of the seventeenth century. Teak stumps were planted at a spacing of 2.8 m x 2.8 m, with intercropping of cash crops. Due to inadequate management, most of these block plantations now remain overstocked and unproductive. During 1993-99, the Forest Department undertook establishment of Farmers Woodlots (FWL) with teak, as wide row intercropping agro-forestry model. Land parcels of 0.4 ha were leased to farmers for a period of 25 years. Rooted teak stumps were planted at a spacing of 2 m x 5 m, followed by intercropping with non-perennial crops. The total extent of pure teak woodlots established was 3,297 ha and 36 per cent of this already exceeds the age of seven years, and were first thinned recently. In spite of the satisfactory growth during the early years, it is necessary that the FWL be intensively managed for highest possible benefits. Trees show frequent low branching due to wide spacing in many stands. Measures to improve the bole quality and optimum thinning regimes are still to be introduced. The beneficiaries faced the problem of selling the thinned material due to poor organizational infrastructure for marketing. Based on the previous and the present agro-forestry programmes, the paper discusses the problems associated with managing the FWL and recommends measures for improvement.

Keywords: Farmers teak woodlots, spacing, growth, yield, bole quality, income, rotation, marketing

INTRODUCTION

Teak (*Tectona grandis* L.f) is widely grown in Sri Lanka as a commercial tree crop by the state, private entrepreneurs and by farmers on government subsidiary schemes provided on donor assistance. The total area of mapped and inventoried teak growing stock is 19,451 ha falling into various age classes. The Farmers Woodlots (FWL) established during the last decade by the Participatory Forestry Project (1993-2000) that amounts to 3,297 ha distributed in the dry- and intermediate agro-ecological zones are not included in this figure.

Block plantations

Even though the Dutch introduced teak into the island in the seventeenth century, the commercial scale planting was initiated by the British in 1873/1875 at Thumpanacholai in the Eastern Province. Most areas planted afterwards had been failures. From 1949 onwards, the Forest Department undertook a more concerted effort to plant teak and the maximum areas planted are reported to be during 1960-1969 and 1970-1979 amounting to 18,911 ha and 38,069 ha respectively. These large-scale plantings have been undertaken under the cooperative reforestation schemes on *taungya* system with the collaboration of farmers. No larger extents of teak have been planted during the following decade, except for the Farmers Woodlots established under the Participatory Forestry Project (PFP).

The cooperative reforestation programmes have been implemented by leasing lands to farmers for a three-year period as a measure of the prevailing drive for increased food production. Selected primary and secondary forests in the dry zone were felled, utilizable timbers were extracted, and each farmer was given an area of 2 ha. The lessees planted teak stumps provided by the Forest Department at a spacing of 2.8 m x 2.8 m and intercropping was practiced for a period of three years. After the validation of the lease agreements ceased, the Forest Department undertook the management of the newly established teak plantations.

Many efforts to bring the teak growing stock under proper management regimes have failed during the past. The Working Plan prepared for teak growing in the Northern and North-eastern Forestry Divisions for the period 1956/1957 to 1966/1967 has recognized the presence of many unthinned and overstocked teak stands in the country and has made prescriptions for stand treatment (Koelmeyer, 1956). The presence of overstocked teak stands due to non-thinning has been further confirmed (Perera, 1975; Sri Lanka Forest Department, 1997).

Baminiwatte (2003) reveals the abundance of overstocked teak stands with considerable anomalies in stand density, mean DBH and mean stand basal areas. Insufficient or failure in thinning at early ages has caused "locking" of stand growth resulting in high number of overstocked stands with low mean DBH and poor bole quality. The presence of suppressed inferior stems is considerably high. The break up of the total teak growing stock in relation to the stand density is as follows.

Age (years)	**Area (ha)**	**Area with high density stand (ha)**	**percentage**
10-20	150.9	150.9	100.0
20-30	4652.6	2792	60.0
30-50	14799	10776	72.8

Farmers' woodlots

The establishment of Farmers Woodlots during 1993-2000 was based on a different strategy contrary to the cooperative reforestation programmes. Each farmer was allocated with 0.4 ha of land on a 25-year lease and was provided with 400 seedlings of forest tree species. Most of the lands available in the dry- and intermediate zones were abandoned shifting cultivation areas. Rooted teak stumps in containers were planted at a spacing of 5m x 2m. The farmers cultivated non-perennial crops between rows for the first two to three years and later abandoned cultivation as the dense foliage of teak saplings disturbed the inter row cultivation. A major difference from the previous practice was that the farmers had the right to own the timber grown on the leased lands.

The total extents of teak FWL established in the dry- and intermediate zone during 1993-1999 amounts to 2153.3 ha and 1144 ha respectively. The oldest teak FWL were planted year 1993 (64.3 ha) followed by the ones established in 1995 (231 ha) and in 1996 (761 ha). An impact assessment of the project incorporating a low intensity sampling indicated variable stand densities of the FWL in different agro-ecological zones as given below (Weeramunde and Baminiwatte, 2000).

Stand density*	**Dry zone (%)**	**Intermediate zone (%)**
<0.5	6.5	50.2
0.5-0.8	38.5	29.1
0.8-1.0	48.5	16.9
>1.0	6.5	3.7

Stand density was calculated as the proportion of existing number of stems to the original number of 400 per allotment (1000 per hectare). As certain farmers have planted on narrow espacement than the prescribed (5 m x 2 m), the stand density has exceeded 1 at certain instances.

The degradation of teak FWL is mainly due to the presence of herds of wild elephants prevalent in the area. During the drought, they overthrow the stems and peel of the bark.

Objectives of the study

A study was undertaken in selected Farmers' Woodlots aged 6 to 9 years, thinned and unthinned, in the dry- and intermediate zones with the following objectives:

i. to ascertain basic stand parameters (mean basal area, mean stand diameter, mean stand height and the top height) as indicators for stand development.

ii. to identify the required stand improvement measures with the objective of raising high quality timber trees.
iii. to discuss the best management options.
iv. to review the current agro-forestry model and to identify improvements for future application.

METHODOLOGY

Six blocks of Farmers' Woodlots in the dry- and intermediate zones of different agro-ecological regions were selected from different parts of the island (Table 1). Each block of FWL was an aggregate of many 0.4 ha land parcels leased to individual farmers and consisted of even-aged homogeneous teak stands. From each block of FWL few land parcels were selected randomly and stand parameters of each stand were assessed in 20 m x 20 m (400 m^2) plots. Trees in the plot were measured to acquire the following data.

i. DBH of each tree
ii. Total height of each 5^{th} tree in the row (to calculate the stand mean height)
iii. Total height of the first four trees with the largest DBH (to calculate the stand top height)

In addition to the above numerical data, the presence of stems with low side branches and epicormic shoots, forked stems, stem removals and evidence of mortality were also recorded. As the survey was done to obtain preliminary results on stand growth, no rigid statistical design was undertaken. The results are given in Table 1.

RESULTS

Site productivity

The quality of a forest stand is a function of the genetic constitution of the growing stock and the productive potential of the site backed by past management practices. The site quality can be indirectly assessed by referring to basic stand parameters given in Table 1. Only limited studies on site- stand relationship for teak have been undertaken in Sri Lanka. Phillips (1995) developed site indices for teak by analyzing permanent sample plot data and numerous temporary sample plots measured during forest inventory surveys. Phillips' site indices are based on the age vs dominant height relationship of the forest stands and the cumulative basal area / age relationship. In both cases, 15 years have been taken as the base age. The

Table 1. Basic stand parameters of the farmers woodlots sampled

No.	District (Location)	AEZ	AER[1]	No. of farmers/ allotments	Age (yrs)	Mean DBH (cm)	Stand mean height (m)	Stand top height (m)	Basal area (m^2/ha)	Mean area (per allotment)	Remarks NST
1	Anuradhapura (Galenbindunuwewa)	Dry	DL 1	30	8	11.9	7.5	8.5	5.5	290	Thinned
2	Anuradhapura (Galenbindunuwewa)	Dry	DL 1	50	7	10.3	7.8	9.8	9.5	440	Unthinned
3	Anuradhapura (Doramandalawa)	Dry	DL 1	50	7	9.5	8.1	10.0	8.2	420	Unthinned
4	Anuradhapura (Doramandalawa)	Dry	DL 1	52	6	11.6	8.6	11.2	8.4	310	Thinned
5	Moneragala (Undugodayaya)	Intermediate	IL 2	28	6	10.7	9.7	10.3	10.7	410	Unthinned
6	Badulla (Nikapitiya)	Intermediate	IM 2	21	9	12.4	10.4	12.3	9.0	290	Thinned

[1] The characteristics of the Agro-Ecological Regions (AER) are as follows (after Panabokke, 1996):
Dry Zone Low Country 1 (DL 1): Receives a precipitation > 775 per annum. A well pronounced rainy season during the northeast monsoon. Undulating terrain.
Intermediate Zone Low Country 2 (IL 2): Receives a precipitation > 1150 per annum. A well pronounced rainy season during the northeast monsoon. Undulating terrain.
Intermediate Zone Mid Country 2 (IM 2): Receives a precipitation > 1150 per annum. A well pronounced rainy season during the northeast monsoon. Rolling to hilly terrain.

dominant heights of 8, 12, 16, 20 and 24 meters have been designated as site indices.

The appropriate site indices or classes of the sampled FWL were determined by comparing the stand parameters both with Phillips' dominant height indices and with site quality classes given in the All India Teak Tables developed first by Laurie and Sant Ram (1940) and revised by Sowani and Gadkari in1977 (Tewari, 1992). For the comparison with All India Yield Tables, basal area of the main crop was taken as the indicator. In the case of thinned stands, the cumulative basal areas were estimated and used for the assessment. The results are given in Table 2.

Figure 1. A six-year-old teak FWL at Undugodayaya, which has not been stem pruned.

Stand structure and bole quality

No canopy closure or interlocking of tree crowns between rows was observed in stands up to the age of 8 years. This was due to wide spacing between rows (5 m). The presence of thick carpets of Guinea grass was a common phenomenon. Canopy differentiation and interlocking of tree crowns was first distinct with the 9-year-old stands. The trees had passed the young pole stage and had reached utilizable dimensions. Due to wider spacing, the presence of low live side branches was quite high than in conventional narrow spaced (2.8 m x 2.8 m) plantations. Some farmers had undertaken stem pruning at early stages and this practice has now been abandoned (Figs. 1, 2). The presence of double stems was quite high in the test areas in the intermediate zone. This was due to failure in singling operations during the early plantation establishment.

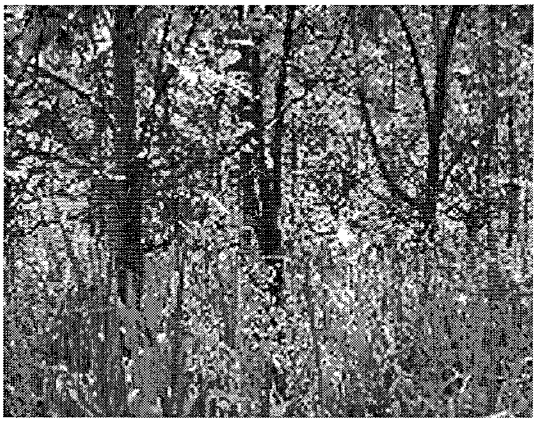

Figure 2. A six-year-old teak FWL in the intermediate zone with inferior stems caused by poor stand treatment at early stages.

Thinning

The first thinning was undertaken by the farmers when the woodlots attained 6 years of age. The removal of stems from each allotment varied from 22.5% to 27.5% of the original stocking. Competition among trees within rows was quite obvious. The thinning undertaken by the farmers was irregular, leaving dense pockets of unthinned areas within stands.

Table 2. Site productivity of the sampled teak farmers' woodlots

FWL No.	District	Location	AEZ	Dominant Height Index*	Site Quality Class**Indicator: Basal Area
1	Anuradhapura	Galenbindunuwewa	Dry	20/24	II
2	Anuradhapura	Galenbindunuwewa	Dry	20/24	I
3	Anuradhapura	Doramandalawa	Dry	20/24	I
4	Anuradhapura	Doramandalawa	Dry	24	I
5	Moneragala	Undugodayaya	Intermediate	24	I
6	Badulla	Nikapitiya	Intermediate	24	I

* After Phillips(1995), ** All India Teak Tables

Benefits to farmers

Most farmers undertook inter-row cropping during the first two to three years. Some of them did soil working by ploughing using animal traction. Chemical fertilizers were provided by the project. Cash crops such as groundnut, chilly, various pulses and vegetables brought them a substantial income during the early years. Most farmers interviewed indicated that the inter-row cropping had to be abandoned after the first two or three years, as the dense foliage of young teak saplings disturbed the farming activities.

The only benefit so far received from the tree crop is the meager income by selling the material from the first thinning, which earned between 600 SLR (at the current exchange rate 1 US$ = 96.72 Sri Lanka Rupees) and 2000 SLR per farmer. In several localities the thinned material could not be sold due to poor size or non-availability of potential buyers; it had to be used for domestic purposes or left in the forest.

Farmers' attitudes

Farmers' interviewed during the field visits were quite unaware of the benefit of thinning to the main crop and had been reluctant to carry out thinning. This was obviously due to poor interaction between them and the forestry extension services. The latter played a more prominent role during the establishment phase of the woodlots, but due to the termination of the project and non-availability of funding and support staff, the management aspects of the FWL were not sufficiently conveyed to the farmers.

DISCUSSION

The results of the survey revealed that all sampled FWL show adequate growth during the early years of their establishment; the woodlots should be carefully managed to maximize the timber production during the rest of the rotation. Failure to thin or inadequate thinning has rendered a large part of the teak block plantations grown over a wide span of years in to poor quality. In the light of this experience, prompt action should be taken to bring the FWL in proper management regimes. However, this activity will face several constraints.

Experience in managing FWL, which are smaller scale individual properties, is not available in the country. The local thinning guidelines for teak have been prepared for denser block plantations established with a narrow spacing of 2.8 m x 2.8 m and a rotation period over 35 to 45 years. Due to practical reasons, the conventional thinning based on basal area reduction may not be feasible for FWL. The best thinning option for the FWL would be periodic and systematic removal of stems maintaining a prescribed distance between each individual element. Selection of 'elite' trees for the final felling should be done during the first thinning. The current wide row-intercropping model can be transformed to a silvopastoral system towards the latter part of the rotation (Wilkinson *et al.*, 2000).

The recent pre-commercial thinning done at the age of 6 years and above at an intensity of 20-30% removed the inferior poorly formed stems, which had an irregular distribution within rows. A closer look at the thinned rows of standing trees yet indicates a potential competition between trees planted at a closer spacing of 2 meters within the rows. Removal of trees in a geometrical pattern at a younger age of 4 years could be of advantageous. The usual mechanical thinning by removing 50% of the stems will bring down the number of stems to 200 per allotment, which brings a low income to the farmers.

The current spacing of 5 m x 2 m for planting teak seedlings in the FWL needs reconsideration. A closer spacing of 2.5 m x 3.0 m will not practically hinder the soil working by animal traction or by common farm tractors for intercropping and would not exercise a negative impact on the respective yields. Even at a higher spacing of 5 m x 2 m, the farmers were able to intercrop only for 2 to 3 years and it will remain the same under narrow spacing with a 50% mechanical thinning at a relatively younger age such as 4 years. A closer spacing will have a higher initial stocking of 539 stems per allotment, promotes the height growth and the formation of good boles, reduces the side branching and will offer a better selection of 'elite' trees retained for the final felling.

High financial returns to the farmers and the quality of timber produced needs to be addressed. Weeramunde and Baminiwatte.(2000) calculated the accumulated value of a fully stocked (400 stems) teak FWL growing on a land parcel of 0.4n ha on a moderate site as 779413 SLR (at 12% depreciation) at the end of the lease period of 25 years. Thinning at the ages of 7 and 15 years at an intensity of removing 15% of the stems would bring an interim income of 12853 SLR and 64831 SLR respectively.

Phillips (1995) calculated the rotation for teak block plantations based on the highest IRR at the age of 18 years. Due to different financial commitments involved in the establishment of FWL and the income generated from intercropping, the maximum IRR of FWL will be reached at a lower age. The quality of teak stems extracted from such shorter rotations as industrial timber remains as low valued material. Even at the end of the 25-year lease period, teak will not reach its biological maturity. Locally, on good sites, teak stands will reach a mean DBH of 30- 35 cm at the age of 25 years.

CONCLUSION

The preliminary investigations on the growth and the establishment of the teak FWL resulted the identification of good growth performance of the most stands sampled. The absence of strategical planning is the major bottleneck for the future management of these FWL. The woodlots should be mechanically thinned at an early age by providing sufficient space for each retained stem in the main crop. Other measures such as singling and stem pruning should be undertaken timely. Optimum thinning regimes for the FWL are yet to be identified. A more concentrated effort should be made to familiarize the farmers on better management practices by improved extension services. The current structure of the agro-forestry model should be revised to incorporate more trees in the allotment without affecting the intercropping practices.

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Soil Conditions and Growth of Teak in Successive Rotations in Kerala State, India

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ABSTRACT

Teak plantations occupy an area of about 69,000 ha in Kerala, of which about 64 per cent is in first rotation and the remaining, in second and third rotations. A study was carried out in teak plantations of first, second and third rotations in Nilambur, Kerala to evaluate the soil conditions and the growth of teak in successive rotations. Twenty-four plantations of 8-17 years age groups were selected. Out of these, six plantations were in the first, 10 in the second and eight in the third rotations. In each plantation, 26, 16 and 17 temporary sample plots (20 m x 20 m) were laid out in the first, second and third rotations, respectively, at the rate of one plot per 10 ha of plantation. Soil samples were collected from 0-20, 20-40 and 40-60 cm layers and analysed. The gbh of all trees in the plots was recorded, while the height was measured on a subsample of trees within each plot. Soil analyses revealed that the soils were sandy loam in the surface and loam in the deeper layers in the first rotation and sandy loam and loam in all layers in the second and third rotations, respectively. The soils were medium acid in all rotations, but a decrease in acidity was seen in successive rotations. Organic carbon contents were highest in the first, while exchangeable bases remained almost same in the three rotations. Total N, available K, Ca and Mg were lowest in the second rotation. Among the 11 soil properties studied, the discriminant analysis revealed that there was significant decline in soil fertility with change in rotation. Tree height differed significantly between rotations while there was no significant difference in the gbh of trees. Only 14 per cent of variation in tree height could be explained by the soil properties, as height growth is also controlled by a host of other factors. The differences in site index between rotations were found to be non-significant and this could be due to the high variation in site index within rotation. The study suggests the need for careful management of the soil to reduce soil deterioration.

Keywords: Teak rotation, soil conditions, growth

INTRODUCTION

Teak (*Tectona grandis* L. f.) planting in India started in 1840's and increased to significant levels from 1865 onwards. In 1995, about 94% of global teak plantations were in tropical Asia, with India (44%) and Indonesia (31%) accounting for the bulk of the resource (Tajuddin *et al.*, 1996). The Kerala Forest Department now has about 69,000 ha under teak and approximately 64% are in the first rotation and the remaining 36% are in the second and third rotation stages (KFRI, 1997). Teak plantations constitute about 46.5% of man-made forests in Kerala (Tajuddin *et al.*, 1996). A plantation may exhibit growth rates of between 10 and 20 m^3 per hectare per year (Pandey and Brown, 2000). There is a general apprehension that productivity of teak would fall in successive rotations (Balagopalan *et al.*,1998). It has been reported that the second rotation crops of teak were generally inferior to the first rotation crops on the same sites on account of exposure of the soils in first rotation (Tajuddin *et al.*, 1996).

Although comprehensive studies revealing changes in soil properties and growth of teak in successive rotations are not available, attempts have been made to understand changes in soil properties in plantations in Kerala. In a study of soils in first and second rotation teak plantations in Kerala, Jose and Koshy (1972) reported that soil compaction increased with age of plantations. They also observed that soil fertility declined in older plantations. Alexander *et al* (1980) found that some of the soil properties showed a tendency to change in second rotation when compared with first. Alexander *et al* (1987) also noted that soil properties influenced site quality of teak plantations. Balagopalan and Jose (1982) observed a decrease in soil organic carbon and total N contents in second rotation teak plantations in relation to the first one. Growth of trees in successive rotations in relation to soil conditions has not been explored in detail (Balagopalan and Chacko, 2001). This paper highlights soil conditions and the growth of teak in successive rotations in Kerala, India.

MATERIALS AND METHODS

The study was conducted in the teak plantations of Nilambur South and Nilambur North Forest Divisions of Central Kerala, India. Twenty-four plantations of comparable age groups (8 to 17 years age) falling under first, second and third rotations were selected randomly; six in the first, ten in the second and eight in the third rotations. Temporary sample plots of 20 m x 20 m were laid out in each plantation at the rate of one plot per 10 ha of plantation with a minimum of one and a maximum of eight. Details of teak plantations in the first, second and third rotations selected for the study are shown in Table 1. Total number of plots laid out in the plantations under first, second and third rotations were 26, 16 and 17, respectively. All the plantations located were at an elevation of 35 to 240 m asl and within a slope class of 0-10°.

From each plot, one soil pit of 0.6 m x 0.6 m x 0.6 m size was dug and samples were collected from 0-20, 20-40 and 40-60 cm layers. The soils were analysed

Table 1. Details of teak plantations in first, second and third rotations

Name of Plantation	Range	Division Nilambur	Elevation (m asl)	Year of establishment	No. of plots	Slope	Area (ha)
First rotation							
Old Amaramblam	Kalikavu	South	110	1981	2	4°	7.118
"	"	"	120	1984	1	2°	1.370
Kanakutha	Nilambur	North	35	1978	8	Plain	82.050
"	"	"	45	1979	6	3°	108.230
Kariem muriem	Vazhikadavu	"	100	1980	8	4°	79.000
"	"	"	100	1982	1	3°	11.350
Second rotation							
Edakkode	Edavanna	"	110	1984	2	5°	20.760
"	"	"	110	1981	2	Plain	13.111
"	"	"	200	1979	1	12°	18.750
Aruvakkode	Nilambur	"	110	1978	1	Plain	10.060
Elancherri	Edavanna	"	60	1987	2	4°	3.630
Erampadam	Vazhikkadavu	"	75	1984	2	4°	22.060
Valluvasssery	Nilambur	"	110	1982	2	Plain	12.868
Pulimunda	Karulai	South	240	1981	1	Plain	27.275
Vettikkal	"	"	90	1981	2	Plain	8.375
"	"	"	90	1982	1	Plain	21.200
Third rotation							
Aravallikkavu	Nilambur	North	110	1987	2	7°	1.114
Moolathumanna	"	"	45	1981	2	Plain	16.099
"	"	"	50	1983	1	Plain	7.200
Edakkode	Edavanna	"	120	1983	3	3°	29.530
Ramallur	"	"	110	1981	2	Plain	1.680
"	"	"	100	1983	2	Plain	7.300
Elancherri	"	"	60	1983	2	Plain	15.800
Pulimunda	Karulai	South	200	1984	3	10°	49.720

Table 2. Analysis of covariance on different soil properties in each layer of teak plantations under different rotations

Sources	df	F values/ Layers (cm)			
		0-20	20-40	40-60	0-60
Gravel					
Rotation	2	0.27ns	0.04ns	3.46*	4.27*
Organic carbon					
Rotation	2	3.47*	0.13ns	1.47ns	4.33*

* = Significant at p = 0.05.

for particle-size separates, pH, organic carbon, exchangeable bases, total N, available K, Ca and Mg as per standard procedures in ASA (1965) and Jackson (1958). The mean values of soil properties in the three layers of different plantations under first, second and third rotations are given in Table 2.

The girth at breast height (gbh) was measured at 1.37 m above ground level of all the trees within the selected plots and height was measured on a sub sample of trees within each selected plot. The girth at breast height (gbh) was converted to diameter at breast height (dbh). Top height for each plot was computed as specified by Chaturvedi and Khanna (1982). The site index was also calculated (Jayaraman, 1998).

The differences in soil properties over rotations and the effect of rotation on height, dbh and site index were studied through analysis of variance. Analysis of covariance (ANACOV) using 'MANOVA Univariate' procedure of SPSS described in Norusis (1988) was done. All the analyses were done after transforming the original data as mentioned in Rugmini and Jayaraman (1998). In order to get a better picture of the influence of rotation on the soil properties combinedly, discriminant analysis was done (Jeffers, 1978).

Table 3. Adjusted mean values of soil properties in each layer of teak plantations under dfferent rotations

Soil Properties	Rotation	Depth (cm)			
		0-20	20-40	40-60	0-60
Gravel %	I	31	34	40[a]	34[a]
	II	28	30	31[b]	28[b]
	III	32	30	33[b]	32[b]
Sand %	I	76	75	74	75
	II	79	76	77	77
	III	74	73	73	73
Silt %	I	12	13	14	13
	II	10	11	11	11
	III	13	14	14	14
Clay %	I	12	12	12	12
	II	11	13	12	12
	III	13	13	13	13
PH	1	5.9	5.8	5.8	5.8
	II	5.8	5.9	5.9	5.9
	III	5.9	5.9	6.0	6.0
Org. carbon %	I	1.47[a]	1.20	0.99	1.25[a]
	II	1.09[b]	0.93	0.83	0.92[b]
	III	1.02[b]	1.03	0.94	0.99[b]
Exch. basesme/100g	I	13	14	11	12
	II	12	10	11	11
	III	11	11	13	12
Total N ppm	I	1484	1153	1046	1226
	II	1288	1158	978	1119
	III	1269	1214	1153	1253
Av.K ppm	I	62	62	139	82
	II	82	75	89	72
	III	133	115	66	107
Av. Ca ppm	I	81	74	70	76
	II	65	70	66	67
	III	87	87	86	90
Av. Mg ppm	I	89	90[a]	109	90
	II	60	62[b]	44	69
	III	104	118[b]	95	105

*Values superscribed by the same letter do not differ significantly

I - First rotation; II – Second rotation and III – Third rotation

RESULTS AND DISCUSSION

Soil properties in different layers under different rotations

Analysis of covariance showed that the gravel contents differed significantly between rotations in the 40-60 and 0-60 cm layers (Table 2). Pair-wise comparison between the rotations after eliminating the influence of age with regard to gravel contents indicated that in the 40-60 and 0-60 cm layers, the mean values corresponding to rotation I were significantly different from those in rotations II and III while the difference in mean values between rotations II and III were found to be non-significant.

There were no significant differences between rotations, with respect to sand, silt, clay, exchangeable bases, total N, available K and Ca contents and soil pH in all the layers (Table 2). The soils were sandy loam in the surface and subsurface and loam in the 40-60 cm layer in the first rotation while they were sandy loam and loam in all layers in the second and third rotations, respectively.

The differences in organic carbon contents between rotations were found to be significant in the 0-20 and 0-60 cm layers (Table 2). Pair-wise comparison between rotations in the 0-20 cm and 0-60 cm layers showed that mean values in rotation I differed significantly from those in rotations II and III while those in rotations II and III showed no significant difference. In the 0-60 cm layer, gravel contents, organic carbon, exchangeable bases and total N contents were highest in rotation I (Table 3). Available K contents were highest in the third rotation in the 0-60 cm layer. In the case of available Mg content, there was significant influence of rotation in the 20-40 cm layer (Table 2). Pair-wise comparison between rotations with regard to available Mg contents in the 20-40 cm layer, showed that mean value in the first rotation differed significantly from those in second and third rotations while those between second and third rotations showed no significant difference (Table 3). Available Ca and Mg showed that they were highest in soils under third rotation in all layers (Table 3).

Discriminant analysis on soil properties

The coefficients of the discriminant functions are reported in Table 4. The two discriminant functions generated explained 71% and 29% of the total variance. The corresponding X^2 values were also highly significant, which indicated that the function identified had significant discriminating ability.

In order to find the contribution of the variables to each function, the correlation coefficients between the variables and the functions were examined (Table 5). The first discriminant function was found to be highly negatively correlated with organic carbon, total N and available Ca. The result indicated that the changes in rotation brought about changes largely in the status of these soil properties. The three soil properties together represent a major portion of soil fertility. The negative sign indicated that the values of function 1 would be high for the least values of organic carbon, total N and available Ca or as the function value increased, the soil fertility decreased (Table 5).

In the case of function 2, it was highly correlated with silt (positively) and sand (negatively). This indicated that the changes in rotation affected the changes in these soil properties. These properties together represent the soil texture (Table 5).It can be seen quite clearly from Table 6 that the mean values of function 1 were lowest in rotation I and highest in rotation III. This revealed that the soil fertility decreased from rotation I through III. There was no specific trend for the mean values for the second discriminant function, viz., soil texture among rotations. Thus the results clearly indicated that soil fertility decreased in successive rotations. The differences in height between rotations were found to be significant. In the case of dbh, the differences were found to be non-significant between rotations. Age did not have

Table 4. Standardized canonical discriminant function coefficients

Properties	Function 1	Function2
Sand	0.81568	1.70827
Silt	1.10449	2.33321
pH	.49384	.36814
Organic carbon	-.96121	.19741
Exchangeable bases	-.43847	-.76213
Gravel	-.14398	.09682
Total N	.50963	-.11698
Available K	.11899	.25176
Available Ca	-.42009	.48813
Available Mg	.00948	.38403

Table 5. Pooled within groups correlations between discriminating variables and canonical discriminant functions

Property	Function 1	Function 2
Organic carbon	-.85686	.37250
N	-.64522	.32639
Ca	-.46275	.33366
Mg	.36769	-.06295
Exchangeable bases	-.36588	.22548
PH	.24978	.20160
K	-.20504	.15629
Silt	-.23170	.66369
Sand	.24952	-.48013
Gravel	-.21087	.21439

Table 6. Adjusted mean values of height and dbh of trees and unadjusted mean values of site index under three rotations

Growth paramers	Rotations		
	I	II	III
Height (m)	16.58^{b}	12.45^{a}	13.70^{ab}
Dbh (cm)	18.09	14.35	14.58
Site index (m)	24.71	21.91	24.21

Figures superscribed by the same letter in the first row indicate non-significance

Table 7. Coefficient of variation of site index within rotation and slope

Rotation	Slope*	Coefficient of variation
I	1	12.88
I	2	38.77
II	1	17.83
II	2	38.34
III	1	11.51
III	2	18.46

* 1 = indicates plain; 2 = indicates hilly terrain

significant effect on height and dbh since there was considerable variation in the characters within any particular age level. Pair-wise comparison between the rotations after eliminating the influence of age with regard to height and dbh is reported in Table 6. The adjusted mean values for height and dbh were maximum in rotation I and minimum in rotation II.

The significant difference in height between rotations could be due to, among several factors, the significant change in soil fertility and variation in soil texture. The effect of soil properties on height was studied through multiple linear regression analysis and it was found that soil properties accounted for 14% of the variation in height, after eliminating the age effect.

Analysis of variance on site index between rotations revealed that the differences were non-significant (Table 7). It was also noticed that there was considerable variation in site index within each rotation. This shows that the effect of rotation is very much dependent on site. Mean values for site index was maximum in rotation I and minimum in rotation II (Table 6).

Before conversion to teak plantations, the areas were under natural forest. In the natural forest ecosystem, most of the nutrients were present in living and dead biomass and tight cycles existed. There would be a shift in equilibrium when the natural forests are clearfelled and the plantations established. The soils in rotations I, II and III were under teak for 8-17, 63-72 and 118-127 years, respectively after clearfelling the natural forest, taking into account, the rotation age of teak as 55 years. Moreover, the soils in first, second and third rotations have undergone complete exposure to environmental factors, once in the case of first rotation while the plantations in the second and third rotations were exposed to twice and thrice, respectively. They were after clear felling the natural forest in the case of rotation I and with respect to rotation II, in addition to this, another one which was after final felling the first rotation teak when it was 55 years old. With regard to rotation III, in addition to the above two, the third exposure was after final felling the second rotation teak.

The disturbances followed by establishment of plantations have affected the soils in successive rotations. This is clearly manifested in gravel, sand and silt as well as organic carbon, total N and available Ca contents. Usually it will take thousands of years for the particle-size separates to change. Here there was significant change in gravel and particle-size separates between rotations, which have taken place in a period of around 8-127 years. This revealed that the plantation activities have significantly affected the gravel and particle-size separates; this could be most probably the disturbance caused by accelerated soil erosion due to exposure of soil surface. With respect to organic carbon, total N and available Ca, removal of slash from the sites, weed problem as well as poor litter accumulation, the latter two due to exposure could be some of the pertinent factors, which have affected the soil fertility.

The decline in soil fertility in successive rotations was found to affect the tree growth significantly. It was also noted that the soil properties accounted for 14% variation in tree height. The effect of soil properties on dbh of trees was not very much. This could be due to the fact that as the plantations selected were in the age group of 8-17 years old, only the first and second mechanical thinnings have taken place. During the period prior to these operations, the emphasis was more on height of the trees rather than dbh and the former was found to be significantly affected. It may be worthwhile investigating these factors little more extensively to further examine the effect of various soil parameters for which evidence for explanation was lacking.

CONCLUSIONS

The study of soils and growth of trees in first, second and third rotation teak plantations at Nilambur showed that

1. the soil fertility, in terms of organic carbon, total N and available Ca, declined from first rotation to second and third rotations
2. decline in soil fertility was reflected on tree height rather than diameter at breast height
3. soil properties accounted for 14% variation in tree height
4. the differences in site index between rotations were found to be non-significant due to the high variation in site index within each slope and rotation
5. there is an urgent need for careful management of the soil to reduce soil deterioration.

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Sustainable Teak Plantations in the Tropics: The Question of Nutrient Management

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ABSTRACT

For more than a century and half, foresters have been growing teak, often repeatedly at the same site. However, sustainability of monoculture plantations in the tropics, in general, and teak in particular, has been questioned recently, because of potential adverse effects on soils. Although chemical and biological fertilizations are suggested as universal remedies to resolve the crisis of site deterioration, there have been few experimental studies on teak nutrition, which is summarised here as the current state of knowledge on nutrient management of teak. Succinctly, N, P, K and Ca availability in the soil, limit teak growth, even though the results of chemical fertilization are inconsistent. As an alternative, growing mixed species stands with N-fixing trees is more promising. A limited number of replacement series experiments available in this respect, indicate that N-fixing trees improve growth of associated teak and soil nutrient concentrations. Drawing on results from studies on other species, such mixtures presuppose complementary resource use and grow well with minimal inputs, even on degraded sites. Although nutrient management is the central premise of sustainable teak plantations, nutritional interactions, N transfer between teak and associated N-fixing trees, besides yield and site quality deterioration and nutrient cycling over successive rotations, have been seldom assessed. Most of the reported studies do not go beyond spasmodically evaluating height, diameter and/or basal area responses of the tree, over short intervals. Therefore, a network of long term coordinated experiments with graded levels of applied nutrients and species mixtures involving N-fixing trees is suggested to gain insight on nutrient relations, site quality deterioration and the contribution of N-fixing species on teak growth and nutrition.

Keywords: Litter dynamics, mineral nutrition, N-fixing woody perennials, site quality, deterioration, species mixtures

INTRODUCTION

Establishing forest plantations to meet the ever-increasing demand for tree products has been a long-standing tradition in the tropics (Evans, 1982), albeit it gained momentum only after the Second World War. These man-made forests are thought to outsource the rising industrial and domestic wood requirement and ease pressure on tropical forests, which are "our doomed warehouses of global biodiversity" (Ewel, 1999). In 1995, there were about 44 million ha of forest plantations in the tropics, but estimates for 1999 exceed 60 million ha (FAO, 1999), implying a dramatic rise in the global coverage of tropical tree plantations. India alone has about 15.34 million ha of forest plantations; of this teak accounts for about 1.3 million ha (ca 8.7%; FSI, 1999). Globally teak ranks third among the tropical hardwood species in plantation area (Table 1) and constitutes about 8% of the plantations in countries with climatic regimes suitable for teak culture (Pandey and Brown, 2001).

Important teak growing countries include India (44%) and Indonesia (31%), having bulk of this resource. Other countries of tropical Asia with significant planted teak are Thailand (7%), Myanmar (6%), Bangladesh (3.2%) and Sri Lanka (1.7%). About 4.5% of global teak plantations are in tropical Africa (largely in moist West Africa, particularly in Côte d'Ivoire and Nigeria) and the remainder in tropical America (mostly in Costa Rica and Trinidad and Tobago) and the Pacific Islands.

Recent changes in land and tree tenure and improved access to markets in some countries have encouraged cultivation of teak by farmers as an integral part of their farming systems, in small woodlots, in home gardens or in mixtures with other trees and agricultural crops (Nair and Souvannavong, 2001). Commercial considerations and the desire to enhance overall profitability from the land are foremost in farmers' decision to cultivate teak. Besides shorter rotations, this has inadvertently led to the extension of teak farming into sites, which are probably less suitable. Promotion of such short rotation and/or poor site plantations, apparently to resolve the chronic wood shortages, has raised concerns about their sustainability.

In addition, loss of nutrients during harvest of short rotation plantations may far exceed the rate of replenishment by weathering of minerals in soils or by input via precipitation (Goncalves *et al.*, 1997). Of particular concern is the threat that frequent harvest related nutrient exports could result in soil fertility deprivation and productivity declines. Further losses may occur due to inter-rotation site management practices such as slash and burn, site preparation etc. (Nykvist *et al.*, 1994). The uncertainty, therefore, is: can teak (other plantations too) be grown perpetually on the same site without risk to their vigour and rate of growth? Silvicultural techniques such as application of chemical fertilisers and/or intercropping N-fixing plants are often recommended to augment soil nutrient availability. This paper attempts to review the literature relating to fertilisation including the use of biological nitrogen fixation to promote sustainability of teak plantations in the tropics.

Table 1. Main tropical hardwood species in terms of plantation area, 1995

Species	Area (ha)	Percentage of tropical plantations
Eucalyptus spp.	9 949 588	17.7
Acacia spp.	3 904 307	7.0
Tectona grandis	2 246 559	4.0
Casuarina spp.	787 200	1.4
Dalbergia sissoo	626 020	1.1
Gmelina arborea	418 050	0.7
Swietenia macrophylla	151 214	0.3
Terminalia spp.	303 957	0.5

Source: Pandey (1998)

EDAPHIC REQUIREMENTS AND NUTRIENT DISORDERS IN TEAK – AN OVERVIEW

Evidently, teak prefers fertile deep riverine alluviums (see White, 1991; Tewari, 1992 for details); clay content, pH, nitrogen, moisture content, silica-sesquioxide ratio, drainage, soil texture, base saturation and root-available depth are major determinants of productivity (Hase and Foelster, 1983; Drechsel and Zech, 1994; Balagopalan *et al.*, 2001). Many workers (Briscoe and Coronado, 1971; Zech and Drechsel, 1991; Glaser and Drechsel, 1992; Hernandez *et al.*, 1993; Sudhakara *et al.*, 2001) also reported that stand basal area and volume increment increased with increasing foliar N, P, K or Ca levels. Yet teak is grown on a variety of soil and site conditions including the acid ferralitic soils of West Africa where P and K deficiency symptoms such as chlorosis, necrosis and dieback are frequent (Zech and Kaupenjohann, 1990). Likewise, stunted growth caused by nutrient deficiencies is typical in several areas of Philippines (Zech, 1990). Drechsel and Zech (1994) using Diagnosis and Recommendation Integrated System (DRIS) concluded that N, Ca and P were most deficient on the high productivity sites of Benin, Cote d'Ivoire, Liberia, Nigeria and Togo, while in 45% of all stands there was a relative aluminum excess.

HARVEST-RELATED NUTRIENT EXPORT

Forest plantations are generally regarded as highly productive ecosystems with an above ground net primary production often exceeding 40 t ha^{-1} yr^{-1} and wood production more than 10 t ha^{-1} yr^{-1} (Lugo *et al.*, 1988). Reports on teak productivity, however, are more variable depending on stand age and/or site characteristics. For instance, Negi *et al.* (1995) estimated the total standing biomass of 10 year-old stands as 74.5 t ha^{-1} and that of 30 year-old stands as 164.1 t ha^{-1}. In another study on a 20-year-old teak plantation in Tamil Nadu, George and Varghese (1992) recorded a total biomass production of 180 t ha^{-1} and an annual productivity of 8.69 t ha^{-1} of non-photosynthetic biomass. Despite teak plantation productivity being lower than some other tropical species (Lugo *et al.*, 1988; Kumar *et al.*, 1998a), the potential for nutrient export through harvest related processes is enormous. Negi *et al.* (1995) found that harvesting of utilizable biomass in a 30 yr old stand resulted in the removal of 247, 41, 170, 632 and 198 kg ha^{-1} of N, P, K, Ca and Mg, respectively. Similarly, George and Varghese (1992) reported an annual uptake of 264 kg N ha^{-1}, 17 kg P ha^{-1}, and 132 kg K ha^{-1} for a 20 year-old stand, nearly all of it could be exported, when the trees are harvested.

LOW ORGANIC MATTER TURNOVER AND PRODUCTIVITY DECLINE IN SUCCESSIVE ROTATIONS

Low organic matter inputs into the soil and the consequent decline in mineralization of organic nutrients is yet another problem in teak plantations, as in other monoculture stands. A progressive degradation of continuously teak-grown sites has, therefore, been reported (Chacko, 1995; Balagopalan *et al.*, 2001 and the references therein). Also, strong indications are available regarding productivity decline in successive rotations. Yet few attempts have been made to compare teak productivity between rotations presumably because of the problems outlined by Evans (1999). Furthermore, it has been predicted that as a consequence of global warming and the resultant accelerated soil organic matter (SOM) oxidation, degradation of these nutrient-poor tropical soils will be faster (Seneviratne, 2000).

LITTER DYNAMICS

To be sustainable, a managed land use system should imitate the structure and functioning of natural ecosystems, which are the results of natural selection over long periods (Ewel, 1999). The dynamics of litter production and decomposition plays a fundamental role in the stability of natural ecosystems. In plantations where a single species dominates, however, decomposition of that species' litter drives the ecosystem-level organic matter dynamics and control fluxes in, and out of the accumulated litter nutrient pool. In a comprehensive review on organic matter accretion and decomposition in forest plantations, O'Connell and Sankaran (1997) noted that litter fall in teak plantations ranges from 5.5 to 12.1 t ha^{-1} with a mean value of 7.7 t ha^{-1} over stand ages varying from 15 to 56 years. However, for the natural moist deciduous forests of Thrissur, Kerala, where teak occurs naturally, Kumar and Deepu(1992) reported an annual litter fall of 12 to 14 t ha^{-1}. Although this implies a modestly higher litter fall rates for the natural forests, the quantum of organic matter inputs in teak plantations is nevertheless substantial. Some workers also noted analogous nutrient accretion rates. For example, Egunjobi (1974) showed that annual litter fall on an average accounted for 91 kg N, 10 kg P, 71 kg K, 188 kg Ca, 22 kg Mg and 2 kg Na ha^{-1} for teak plantations in Nigeria (9024±882 kg litter ha^{-1}).

Once on the forest floor, the litter is subject to a variety of processes, which result in its disappearance. Half lives of teak litter reported in the literature ranges from 2.2 to 5.9 months (Kumar and Deepu, 1992; Sankaran, 1993; O'Connell and Sankaran, 1997). Indications are that teak litter decomposes rapidly (George and Varghese, 1992; Sankaran, 1993), but it may inhibit N-mineralization (Maheut and Dommergues, 1960).

Litter production-decay relationships and associated nutrient cycling in teak are perhaps more complex in view of the dramatic effects of stand age, site, climate, disturbance and other factors that affect productivity. However, number of studies investigating temporal changes in litter fall/decay are few; while some have examined a single age-class, others have used an isolated site class. Moreover, results of young plantations are not necessarily relevant for subsequent phases of stand development. Generally in plantations, litter fall increases as stand age increases and plateaus out at about the time of crown/canopy closure (Jamaludheen and Kumar, 1997). Consequently, after canopy closure, plantations may act as self-nourishing systems as they recycle a higher proportion of nutrients. In addition, older teak trees take nutrients more efficiently from deeper soil horizons and return them to the soil surface as leaf litter (Marquez *et al.*, 1993). Coincidentally, favourable impacts of teak planting on soil characteristics have been observed. For instance, Hosur and Dasog (1995) asserted that teak planting decreased soil bulk density and pH, whereas, soil aggregation, organic matter and exchangeable calcium increased in the red loam

(Inceptisol) soils of Karnataka. Nonetheless, quick growing trees may actively withdraw soil nutrient reserves, especially during the early phase of growth (Kumar *et al.*, 1998a), when the biogeochemical processes are insufficient to provide for the nutrient requirements of an actively growing stand, necessitating fertilisation prior to canopy closure (Miller, 1981).

MINERAL NUTRITION OF TEAK PLANTATIONS

It is widely believed that teak is an exacting species, and that intensively managed plantations (high density) are expected to place large demands on soil nutrient reserves. However, the extent of scientific studies on teak nutrition have been disproportionately lower than what the economic value, ecological benefits, and/or silvicultural importance of the species would warrant. Although nutritional studies on teak were initiated as early as 1933 in Java (Coster, 1933; Drees, 1940) and 1934 in Nilambur (Schnepper, 1934), there are surprisingly few published reports on teak plantation fertilisation. The CAB abstracts (1939 to present) list only less than a dozen studies on this aspect (excluding those on teak nurseries).

A plausible explanation for the fewer number of teak fertilization studies is that many early authors found fertiliser application had little or no beneficial effect on teak growth or that the effect was at best temporary. For instance, Drees (1940) reported that application of ammonium sulphate, potassium chloride and slaked lime did not favour teak growth. Later on, Briscoe and Coronado (1971) stated that neither height nor basal area was significantly influenced by added N, Ca or Mg for 3 to 16 years old teak plantations in Puerto Rico. In another trial at Chiengrai, Thailand, height and radial growth increments of 10-yr-old teak trees treated with ammonium phosphate at 2.1 kg tree^{-1} were not significant after one year (Thaiutsta *et al.*, 1976). Likewise, application of nutrients at 50:25:25, 100:50:50 and 150:75:75 kg N, P_2O_5 and K_2O ha^{-1} (Gawande, 1991) and urea at 100, 200 and 300 g/plant (Bheemaiah *et al.*, 1997) did not result in significant growth responses for five-year-old teak in Kerala and 2.5 year-old teak in Andhra Pradesh respectively.

RAISON D'ÊTRE FOR LACK OF FERTILISER RESPONSE

Although Miller (1981) argued that fertiliser response lasting three to many years is probable prior to canopy closure, several experimental studies on teak (listed above) did not show positive growth responses, regardless of stand age. This lack of fertiliser response may be explained on the basis of three factors, which may operate either separately or in unison. First, fertilisation may enhance the growth of competing understorey vegetation, especially in young stands. This, if happens, may curtail fertiliser response through limiting availability of not only those nutrients supplied, but also suppressing the availability other site resources such as moisture or light. Although data relating to competition between teak and understrorey plants are not available in the papers cited in the preceding paragraph, evidences from other tropical species signify that (Shujauddin and Kumar, 2003).

Second, chemical fertilisers in general and N in particular, tend to enhance the palatability/nutritional quality of the leaves and twigs, in turn, increasing herbivore pressure. Also, since resource availability in the environment is inversely related to plant defense (Coley *et al.*, 1985), added nutrients may increase the herbivore food choice and herbivory pressure. Thus, it is probable that heavily fertilised stands experience greater pest incidence, in turn, suppressing growth response to added nutrients (Shujauddin and Kumar, 2003). However, data on herbivory levels in fertilised and unfertilised teak stands are not available, though information on field crops abounds in the literature.

Thirdly, if the inherent mineral nutrient supplying power of the site is high, then there may be little response to applied fertilisers. Interestingly, when favourable responses were observed, this was on poor sites (e.g., Drees, 1940; Ananthapadmanabha *et al.*, 1998). In addition, there may be long-term increase in soil fertility of repeatedly fertilised sites, as the nutrients stored in organic matter are released at an increased rate (Thomas *et al.*, 1998). This increased rate of nutrient recycling will reduce the use efficiency of inorganic nutrients and may also lead to their reduced retention, especially under low

SOM levels. Other factors such as nutrient immobilisation and/or leaching may be important in stopping the fertiliser response. However, published reports seldom contain such details as soil fertility changes of continuously fertilised stands and the extent of nutrient immobilization/leaching.

AFFIRMATIVE RESPONSE TO NUTRIENT ADDITION

Despite such lack of response to applied fertilisers reported by many, some authors (e.g., Schnepper, 1934; Bhatnagar, 1969; Briscoe and Coronado, 1971; Prasad *et al.*, 1986; Kishore, 1987; Singh, 1997) demonstrated that teak growth and basal area increment are positively correlated with nutrient additions. Miller (1981) based on empirical evidences from temperate plantations, suggested that response to added fertiliser is best considered as a reduction in rotation length. However, this aspect has not been elucidated in teak. Furthermore, in some studies, which report positive influences of added nutrients, the effects were not consistent; whilst some parameters were stimulated, others were not affected. For instance, Kishore (1987) reported that diammonium phosphate (DP) significantly increased height growth of teak in the first 2 years after establishment, but no perceptible increase in radial growth was observed. In another study on continuous fertilisation (for 5 years) of 10 and 20 year old teak plantations with 0, 150 or 300 kg ha^{-1} N (as urea) and 0, 75 or 150 kg ha^{-1} P (as superphosphate), though height and diameter increased in both plantations, volume production increased only in the 10-yr-old plantation (Prasad *et al.*, 1986).

Regarding rates, methods and sources of P to teak, Kishore (1987) found that DP (80, 120 or 160 g) applied in circular ditches 10 cm deep and 20 cm from each plant significantly increased height growth of teak in the first 2 years after establishment. Synergistic effects of soil management practices such as irrigation, drainage and application of biofertilisers were also depicted in some studies. Gogate *et al.* (1995) after a critical assessment of a series of high input teak plantations in Thane, Maharashtra observed that irrigation in conjunction with NPK fertilizer (50 g per plant annually for 3 years) gave positive growth (height and girth) responses. Torres *et al.* (1993) working on alluvial sites with moderate drainage in Venezuela, found more diameter and height growth for 2-year-old plantations when a fertiliser dose of 740 kg ha^{-1} (28% P_2O_5, 39% CaO) was applied, compared to 0 and 370 kg doses. Ananthapadmanabha *et al.* (1998) also reported that application of calcium nitrate (CN), DP or CN + DP (at rates equivalent to 250 kg ha^{-1}), with inoculation of *Glomus caledonium* or composite teak rhizosphere VAM (250-300 spores/100 g soil) showed better height growth and foliar N and P levels on a poor site 2 years after treatment.

In general, most reported studies do not go beyond spasmodically evaluating height, diameter and/or basal area responses over short intervals (one or two years). There has been seldom a study on changes in soil organic matter dynamics, changes in site nutrient capital, tree/stand leaf area index and/or canopy coverage/thinning vis a vis nutrient relations over successive rotations. Although positive response to the fertiliser applied in conjunction with thinning is legitimately expected, such studies are conspicuously absent in teak. Despite this, fertiliser application to teak has become a common practice in recent years. In particular, application of 163 kg urea, 375 kg Mussorie rock phosphate, 145 kg Muriate of potash, 105 kg quick lime and 373 kg of magnesium sulphate per ha has been recommended (Balagopalan *et al.*, 2001) for young plantations in Kerala (two splits in the first year and four splits during second and third year). Such practices generally aim at ameliorating soil conditions, especially in the private teak plantations that are springing up under a wide variety of site conditions.

SPECIES MIX INVOLVING NITROGEN FIXING TREES

Many natural forests contain simultaneous or sequential mixtures of nitrogen fixing and non-nitrogen fixing species. Examples include native stands of *Acacia* and *Eucalyptus* in Australia, besides alder and conifers in many temperate locations. As N losses are likely to be very important in plantation production systems, new systems of plantation management, which mimic the natural ecosystems where significant quantities of N are added via the biological fixation pathway, assume significance. Leguminous cover crops are widely used in the rubber (*Hevea brasiliensis*), oil palm (*Elaeis guineensis*) and cacao (*Theobroma cacao*) plantations of the tropics (Nair, 1993), but use of woody legumes as a source of N nourishment to forest plantations has been less frequent. Furthermore, few experiments involving replacement series of N-fixing trees and teak have been published. Incentives for adoption of mixed species plantations as alternatives to monocultures, however, may include economic considerations (increased productivity), plantation health (reduced losses due to disease and insect attacks), sustainability and diversification of wood products (Montagnini *et al.*, 1995; Khanna, 1997; Nichols *et al.*, 2001), besides greater C sequestration (Kaye *et al.*, 2000).

In one such experiment on intercropping teak with *Leucaena leucocephala*, Kumar *et al.* (1998b) reported that teak growth (height and diameter) increased linearly as the proportion of *Leucaena* increased (Fig.1). At 44 months after planting, teak in the 33:67 teak-*Leucaena* -mixture was 45% taller and 71% larger in diameter at breast height than those in pure stands. Soil analysis of the experimental plots provided corroborative evidence in this respect: i.e. total soil nitrogen and available P increased with increasing relative proportion of *Leucaena* in the mixture.

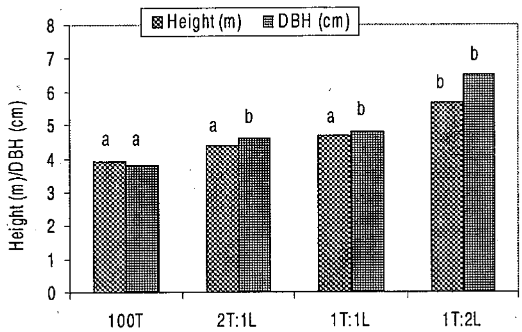

Figure 1. Mean height and diameter at breast height (DBH) of teak saplings at 44 months of age as affected by relative proportions of teak and *Leucaena* in the mixture (100T= teak monoculture, 2T:1L= two rows of teak for every row of leucaena, 1T:1L= alternate rows of teak and leucaena and 1T:2L= one row of teak for every two rows of leucaena). Bars with the same superscript do not differ significantly for a given parameter. Probability level of significance for height <0.05 and DBH <0.01. *Source:* Adapted from Kumar *et al.* (1998b).

Although other studies on intercropping teak with N-fixing trees are not readily available, a few workers reported similar favourable influence of N fixing trees on other plantation species. For instance, *Eucalyptus saligna* showed higher growth when mixed with *Acacia mearnsii* (Smith *et al.*, 1989) and *Albizia falcataria* (syn. *Paraserianthes falcataria*; DeBell *et al.* 1989; Binkley *et al.*, 1992). Likewise, Khanna (1997) observed better height and volume increments of *Eucalyptus globulus* grown in association with *Acacia mearnsii* besides, higher N concentrations of live and senescent leaves and fine roots. *Terminalia amazonia* in combinations with *Inga edulis*, also achieved early canopy closure, thus obviating the need for continued weed control in plantations (Nichols *et al.*, 2001).

The implicit assumption in such studies is that the N fixing species may improve the environment experienced by teak (facilitative production principle; Vandermeer, 1989) and/or complementary resource use. However, species growing in mixture can potentially compete with one another for site resources such as light, water and nutrients. Teak being shade intolerant, selection of appropriate species with compatible crown form and growth characteristics is critical. Furthermore, tree species differ substantially in their effects on soil development and nutrient supply (see review by Binkley and Giardina, 1998), and that there may be potential interaction between site quality and the additional quantities of N fixed by the legume/ actinorhizal component. Overall, the usefulness of growing mixed species stands compared with monoculture will depend on any positive effects of mixed stands on productivity of the target species and site fertility as well as on the silvicultural options of managing the mixtures. It is also essential to consider the impact of harvesting on site nutrient relations, and the productivity of subsequent rotations.

IMPLICATIONS FOR MANAGING TEAK STANDS

Despite results of nutritional experiments on teak being largely inconsistent, fertiliser (chemical or biological) application in young stands prior to canopy closure or in conjunction with thinning operations, which open up the canopies in older stands, seems to be indispensable to sustain productivity. Paradoxically, large variations in the ability of trees to absorb nutrients under different conditions of nutrient supply and stocking levels are plausible. Application of fertilisers under conditions of weed competition, pest incidence and/or moderate to high inherent soil fertility may not be beneficial. Conversely, in systems where the inherent fertility of the soil is lower, favourable response to fertilisers is almost certain. Hence fertiliser application to teak plantations should consider the site nutrient supplying power, stocking levels and silivicultural strategies, besides the potential for weed competition/pest incidence.

Using N_2 fixing trees (*Leucaena, Gliricidia* or other woody legumes) could be a viable silvicultural option for stimulating early teak growth, especially on unfertilized sites. Many teak plantations being unfertilized, this has considerable practical significance. Despite the favourable effects of intercropping on teak growth (Fig. 1), increasing the relative proportion of N fixing tree substantially (>50%) may be counter-productive on good sites, as this would substantially reduce the teak population density. A 50% mixture (alternate rows of teak and N fixing tree), however, is considered optimal even under such conditions. The rationale is that in a conventional 50-year-rotation of teak, first mechanical thinning (removal of alternate diagonal rows of teak) that reduces teak density by 50% is carried out around the fifth year. Therefore, teak density in a monoculture stand after the first mechanical thinning will be at par with that of a 1:1 teak-N fixing tree binary mixture. Moreover, teak generally does not yield merchantable materials at the first mechanical thinning. In contrast, *Leucaena* or other N-fixing species planted in the interspaces may yield substantial quantities of firewood, small timber and green leaves.

Furthermore, as the initial stand density in a typical 50-year rotation of teak is reduced to a quarter by around the 10th year, even a higher proportion of the nitrogen fixing tree component (>50%) could be appropriate, especially on poor sites. Therefore, it makes sense to mix teak with a nitrogen fixing tree species even up to 67% of the total stand density (one row of teak for every two rows of N fixing tree on such sites) without any appreciable loss of teak yield due to the reduced initial density. Nonetheless, factors such as site quality and managerial considerations are perhaps important determinants of the proportion of N_2 fixing species to be included in the mixture. Teak being a strong light demander (White, 1991), the intercropped fast growing multipurpose trees also must be managed (pruned/lopped etc.) to avoid any possible suppression of teak. Besides, many leguminous trees perform well only when inoculated with the appropriate strains of *Rhizobia*, and the cultures of arbuscular mycorrhizal fungi (AMF), implying the need for judiciously managing the N-fixing tree components.

CONCLUSIONS AND FUTURE LINES OF WORK

Nutrient cycling processes endow mature teak plantations the ability for self-nourishment. A clear understanding of the various aspects of nutrient cycling is, therefore, fundamental for teak plantation systems to continue to provide social, economic and environmental benefits over successive harvests. Measures suggested for sustaining soil fertility include application of mineral fertilizers and the introduction of N-fixing species either in admixture or as an understorey. However, the empirical data have not supported strong generalisations. Number of studies presently available on teak nutrition and site quality decline over successive rotations is perhaps too small and that long term studies are clearly absent. Although mixtures that include N-fixing species showed increased soil N availability in comparison to teak monocultures, foliar data are not readily available. Quantitative estimates of nitrogen transfer between the legume and non-legume components are also rare. Therefore, a modest network of coordinated experiments on graded levels of applied nutrients to teak and species mixtures involving teak and N fixing trees is proposed. This will provide insights on species interactions and the contribution of the N-fixing species and applied nutrients on teak growth and nutrition over successive rotations. Attempts should also be made to standardise the quantum of fertilisers to be applied under differing site qualities, periodicity (repeated annually or at longer intervals) and methods of application (broadcast, placement or banding), which have been neglected in the past, but is critical to avoid failures, minimise ecological damage and optimise the use of soil, water and energy resources.

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Teak and its Canopy Parasite *Dendrophthoe* – Water Relations and Ecophysiology

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ABSTRACT

Teak (*Tectona grandis* L. f.), the most important timber species in India, is widely infested by an angiosperm hemiparasite, *Dendrophthoe falcata*. The mistletoe clumps cause enormous damage to the trees, sometimes leading to their death. The paper explains the ecophysiological factors that help the survival of this parasite. The diurnal water potential measurements done on both the host and the parasite during different seasons revealed that the parasite always maintains lower water potential compared to the host tree, which is ideal for taking up water from the host. The lowest water potentials recorded were –1.07 MPa in teak and –1.08 MPa in parasite. The stomatal conductance values recorded during pre-monsoon (dry) period were similar in both the host and the parasite. Maximum values were in the range of 500-to 600 mmol m^{-2} s^{-1}. A maximum net photosynthesis of 13 mmol m^{-2} s^{-1} was observed in teak whereas the parasite showed values >9 mmol m^{-2} s^{-1}. Diurnal measurements of light availability showed that the parasite received only 40 per cent of the light received by the host. The parasite was seen to survive well in well-exposed situations and even when the host leaves blocked 70 per cent of the solar radiation. The data on the light requirement by the host and parasite indicate that the parasite is able to survive both under shaded and fully exposed condition. This behaviour has great implications on the adaptability of this parasite to opposing light environment and this is to be taken into account in work aimed at controlling the parasite. Transpiration measurements showed that the parasite transpired less during mornings and evenings, but during peak hours, it transpired more as compared to teak. Chlorophyll fluorescence measurements revealed differences in the photosynthetic efficiency between the host and the parasite. Chemical analysis of leaves indicates more K and Na in the leaves of the parasite compared to host. Any control measures targeted at the parasite should be done during the deciduous stage of the host tree.

Keywords: Teak parasite, *Dendrophthoe falcata*, water relation, ecophysiology

INTRODUCTION

Infestation of teak plantation by mistletoes is common all over India. The hemiparasite, *Dendrophthoe falcata* var. *pubescens* is the most widely occurring mistletoe on teak trees in India. Like any other hemiparasite, it is believed to draw water and minerals from the host tree, at the same time, capable of photosynthesizing in its own leaves. The infested trees show enormous growth retardation, and at a later stage even resulting in death. It is really perplexing to note that a small parasitic plant can reduce the timber yield from such a large tree and sometimes completely damage the tree. To find an answer to this question, we studied the ecophysiological relations between the host and the parasite with the following objectives:

a. to understand the water relations, transpiration and gas exchange characteristics of the hemiparasite *Dendrophthoe falcata* in relation to its host, the teak tree.
b. to examine the interaction of the water relations of the hemiparasite with the nitrogen and mineral nutrition of teak, and

c. to study the ecophysiological factors that promote the growth of the parasite on teak.

For the past few years, Kerala Forest Research Institute has been actively involved in the study of parasite control in teak (see Ghosh *et al.*, 1984; Balasundaran and Ali, 1989). The above studies have been directed to control the infestation of the parasite in teak plantations. Although much work has been done to understand the ecophysiological relationship between the host and parasite in several temperate trees, there is hardly any such detailed study from the tropics.

MATERIALS AND METHODS

Site details

Detailed measurements on the physiological parameters on teak infected by *Dendrophthoe falcata* were carried out for three years at two locations, *viz.*, Peechi (Site I) and Kayampoovam (Site II), details of the sites are given in Table 1. Steel scaffold towers of 12 m height were erected at both the sites to gain access to the crown of both the host and the parasite for the ecophysiological measurements.

The weather parameters of the locations were collected hourly using an automated weather station (Minimet, Skye Instruments, UK). Water status of the leaves was checked by measurements of water potential (y), using a pressure chamber (Soil Moisture Corporation, Ohio, USA).Stomatal conductance (g_s) of the host and parasite leaves was measured using a Steady State Porometer (Model Li-1600, Li-Cor, Nebraska, USA). An average of eight leaves were measured on an hourly basis starting from sunrise to sunset. Leaf Net photosynthesis (P_n) was measured using a portable infrared gas analyser (Model LI-6200, Portable Photosynthesis System, Licor Inc., Nebraska, USA) using a one-liter leaf chamber.

Chlorophyll-a fluorescence

To study the function of the photosynthetic apparatus of the host and parasite leaves, a JIP-test was applied based on the description of this method by Strasser *et al.* (1996). *Chlorophyll-a* fluorescence was measured in the field using the direct fluorescence method employing a direct fluorescence meter (Handy PEA, Hansatech, UK).

Transpiration

The water that flows through the branch of a tree where the parasite is attached was measured using Sap flow gauge (Greenspan Technology, Warwick, Australia).

Leaf area

A non-destructive method of leaf area measurement was followed on the twigs using a leaf area meter (Model LI-3000 A, Li-Cor Inc., Nebraska, USA).

Table 1. Site details of the two locations where observations and experimental measurements were made during the study.

Sl.No	Particulars	Site-I (Peechi)	Site–II (Kayampoovam)
1	Forest Division	Thrissur	Palakkad
2	Forest Range	Pattikkad	Machad
3	Section	Peechi	Kayampoovam
4	Latitude	10° 32′N	10° 42′
5	Longitude	76° 20′E	76° 24′
6	Altitude	100 msl	120 msl
7	Annual rainfall	2500 mm	1500 mm
8	Year of planting	1984	1969
9	Average dbh of teak trees	20 cm	22.75 cm
10	No of stems/ha	Multi-tier	700
11	Planting distance	4 x 2 m	2 x 4 m
12	Average tree height	10 m	12 m
13	Period of study	1997-1999	2000-2001

Phenology

Phenological behaviour of teak and *Dendrophthoe* with respect to flushing, flowering and fruiting was observed at fortnightly intervals in the field for four years. Observations on 100 trees at various locations in Kerala were recorded.

Microclimate

The light availability to the host and the parasite was measured by fixing two light sensors, first a point sensor, above the canopy of the host (Quantum sensors, Model LI-190SA, Li-Cor Inc., Nebraska, USA) and the second, a line quantum sensor (Line Quantum Sensor, Li-Cor Inc., Nebraska, USA), within the teak canopy, just above the clumps of the parasite. Leaf temperature of the host and the parasite was measured by fixing very fine wire thermocouple sensors (Model .001, Campbell Scientific, USA) at the lower side of the leaves and connecting them to a data logger (CR-10, Campbell Scientific, USA).

Nutrient analysis

The leaves were collected during different seasons of the year from the two sites. They were later dried and pooled separately for each site. Powdered leaf samples (0.3-0.5 g) were pre-digested with 5 ml of concentrated sulfuric acid and a pinch of Sodium salysilate overnight. The pre-digested samples were then digested for 3 hours at 350^{0}C in presence of hydrogen peroxide. The N and P contents in the digested samples were then determined by salysilate-hypochlorite and ascorbic acid reduced molybdophosphoric acid blue color method, respectively, using an autoanalyser. The exchangeable bases K^+, Na^+, Ca^{2+} and Mg^{2+} in the acid digests were determined using Atomic Absorption Spectrometer with respective halo-cathode lamps.

RESULTS

Water status

During the dry season an average RWC (relative water content) of 81.7 % was observed for teak and 76.5 % for *Dendrophthoe*. It can be seen that the RWC of *Dendrophthoe* is lower than teak by 5%. The water saturation deficit for teak was found to be 18.2% and that for *Dendrophthoe* was 23.5% during summer months. Other water relations parameters measured in the parasite and host are presented in Table 2.

Solute potential at both full saturation (y_{p0}) and at zero turgor (y_{pz}) were significantly lower in *Dendrophthoe*. The apoplasmic water content was 1.3% in *Dendrophthoe* while in teak it was 10.5 %, which was significantly higher than that of *Dendrophthoe*. Larger values of (y_{p0}) imply better maintenance of cell turgor at given water potential.

The measurements done on both the host and the parasite revealed that the parasite always maintained lower water potential compared to the host tree. Predawn water potential showed a maximum of –0.05 MPa in teak and – 0.34 MPa in the parasite. The

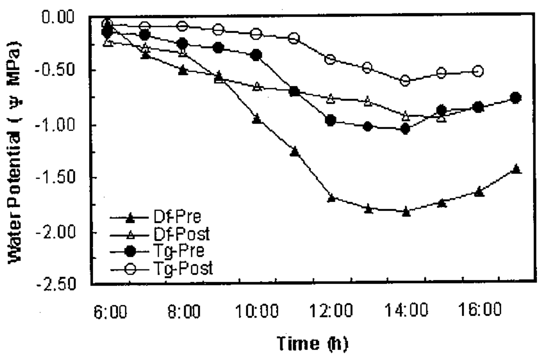

Figure 1. Water potential measurements in teak and the parsite at site I (*Dr- Dendrophthoe;* **Tg**-Tectona; **Pre**-premonsoon; **Post**-postmonsoon.

Table 2. Water relations parameters of teak and the parasite leaves after analysis of the PV-curve.

No.	Water relations parameter	*Dendrophthoe*	Teak
1	Tissue osmotic potential at full turgor	-13.3	-9.0
2	Water potential at turgor loss point	-13.4	-9.2
3	Apoplasmic water content	1.3%	10.5%

lowest water potentials recorded in teak was – 1.07 MPa and –1.8 MPa in parasite at Peechi. At Site II, slightly lower water potentials were observed for both host and the parasite.

The midday water potential of *Dendrophthoe* decreased down to –2.2 MPa and of teak to –1.8 MPa. (Fig.1). Fig.1 shows that the water potential always had lower values during the premonsoon on both the host and the parasite at both sites examined. More interestingly, the parasite always maintained a lower value of water potential compared to the host. It may be noted from Fig.1 that this difference can be as high as »1.0 M Pa.

Stomatal conductance (g_s)

The stomatal conductance measurements indicated that teak leaf is having stomata on the abaxial side only, whereas parasite is having stomata on both

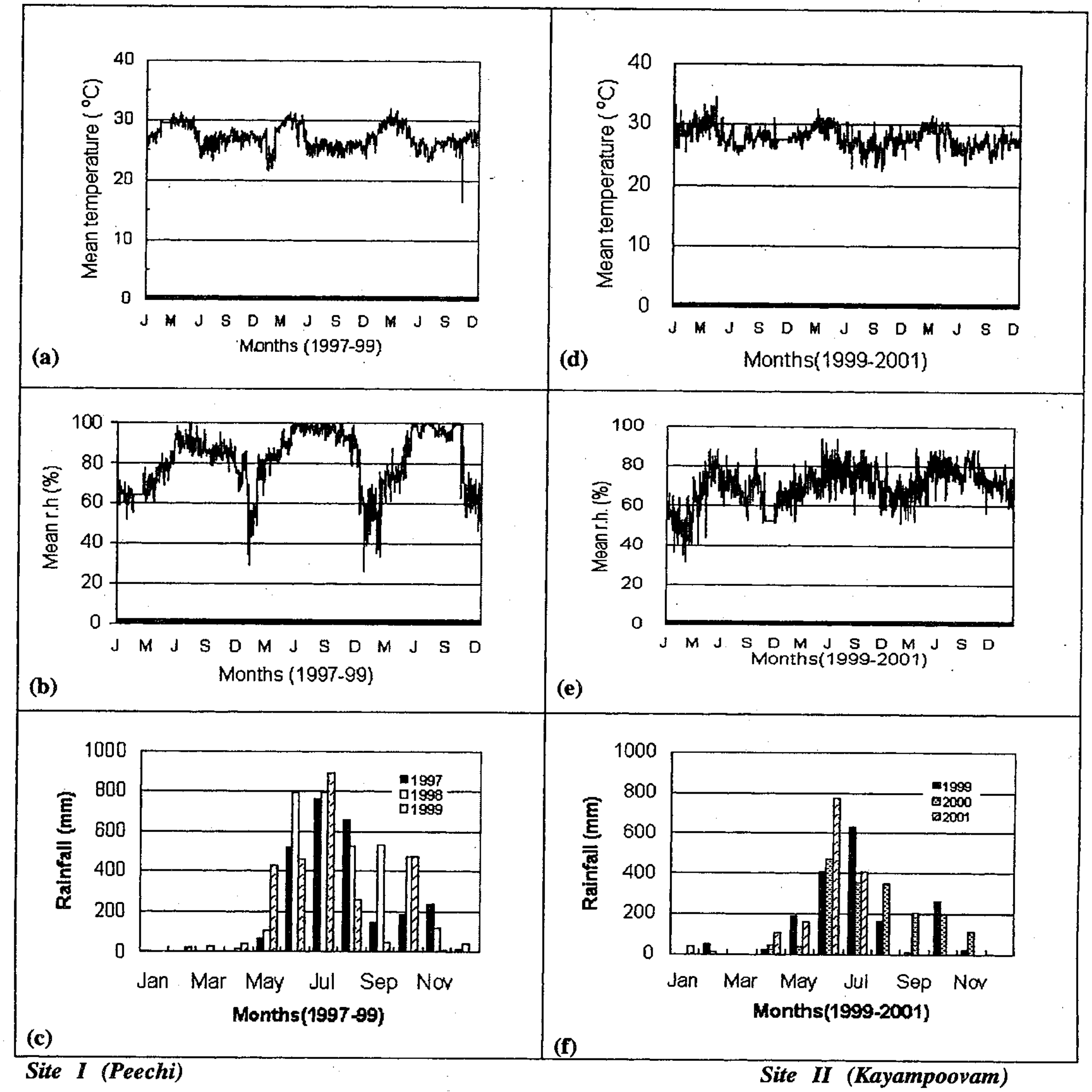

Figure 2. Daily variations in mean temperature (a), mean relative humidity (b) and rain fall (c) at Site I for the period 1997 to 1999 and the same (d), (e) and (f) at Site II for the period 1999 to 2001 respectively.

sides. The conductance values recorded during both periods showed that the parasite has lower conductance values compared to the host during post-monsoon and the opposite during pre-monsoon period (Fig. 3). This could be an effect of the difference in light availability to the parasite during the two periods. Maximum values of conductance ranged from 500 to 600 mmol m^{-2} s^{-1} both in the parasite and went up to 1000 mmol m^{-2} s^{-1} in the host (Fig. 3). A midday closure of the stomata was very apparent in teak, but not in the parasite.

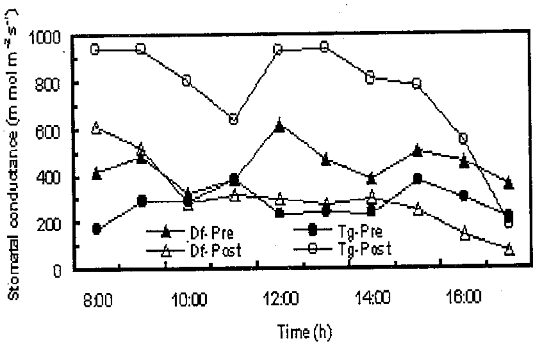

Figure 3. Diurnal variations in stomatal conductance in teak and Den drophthoe during pre and postmonsoon seasons at Site I.

Net photosynthesis (P_n)

Net photosynthesis was higher in teak compared to the parasite during both periods (Fig. 4). A maximum net photosynthesis of 12 mmol m^{-2} s^{-1} was observed in teak whereas the parasite showed values less than 6 mmol m^{-2} s^{-1} (Fig. 4). It is interesting to note that the parasite showed higher photosynthetic rates during the premonsoon period compared to the post monsoon period. This is because the leaves of the parasite are well exposed to sunlight during the premonsoon period when the host leaves are already shed or in the process of shedding.

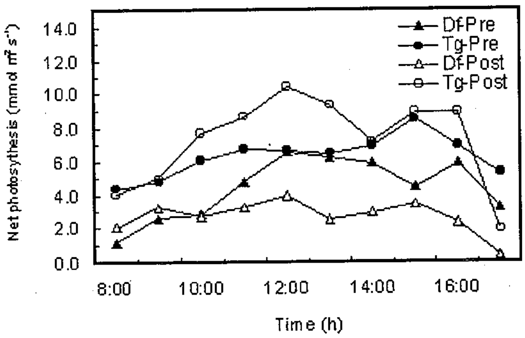

Figure 4. Diumal variations in net photosynthesis in teak and Dendrophthoe during pre-and post monsoon seasons at Peechi

Chlorophyll fluorescence

Results of the *chlorophyll-a* fluorescence transient

Table 3. *Chlorophyll-a* fluorescence parameters derived after analyzing the fluorescence transients from the distal and proximal leaves and leaves from uninfected branches of teak and leaves of the parasite, *Dendrophthoe falcata*. The leaves were dark adapted for 20 minutes before fluorescence measurements.

Parameter	Parasite	S.E	Teak-distal	S.E.	Teak-proximal	S.E.	Teak-uninfected	S.E.
Extracted and Technical Fluorescence Parameters								
Fo	375.17	7.96	476.17[a]	50.36	462.83[a]	52.36	477.50[a]	43.89
Fm	1957.67[a]	65.68	1962.67[a]	105.33	1911.83[a]	53.68	1881.92[a]	65.70
Fo/F_m	0.21	0.01	0.28[a]	0.04	0.28[a]	0.04	0.29[a]	0.03
Fv/F_o	3.76[a]	0.14	2.98[a]	0.60	3.02[a]	0.57	2.93[a]	0.39
Fv/F_m	0.80		0.75		0.76		0.74	
Phenomenological Fluxes or Phenomenological Activities								
RC/CSo	258.98[a]	5.73	261.86[a]	7.30	260.98[a]	5.85	242.70[a]	12.16
ABS/CSo	411.92	9.83	535.67[a]	59.04	521.33[a]	63.94	524.67[a]	48.85
TRo/CSo	324.46[a]	7.78	370.61[b]	16.31	364.35[ab]	26.59	356.39[ab]	13.03
ETo/CSo	204.66[b]	4.84	136.19[a]	32.79	136.73[a]	30.18	180.02[ab]	27.17
DIo/CSo	87.46	3.50	165.05[a]	43.03	156.98[a]	38.21	168.28[a]	38.90
PI(abs)	42.25[a]	3.71	23.87[a]	11.83	31.42[a]	14.48	39.69[a]	11.85

Note: Values with the same letter as superscripts in the adjacent rows are not significantly different (P [0.05). Mean and S.E. are presented for each value.

curves analysis are presented in Table 3. From the large number of parameters derived from the analysis of the transient curves from the parasite, proximal and distal leaves of the teak tree and leaves from uninfected branches of the teak tree, it was noticed that, out of 41 derived parameters, the parasite has more than 30 parameters common with the teak leaves. The Performance Index (PI), which gives an overall synthesized value, is not significantly different in the parasite and the host leaves.

Transpiration

Transpiration measurements for six days using sapflow sensor are given in Fig. 5. The complete weather data at hourly intervals were recorded for the site during this period (Fig.2). It shows that the parasite transpired in a similar pattern compared to teak.

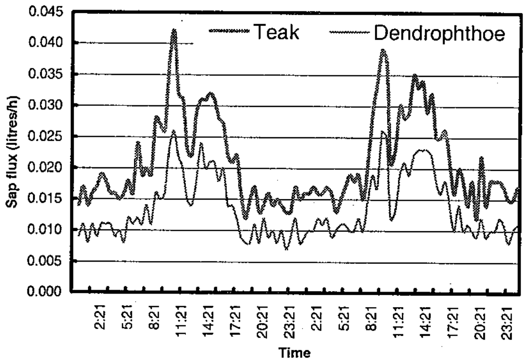

Figure 5. Variation in the sap flow in the parasite and host branch of a teak tree infected with *Dendrophthoe* for two days (20 to 21 May 2001) at Site II.)

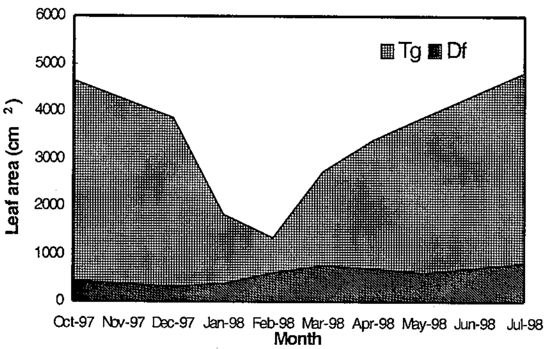

Figure 6. Leaf area development of teak and *Dendrophthoe* twigs followed at monthly intervals at Site I.

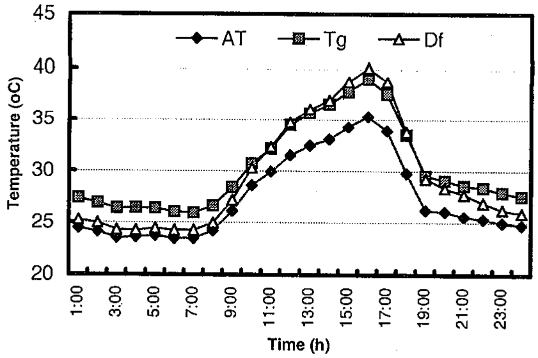

Figure7. Diurnal variations in another (AT) and leaf temperature in the host (Tg) and the parasite (Df).

Leaf area development

In teak, the leaf area decreased December onwards, reached minimum by February, and again reached a maximum by July. But the parasite always maintained a uniform leaf area throughout the year as in an evergreen species (Fig. 6). No particular leafless stage was noticed for *Dendrophthoe*. Phenological differences existed between parasite and host (Table 4). Parasite flowered in February and the host in July.

Microclimate

Continuous recording at hourly intervals showed that the parasite received only 30 % of the light as received by the host (Fig. 8). Parasite was seen to survive well in well-exposed situations and also when the host blocked 70% of the light. This gives an indication that the parasite is able to survive in both shade and exposed conditions. Leaf temperature measurements indicated that both host and the parasite maintain 2 to 3° C higher temperature than the atmospheric temperature (Fig. 7).

NUTRIENT ANALYSIS

Leaf samples collected from both the sites during May 1999 and November 1999 when the host and parasite were in full flushes, were analyzed for nutrients such as K, Mg, Ca, Na, total P and total N. The K and Na in the leaves of the parasite were found to be high as compared to the host. Analysis done on the parasite

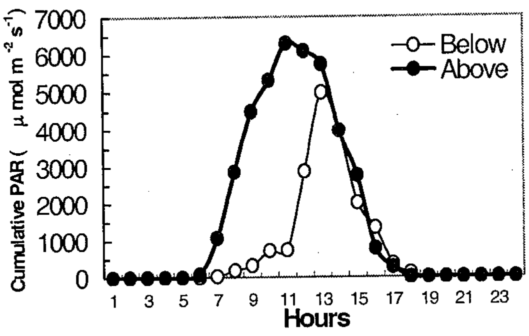

Figure 8. Hourly PAR received by the upper and lower canopy. The measurements are averages for 3 weeks during postmonsoon period.

during the leafless stage of the host also showed extremely high amount of K (more than three times than the host) in the leaves of the *Dendrophthoe*. The Mg and Ca concentrations were similar in the host and the parasite. The Na concentrations were almost twice in the parasite compared to the host. Total P was very similar in the parasite and the host, however total N showed a slightly lower concentration in the parasite compared to the host. The results are presented in Fig. 9.

DISCUSSION

Mistletoes are hemiparasites, they rely upon their hosts for water and minerals, and to some extent they photosynthesize and generate their own assimilate supply (Kuijt, 1969). This results in an unusual partitioning of water and carbon between the host and the parasite. Earlier studies in this respect have been reviewed by Glatzel (1983).

One of the important ecophysiological problems to be dealt within the host-parasite relationships is the dependence of the parasite on host for the nutrition. It is certain that in a xylem parasite, the parasite will be absorbing water and nutrients from the xylem sap of the host. Then the question is how good is the photosynthetic capacity of the parasite. It is reasonable to assume that if the parasite is photosynthetically efficient, then its virulence on the host plant is increased because the plant body can develop more leaves and thereby more water and minerals are also absorbed by the parasite. Our studies have shown that the parasite has photosynthesis (P_n) at nearly half the rate as that of the host plant. However, the reduction was mainly because of light limitations, since the parasite grows in the shade of the canopy of the host. But during the leafless stage of the host, in the dry period, the parasite leaves are fully exposed to the sun and they

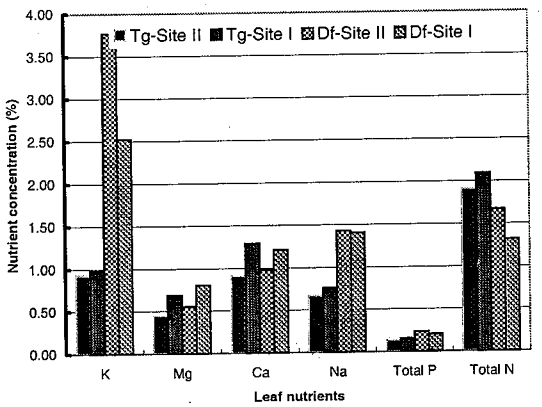

Figure 9. Variations in nutrient levels in teak and *Dendrophthoe* leaves at Site I and II expressed as percentage of the total dry weight.

Table 4. Fortnightly phenological observations in teak (T) and *Dendrophthoe* (D) made round the year at Peechi. The specific fortnight when each event occurs is depicted by a shaded square.

Event		Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
Leaf fall	T																								
	D																								
	D																								
Flowering	T																								
	D																								
Fruiting	T																								
	D																								

are able to photosynthesize at a much higher rate, although not at the same rate as that of the host. Karunaichamy *et al.* (1993) recorded maximum P_n rates of 5.57 and 6.97 in *Azadirachta indica* and its parasite *Dendrophthoe falcata* respectively. Davidson *et al.* (1989) recorded higher g_s and transpiration in *Amyema* on *Casuarina*, however the P_n rates of the parasite were similar. Johnson and Choinski (1993) have shown that the parasite was photosynthetically less active than host plant; and the infection reduced the carbon assimilation rates in the host compared to uninfected trees in *Tapinanthus-Diplorhynchus* parasite-host relationship. Marshall *et al.* (1994 a) made a detailed analysis on the C gain by 11 mistletoe species (belonging to 3 genera) in Australia. They found that the difference in P_n between the host and parasite was not statistically significant. Moreover, the heterotrophic carbon gain from the host accounted for approx. 15% of the total C gained by the parasite. Marshall *et al.* (1994 b) have shown that the xylem-tapping mistletoes have low instantaneous water use efficiency (WUE). This is interpreted as a facility for assimilating N dissolved at low concentration in the xylem sap. However, during this process C dissolved in the xylem sap also gets assimilated heterotrophically. This finally results in almost similar net carbon gain in the host and the parasite.

Several aspects of the photosynthetic efficiency have been investigated in the present study by analyzing the transient fluorescence curves generated by the *chlorophyll-a* fluorescence of the host and the parasite. By looking at the large number of parameters, it can be concluded that the photosynthetic abilities of the parasite and the host are not so different when we look at the Performance Index *(PI)*, which is an overall synthesized parameter. However, when the parameter for electron transport capacity for unit cross sectional area of leaf *(Et_o/Cs_o)* is taken into consideration, the parasite shows a much higher capacity compared to the distal and proximal leaves of the host teak tree. At the same time, there is no significant difference between the leaves of the parasite and those of an uninfected teak tree in the electron transport capacity. Similarly, the dissipated quantum flux *(DI_o/Cs_o)*, which is the quantum absorbed by the leaves and dissipated as unused energy, is much lower in the parasite compared to the host. Close examination of some such parameters shows that leaves of the parasite have a much more efficient photosynthetic apparatus compared to the host tree. This is indicative of the evolutionary adaptive nature of the parasite to survive on the host tree. Chlorophyll fluorescence measurements on several host-parasite pairs in Brazil have shown that photosynthetic efficiency was similar in both host and parasite (Lüttge *et al.*, 1998).

The water relations of the host-parasite entity are also interesting. It has been observed by a number of previous investigators that the parasite always maintains water potential lower than that of the host. This is a contrivance for creating a gradient in water potential between the host and the parasite so that water movement occurs from the host to the parasite during transpiration. It should be realized that the point of attachment between the host and the parasite is a region of resistance because this is the region where the vasculature of two different species unite. This means that sufficient water potential gradient should be generated for the flow of water from the xylem of the host to the parasite. In the teak-*Dendrophthoe* relationship we have observed a gradient as high as 1.0 Mpa. The parasite that has amphistomatous leaves will be certainly having a higher stomatal conductance per unit leaf area, probably helping to lower the water potential during the daytime. Davidson *et al.* (1989) recorded higher g_s and transpiration in *Amyema* growing on *Casuarina* trees. Their experiments have shown that the difference in water potential gradient between the host and the parasite was due to the resistance at the haustorial junction and not due to differences in tissue water relations.

The lower solute potential in the parasite compared to the host also helps to maintain low leaf water potential in the parasite compared to the host. This can also give much more drought tolerance to the parasite. The lower solute potentials are probably due to the presence of high K and Na concentration in the leaves of the parasite.

The quantity of water transpired certainly depends on the leaf area of the host or parasite. However, we could show that the pattern of water flux through the stem of the parasite and the host were the same. The microclimate parameters affected both the plants in a similar way. In the sample twig examined, it can be seen that the host transpired slightly more than the parasite at all times. However, the most interesting aspect is the high transpiration rates shown by the parasite during the premonsoon. Since teak is a deciduous species, without leaves during two months of the year (January to February in the study area), the high water consumption by the parasite can be certainly very damaging to the tree. This is the time when the stomatal conductance increases in the parasite and the water potential decreases. At this time there is a good possibility that the parasite is deriving most of its water from the surrounding wood tissue because the flux of water from the soil is minimal at this period. This can cause permanent cavitations in the wood xylem, resulting in drying of the branches and finally the death of the tree. It may be pointed out here that the chance for a deciduous tree to be affected more severely is higher compared to an evergreen tree. Evidence for the loss of hydraulic conductivity of the distal branches compared to the proximal wood has been presented in the host-parasite relationship of *Acacia acuminata-Amyema preissii* (Tennakoon and Pate, 1996). Evidence for higher transpiration rate in the mistletoe was shown in *Arceuthobium* infecting juniper trees in Tajikistan (Molotpkovski and Konnov, 1995). The high transpiration and the low rate of photosynthesis give the parasite low water use efficiency as shown in several host-parasite relationships (Hollinger, 1983).

Nutrient analysis shows that Na and K were found at much higher concentration in the parasite compared to the host. The changes in other nutrients were comparatively lesser except for total N, which showed a lower concentration in the parasite compared to the host. Glatzel (1983) found that the mistletoe *Loranthus europaeus* accumulated more nutrients in its leaves than its host, *Quercus petraea*. He attributed this accumulation to a higher rate of transpiration in the mistletoe than its host and to the absence of phloem connections between the parasite and the host. Some mineral elements, especially potassium, normally cycle back down the phloem, which does not happen here because of the absence of phloem connections. The same conditions could be applicable in the teak-*Dendrophthoe* relationship. Ehleringer *et al.* (1986) found higher concentration of N in the mistletoe leaves of *Phoradendron* compared to its host *Juniperus*. Most of this N was in the form of arginine. Panvini and Eickmeier (1993) who measured Cu and Zn showed that the mistletoe had nutrient concentrations 0.97 - 2.88 times greater than the host in *Phoradendron* and its several known hosts.

CONCLUSIONS

Based on the above studies, the following conclusions are drawn:

1. The parasite always maintains lower leaf water potentials compared to the host tree, helping in maintaining a water potential gradient between the host and the parasite, so that water is easily transported from the host to the parasite.
2. During the deciduous stage of the host tree, the parasite is drawing most of the water from the neighbouring wood tissue, thereby causing death of the twigs, and finally the death of the trees.
3. The water use efficiency of the parasite is lower compared to the host.
4. The photosynthetic performance is more or less similar in the parasite and the host; however, electron transport ability and quantum energy use efficiency are better in the parasite leaves.
5. The K and Na content in the parasite leaves were much more than that of the host leaves. Since these are phloem mobile minerals, their high concentration is indicative of the absence of any phloem connections between the host and the parasite.
6. The parasite is able to photosynthesize at shade and exposed conditions, showing its high adaptability on the host.,
7. All the ecological and physiological studies lead us to the conclusion that the parasite is highly adapted to surviving in stressed conditions, thereby giving it a high survival value.

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Storage and Flux of Organic Carbon in *Tectona grandis* Plantations of Moist Deciduous Region

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ABSTRACT

Enhancing carbon sink through creation of man-made forests is being considered as a mitigation option to reduce the increased atmospheric carbon dioxide level. Fixation of carbon was studied in an age series plantations (1, 5, 11, 18, 24 and 30 years) in the Tarai forest of Kumaun Himalayan region. Organic carbon concentration in different tissues was assessed and multiplied by the biomass to get total carbon content. Concentration was found to be different in different tissues. It ranged from 49.34 per cent to 56.79 per cent. Standing state varied between 1.62 t / ha and 74.38 t / ha. Net uptake after correction of retranslocated amount ranged between 0.94 t /ha / year and 5.99 t/ ha/ year. Total carbon return on forest floor through litter fall was between 0.90-t/ha/year and 3.36 t/ ha/year. Soil pool contained 35.7 t/ha to 43.9 t/ha and total system stored 46 t/ha to 113 t/ha of carbon. Storage and flux of organic carbon in different plant parts of different plantations were assessed and depicted through compartment models. Carbon budgeting indicated that teak plantation is an accumulating system. Regression equations were developed between girth and total carbon content using y = a + bx equation (where y = total carbon, x = girth at breast height, a and b = equation constants). Except in one-year-old plantations these equations were significant at 1 per cent level.

Keywords: Teak, chronosequence plantations, carbon pool, allocation, uptake, retranslocation

INTRODUCTION

Carbon finds its way over widely varying time scales through the atmosphere, oceans, terrestrial ecosystems and fossilized geological deposits. Human activity, particularly the deforestation, whereby the terrestrial ecosystems have been modified, has put the carbon cycle out of balance (Trexler, 1991). There are two general approaches to put the carbon cycle back into balance (i) changing the activities which have caused the imbalance and (ii) expanding sinks which draw carbon from the atmosphere. Sink expansion can be achieved easily through existing forest management, supplemented by afforestation so as to increase carbon uptake per unit land area (Muller, 1991). Dixon *et al.* (1994) have also suggested that much of the potential for global climate warming could be averted by planting millions of hectares of new forests to sequester more of the 5.5 Pg of C annually transferred into the atmosphere by combustion of fossil fuels. Sedjo (1989) estimated that to sequester 1.8 Pg of atmospheric carbon annually in forest biomass would be equivalent to planting over 400 million hectares of fast growing plantations.

Although forests do not sequester carbon permanently on account of harvest or natural death (Harmon *et al.* 1990), most recently, Kraenzel *et al.* (2003) have advocated that plantation is being considered as a mitigation option to reduce the increase in atmospheric carbon dioxide and predicted climate change. Today teak (*Tectona grandis*) is widely planted in South-East Asia and as exotic species in Africa, South and Central America (Ball *et al.*, 1999). This is one of the five major species in the world to be used in native area as well as the zone outside its natural occurrence. Krishnapillay (2000) has reported that teak plantations have covered around 2,246,559 ha area on global scale. This is only next to *Eucalyptus* (9,949,588 ha) and *Acacia* (3,904,307 ha). This teak-based global sink would certainly increase because during the past 20 years most supplies of teak wood from natural forests have dwindled and increased interest has developed in the establishment of teak forest plantations (Pande and Brown, 2000). The future trend is also highly encouraging, for teak resources no longer suffice to meet the very high demand from Asian countries, Europe and the United States. Teak wood production, currently estimated at 4 million m^3, will rise to more than 20 million m^3 by the year 2020 (Behaghel, 2000).

Estimation of carbon stocks and flows in forest ecosystems is in fairly preliminary stage. The best data is for commercial timber yield, but that does not tell us how much carbon is stored in roots, branches, etc. (except by extrapolation), nor does it cover the wide range of species and environments. Data for soil carbon is particularly limited (Muller, 1991). The dynamics of organic carbon is inadequately studied in teak ecosystems (Jha, 1995). The present study is conducted in one of the best teak-growing regions of India. This investigation is aimed at understanding following aspects of carbon cycling in teak plantations up to thirty years of age, since this species has attracted short rotation forestry recently (Balooni, 2000; Centeno, 1997; Keh, 1997).

1. Magnitude of storage of organic carbon,
2. Quantum of uptake and internal cycling of organic carbon,
3. Efficiency of cycling of organic carbon through litter fall, and
4. Comparison of organic carbon cycling in teak with other systems.

MATERIALS AND METHODS

Study site

Three experimental plantation stands of each age group (1, 5, 11, 18, 24 and 30 year) were selected in moist deciduous forests region for the study of structure and functioning aspects. These plantations were raised and managed as per standard silvicultural practices for the region (Prakash and Khanna, 1979). All the plantation sites were located in *Tarai* region of *Kumaun* Himalaya. Geographical location of these sites is between 29° 3' - 29° 12' N latitude and 79° 20' - 79° 23' E longitude. *Tarai* is an outlying belt in the foothills with deposition of finer materials and abundance of surface water. According to Champion and Seth (1968) natural vegetation of this area, presently highly altered, is "Alluvial Savannah Woodland - type 3/1S1, with some pockets of Moist *Tarai Sal* - type 3c/C2c". The low-density forest areas were clear-felled and converted into plantations of exotics like poplar, eucalypts, teak and other miscellaneous species (Jha, 1995).

Climate of this region is subtropical and monsoon type with long dry (eight months) and short wet seasons. Winter extends from November to mid-March. December and January are the coolest months. Summer stretches from mid-March to June. June is the hottest month. Another conspicuous season is the rainy season, which invariably starts in later half of June and lasts, generally up to September. Mean monthly temperature ranges from 14.4°C to 31.3°C and annual average rainfall is 1593 mm. Distribution of average total rain in different seasons are approximately 3%, 14% and 83% in winter, summer and rainy season, respectively. Average humidity is 65%. Ombrothermic diagram of the study site is presented in Fig. 1. Soil of this part of *Kumaun* Himalayan *Tarai* is typic hapludoll and fine loamy in texture (Kumar and Sharma, 1990).

Sample collection and chemical analysis

After complete enumeration of the plantation stands,

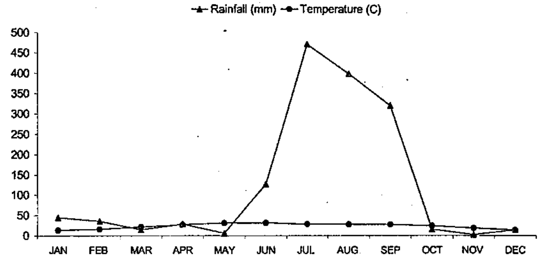

Figure 1. Ombrothermic diagram

representative trees of all diameter classes from all the six plantations were marked for studying dry matter dynamics and consequently for storage and flux of organic carbon. Different samples of tree parts like bark, bole, branch, twigs, foliage and litters collected during biomass estimation were pooled age-group wise. They were mill ground and powdered using domestic mixer cum grinder. Prior to grinding woody samples were sawn by power driven saw to get sawdust to facilitate easy grinding. The powdered composite samples of different tree parts were analysed chemically to find out the organic carbon concentration in them by Walkley and Black method as in Jackson (1958).

Storage and flux estimation

Stand biomass of different tree components and their respective carbon concentration were used for calculation. Standing state was computed as the sum of the products obtained by multiplying dry weights of components with their concentration. Standing state in different components was summed to obtain total nutrient storage in the stand. Gross uptake was computed by multiplying the values of net primary productivity of different components by their respective concentrations. Nutrient net uptake was estimated after adjusting the retranslocation amount. Retranslocation was assessed after Ralhan and Singh (1987). Total return through litter fall was calculated as the sum products of magnitude of different kinds of litter by their respective nutrient concentrations.

For soil carbon concentration estimation also Walkley and Black method was used. Thirty-centimeter depth of soil was taken into account for soil carbon calculation since fine roots of teak are confined to this stratum only (Choompol, 1973). Bulk density and complete mineralization of litter were not assessed during the present study. Therefore, these data were used from Lodhiyal (1990) and Singh *et al.* (1993), respectively. For fine root turnover, data were taken from Singh and Singh (1991).

Statistical analysis

The data of plantation stands were subjected to ANOVA. This indicated no significant difference within an age group. Therefore, data from different stands were pooled together for each age group. Linear regression equations were developed age-group wise using girth at breast height (in the case of one-year-old plantation, girth measuring height was chosen 50 cm above ground level) as the independent variable and total tree, aboveground and belowground carbon storage as dependent variables. Equations were also developed for all the age classes clubbed together by pooling up data of all the trees belonging to all the plantations.

Table 1. Concentration of organic carbon in different components of teak tree.

Components	Concentration %
Bark	49.34 (±0.27)
Bole	52.98 (±0.75)
Branch	56.79 (±1.27)
Twig	49.48 (±1.80)
Leaf	52.54 (±0.53)
Seed	50.00 (±0.58)
Tap root	53.07 (±0.08)
Lateral root	50.41 (±0.35)
Fine root	53.07 (±1.15)

(Figures in parentheses are standard errors).

RESULTS AND DISCUSSION

Carbon concentration and standing state

Very recently Kraenzel *et al.* (2003) have reported that woody tissues like trunk, branches, twigs and coarse roots have higher carbon concentration than soft tissues like leaves, flowers and fine roots. However, concentration pattern of carbon in different plant parts in present study supports this finding only to certain extent. Only branch and bole had higher concentration than leaf. The exact pattern was in the following decreasing order: branch > tap root = fine root > bole > leaf > lateral root > seed > twig > bark. Carbon concentration in different tree parts varied between 49.34% and 56.79% (Table 1). Average tree concentration of carbon in present study (51.9%) compares well with the latest study (49.5%) of Kraenzel *et al.* (2003).

Storage in the standing crop differs substantially in different forest types according to the degree of uptake and crop biomass. Increase in standing crop with stand age showed direct bearing on total

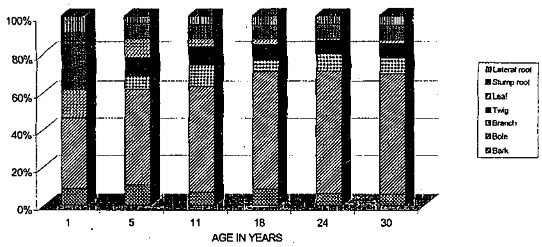

Figure 2. Standing state of organic carbon in different tree components

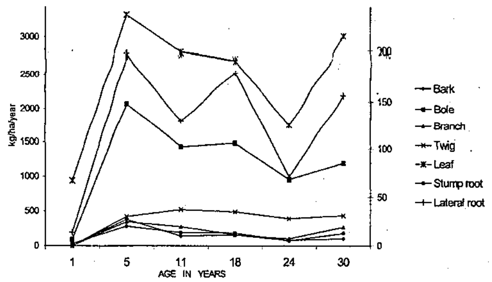

Figure 3. Gross uptake of organic carbon in different tree components

biomass of forest stand (Ovington, 1959). In present study also, distribution of organic carbon in different components in different stands differed considerably (Fig. 2) on account of biomass variation. Range of total carbon in standing trees was 1.62 to 74.3 t/ ha. Above-ground carbon storage was 1.01 to 65.01 t/ ha. Magnitude of total storage of carbon (40 to 80 t/ ha) in trees compares very well with the report of Dewar and Cannell (1992). However, as compared to the present study, carbon storage in Panama plantations is much higher (100 to 140 t/ ha) which is probably due to high stand density and high rainfall regime. This is supported by the earlier reports that dry matter accrual depends on density and climatic factors also (Jha, 2000). Perusal of carbon storage data in different tree components of different stands indicated that although relationship between age and storage in twigs and foliage was not consistent, storage in bark, bole, stump root and lateral root increased as the age of the stand progressed. Total storage in parts above-ground, below-ground and total tree also had positive relationship with increasing age. Like many others (Bargali, 1990; George and Verghese, 1991;1992; Lodhiyal, 1990) the present study also supports that biomass plays more important role than element concentration in its accumulation in different plant parts at different ages.

Carbon uptake and retranslocation

The magnitude of gross uptake (amount associated with net nutrient production) in different components of an age series plantations of teak is represented in Fig. 3. The annual production range of organic carbon was 1.08 to 7.01 t/ha/year. Highest uptake was in five-year-old plantation and lowest in one-year-old plantation. As regards the component-wise gross uptake, leaves were the highest in carbon. Bole was next to foliage and roots carried minimum of it. Highest uptake in five-year-old plantation as compared to 1, 11, 18, 24 and 30-year-old indicated that nutrient requirement at this stage is more for structural building. This is related to the fact that at initial age teak grows faster than many other timber species. Component-wise maximum uptake in foliage is related to the highest biological activity in leaf as compared to any other above-ground part. Further, lowest uptake in coarse roots suggested minimum requirement for structural building. This corroborates the fact that coarse root development is very slow as compared to aboveground parts.

More than half of all tropical soils are highly weathered, leached, and impoverished requiring the ecosystem to develop conserving mechanism (Singh *et al.*, 1979). Retention and withdrawal mechanisms are most effective in nutrient-poor systems (Chapin, 1980; Singh *et al.*, 1984). Resorption of nutrient elements in leaves during senescence is well known. In the present study withdrawal of organic carbon in different plantations was observed between 14.5 and 49.4%. Report of Lal (1990) on carbon loss (26%)

Table 2. Magnitude of retranslocation of organic carbon in an age series teak plantations.

Age (year)	Retranslocation
One	136.3(14.5)
Five	1023.7(30.8)
Eleven	1377.2(49.4)
Eighteen	1299.9(48.0)
Twenty four	674.0(38.7)
Thirty	986.8(32.8)
Average	916.3(33.7)

Figures in parentheses are percentages

during senescence based on the data of 90 tropical woody species compares with present finding in 30-year-old plantation (32.8%) of teak. Quantum of retranslocation was 0.13 - 1.37 t/ha/year, respectively (Table 2). Moderate quantity of carbon conservation indicated that it plays substantial role in annual retention and net carbon uptake. This also suggests that soil carbon pool of the study site is not deficient one. Net uptake of carbon after correction for retranslocation was in the range of 0.94 and 5.99 t/ha/year. This compares very well with the annual storage of carbon (2 to 5 t/ha/year) in UK plantations as reported by Dewar and Cannell (1992).

Carbon return

Carbon return on plantation floor through different kinds of litter of an age series teak plantations is represented in Fig. 4. Foliage returned maximum carbon followed by twigs and fruits. Contribution of foliage, twigs and fruits was in the range of 84.5% to 100%, 4.7% to 14.9% and 0.7% to 3.2 %, respectively. Range of total return across all stands was 0.90 t/ha/year (one year) to 3.36 t/ha/year (30-year). Lowest return from youngest and highest return from oldest stand indicated its direct

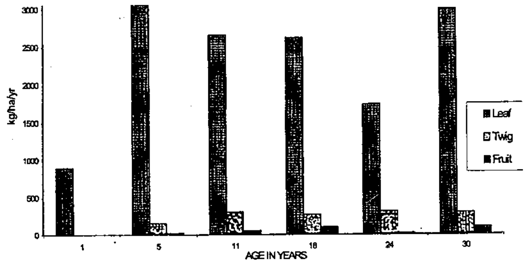

Figure 4. Organic carbon return on forest floor through litter fall

relationship with age. But inconsistent pattern in intermediate stands indicated the contribution of some other factors. However, return or litter accretion is also the function of stand density (Prasad and Mishra, 1985; Zavitovsky, 1981) combined with the age.

Linear regression equation

Tree girth had significant relationship with aboveground, belowground and total carbon storage within each age group (except one year) and across the age groups. In all, twenty-one regression equations derived from girth and carbon content of the tree are presented in Table 3. These equations

Table: 3. Linear regression equations (y = a + bx, where y is carbon storage; and x is girth at breast height)

Age (year)	C storage	Intercept	Slope	RSQ
1	Above ground	-0.33332	0.11752	0.641701ns
	Below ground	1.19093	-0.07007	0.726368ns
	Total	0.85761	0.04745	0.116262ns
5	Above ground	-8.57086	0.663663	0.861931**
	Below ground	-1.09564	0.08738	0.745487**
	Total	-9.6665	0.751043	0.851883**
11	Above ground	-126.029	3.395826	0.958666**
	Below ground	-16.2917	0.451445	0.919165**
	Total	-142.32	3.847271	0.960815**
18	Above ground	-103.669	2.960928	0.950931**
	Below ground	-19.6557	0.501736	0.802495**
	Total	-123.324	3.462664	0.9395**
24	Above ground	-159.32	4.109737	0.94092**
	Below ground	-13.2165	0.454425	0.921416**
	Total	-172.536	4.564163	0.941708**
30	Above ground	-216.925	4.688846	0.93144**
	Below ground	-44.7686	0.842783	0.748298**
	Total	-261.693	5.531629	0.940231**
1-30	Above ground	-114.784	3.567878	0.903248**
	Below ground	-18.3503	0.54719	0.780702**
	Total	-133.135	4.115068	0.902572**

were highly significant at 1% level excepting the three related to one-year-old plantations. This strong relationship between these two parameters suggested that these equations could be used in estimation of growing carbon stock for similar localities and future planning.

Carbon cycling

An ecological system is visualised as a set of compartments interconnected by flow of dry matters, energy and information. The selection of compartments is based on the existing knowledge on structure and function relationship of recognizable units (Singh *et al.*, 1979). Vegetal structure in teak plantation ecosystem virtually consists of trees only since herbs and shrubs do not contribute to productivity significantly (Jha, 1995). The tree component has been divided into a set of three compartments like leaves, wood and root. Litter and soil compartments are also a part of the arboreal ecosystem. Compartment models of carbon dynamics are depicted in Figs. 5 and 6. in which mean standing states are given in circular tanks and annual fluxes in the boxes between arrows. In these figures direction of organic carbon flow from foliage to soil one way movement, although nutrients utilized by foliage in organic matter synthesis are redistributed among different components during the assimilate transfers (Singh and Singh, 1991).

Quantity of carbon stored in vegetation (standing state of carbon) increased with increase in age from 1.62 t/ha (one year) to 74.38 t/ha (thirty year). Out of the above total quantity above-ground storage was 1.01 t/ha in one-year-old stand while 65.01 t/ha in thirty-year-old stand. The belowground quantity was 0.61 t/ha in one-year-old plantation while it was 9.36 t/ha in thirty-year-old plantation.

Storage of carbon in 30 cm deep soil varied with age variation but there was no consistent relationship. However, from one-year-old plantation (43.89 t/ha) it decreased in 30-year-old plantation (35.71 t/ha). Vesterdal et al. (2002) have also reported that carbon storage in soil decreases with increase in age of oak and Norway spruce plantations on former arable land. However, in 24-year plantation this storage (29.76 t/ha) was still lower. This may be attributed to the fact that from soil properties point of view,

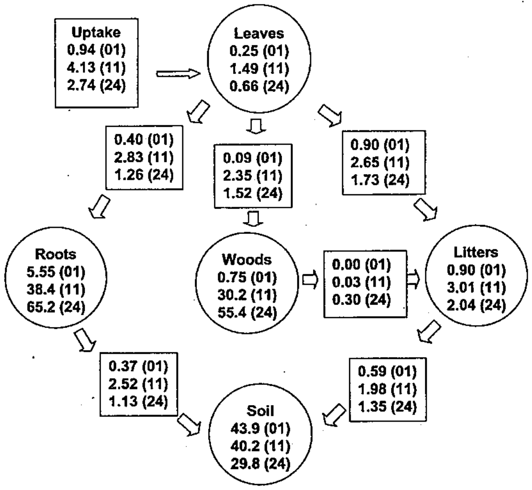

Figure 5. A compartment model showing annual carbon budget for one, eleven and twenty-four year old plantations. Values in circular tanks represent carbon content (t/ha). Net annual fluxes (t/ha/year) are given in rectangular boxes between the compartments. Root compartment shows virtual storage since fine roots included in this is derived by extrapolation.

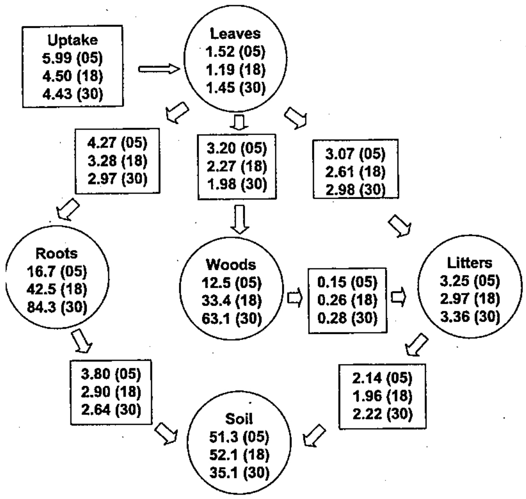

Figure 6. A compartment model showing annual carbon budget for five, eighteen and thirty-year-old plantations. Values in circular tanks represent carbon content (t/ha). Net annual fluxes (t/ha/year) are given in rectangular boxes between the compartments. Root compartment shows virtual storage since fine roots included in this is derived by extrapolation.

practically, this plantation is much older than 30-year-old (24 + 50year) plantation, as this crop was a second rotation teak. However, soil carbon storage at thirty years (35.7 t/ha) is lower than that reported by Chhabra et al. (2003) in Indian forests like tropical dry deciduous (37.5 t/ha) and littoral and swamp forest (92.1 t/ha) and the report of Dewar and Cannell (1992) in UK plantations (40 to 80 t/ha). Annual carbon input to the above soil carbon pool from decomposing litter in the present study varied between lowest value in one-year-old plantation (0.59 t/ha) and highest value in 30-year-old plantation (2.22 t/ha).

Total carbon storage in the teak ecosystem ranged between 46 t/ha and 113 t/ha in one-year-old and 30-year-old plantations, respectively. Assuming the one-year stock at the bench level, this increase of approximately 67 t/ha carbon is definitely due to sequestration by the vegetation. As suggested by Jose *et al.* (1998) also the expansion and conservation of this carbon pool might remove carbon from atmosphere to help compensate for carbon liberation associated with other land use. Average storage data across all the age groups showed that 56%, 41% and 3% carbon is present in soil, tree and litter compartment, respectively. However, highest storage of carbon in youngest plantation (one year) was in soil and lowest in litter but in oldest (thirty-year) plantation it was highest in tree layer and lowest in litter. Storage at the age of thirty years (113 t/ha) compares well with storage in *Euxylophora paraensis* plantation (110 t/ha) in Brazil (Smith *et al.* 2002). However, the report in the present study was very low as compared to teak plantation (351 t/ha) of Panama (Kraenzel *et al.*, 2003). Carbon storage in natural forest ecosystem was still higher in *Nothophagus* forests (192-344 t/ha) as reported by Davis *et al.* (2003) and Hart *et al.* (2003) and in Norway spruce mixed forest (175 t/ha) by Finér *et al.* (2003).

CONCLUSION

The Foregoing discussion summarises the basic ecological characters of teak plantations related to carbon functioning. Carbon storage is primarily the function of age of the plantation, which may be affected by density and climatic factors on spatial scale. Teak plantations have appreciable carbon storage capacity, though, much less than the natural forest, is definitely higher than the degraded and barren land. However, teak planting can be encouraged in favourable areas from carbon sequestration point of view apart from other management objectives.

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Effect of Moisture Conservation Methods and Fertilizers on Nutrient Uptake in Two-Year-Old Teak (*Tectona grandis* L. f.) Plantation

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ABSTRACT

An experiment was conducted in a farmer's field at Sughavi village in hill zone of Karnataka State, India, with four moisture conservation methods and five fertilizer levels. The experiment was laid out in split plot design. The results revealed that moisture conservation methods and fertilizers significantly influenced the leaf area, nutrient content of leaf and nutrient uptake by the plant. The leaf area recorded among the treatments varied from 0.333 to 5.092 m^2. The lowest leaf area was recorded in the control, and highest was found with ring basin method + chemical fertilizer + vermicompost. The nutrient contents in leaf varied among the treatments from 1.28 to 2.89 per cent N, from 0.04 to 0.33 percent P_2O_5 and from 0.61 to 1.46 per cent K_2O. Based on the leaf area and the nutrient content of the leaf, uptake of nutrients through leaf in different treatments varied from 2.05-48.52 kg N/ha, 0.17 to 3.91 kg P_2O_5/ha and 1.62-22.32 kg K_2O/hectare. All the moisture conservation methods (trenching, half ring basin and ring basin), except control, significantly influenced the nitrogen uptake, whereas, uptake of phosphorus and potassium was not significantly influenced by moisture conservation methods. Fertilizer treatments (chemical fertilizer (CF)+ farmyard manure and CF+ vermicompost) were found to affect significantly the uptake of Nitrogen and Potassium. The influence of the interaction treatments was highly significant on the uptake of all the nutrients.

Keywords: High input plantation, moisture conservation, nutrient management

INTRODUCTION

High rainfall coupled with faulty management practices cause excessive erosion, leading to land degradation. Most of the upland areas in hill zone of Karnataka are exposed to soil erosion and have become unproductive (Prasad and Singh, 1994). Growing of agricultural crops on such lands is non-remunerative; hence the farmers prefer to grow forest tree species on such lands, which fetches more value. Teak is one such species, which has attractive market value, but the proper package of practices to grow the teak plantation is the limitation for the farmers to grow teak plantation on large scale. Growth of teak on uplands hinders due to lack of soil moisture and soil nutrients. Proper nutrient application and soil moisture availability would bring the drastic change in growth of the tree. The growth of teak depends mainly upon the uptake of nutrients, which in turn depends on the moisture availability in the soil. Keeping these points in view an experiment was conducted to study the effect of moisture conservation methods and fertilizer application on uptake of nutrients through leaf.

MATERIALS AND METHODS

The experiment was conducted in a farmer's field at Sughavi village (14^0 30'N Latitude and 75^0 20' E Longitude) during 2000-2002. The experimental site was upland with well-drained soil and poor in fertility. The average (15 years) annual rainfall in the experiment area was 1846 mm, more than 90 per cent of the rainfall was received from June to October.

Teak stumps prepared from one-year-old seedlings were planted in pits (30x30x30cm) in slanting position at 2m x 2m spacing during the month of June 2000. The experiment was laid out in split plot design with moisture conservation methods {no moisture conservation (M_0), trenching method (M_1), half ring basin (M_2) and ring basin method (M_3)} as main plots. Fertilizers {no fertilizers (F_0), chemical of fertilizer (CF) (F_1) CF + farmyard manure (FYM) (F_2), CF+ vermicompost (VC) (F3) and CF+ leaf litter (LL)(F5)} as subplot treatments. Treatments were replicated thrice. Each treatment consisted of 16 plants. Trenching (1.4m length x 0.6m width x 0.6m depth) was dug in between the teak rows for every alternate row. Each trench in a row was separated by a gap of 0.6m. Ring basin (0.6m radius) and half ring basins (0.6m radius) were made around each plant base in the respective treatments. The organic fertilizers (FYM 10 t/ha and VC 5 t/ha) were properly mixed with soil before planting. Leaf litter (2.54 t/ha) was spread around the plant after planting. Half dose of N, P_2O_5 and K_2O /ha (100:50:100 kg/ha, 200:100:200 kg/ha for first and second year respectively) was applied through Urea, Diammonium Phosphate (DAP) and Muriate of potash (MOP) in the month of June. Remaining half dose of CF was applied two months after the first dose application.

The number of fully opened leaves was recorded. Based on size, leaves were groped into thee categories (small medium and large). Leaf area was estimated using the product of leaf length (L) and width (W) multiplied by a constant (K). The value of K for different size leaflets was derived by dividing the actual leaf area (determined using graph sheet) by LB (Murugesh *et al.*, 1998). The representative leaf samples were oven dried. The dry weight of the sample was recorded for the known leaf area.

The second and third leaf from the tip of each plant was collected for estimating plant nutrients (Jayamadhavan *et al.*, 2000). The collected leaves were dried under shade and powdered. The sample powder was used for estimating the N, P_2O_5 and K_2O content. Nitrogen was determined by Microkjeldhal method as suggested by Yoshida *et al.* (1976). Triacid mixture was used for digestion of samples for estimation of phosphorus and potassium as suggested by Yoshida *et al.* (1976). Phosphorus was determined by Vanado-molybdo phosphoric yellow color method (Jackson, 1967). potassium was estimated using flame photometer method. The estimated uptake of nutrients by teak plant was statistically analyzed in M-STAT-C Program. The mean values of the treatments were separated subjected to Duncan's Multiple Range Test (DMRT) at 5 per cent probability under M-STAT-C program.

RESULTS AND DISCUSSION

The leaf area of teak plants in different treatments is shown in Table 1. which shows that the leaf area was not significantly influenced by moisture conservation methods. However, ring basin method recorded higher leaf area (2.115 m^2) followed by trenching method. Fertilizer treatments significantly influenced the leaf area. Among the fertilizer treatments, CF+VC recorded significantly higher leaf area (3.371 m^2) compared to other fertilizer treatments. However, CF+FYM also recorded on par with CF+VC and significantly higher than other fertilizer treatments. The treatment combinations influenced leaf area more effectively than individual treatments. Among treatment combinations, ring basin method plus CF+VC (M_3F_3) recorded significantly higher leaf area (5.092 m^2) than the other treatments. M1F2 also recorded leaf area (4.437 m^2) on par with M_3F_3. Control (M0F0) recorded significantly lower leaf area (0.906 m^2) compared to all the interaction treatments. The variation in leaf area can be attributed to moisture and nutrient availability in these treatments. Moisture conservation methods alone did not influence leaf area but moisture conservation methods along with fertilizers significantly influenced leaf area. This might be due to organic fertilizers, which improved the soil physical characteristics and increased the moisture availability, which helped the plant continue to grow even during dry season. This could be the reason for increased leaf area in these treatments (Nonhare and Chowbey, 1996). The better moisture availability would result in better root spread in soil, which help the plant for better growth, which would result in increased the leaf area (Ramprasad and Mishra, 1984).

Moisture conservation methods did not influence significantly the leaf nutrient (N, P_2O_5 and K_2O) content (Table 2). However, the fertilizer treatments significantly influenced leaf nitrogen and potassium content but did not influence phosphorus content.

Table 1. Leaf area of teak plants (2-year-old) as influenced by moisture conservation and fertilizer treatments

Treatments		Leaf area (m^2)
Main Plot treatments	**(M)**	
No moisture conservation	:M0	1.331 b
Trenching	M1	2.064 a
Half ring basin	M2	1.925 ab
Ring basin	M3	2.115 a
LSD	0.656	
F test	NS	
Sub plots treatments	**(F)**	
No fertilizers	F0	0.613 b
CF :	F1	0.988 b
CF + FYM 10 t/ha	F2	2.871 a
CF + VC 5t/ha	F3	3.371 a
CF + LL 2.5t/ha	F4	1.449 b
LSD	0.810	
F test	S	
Interaction (MxF)		
M0F0	0.906 e	
M0F1	1.232 de	
M0F2	1.108 de	
M0F3	1.839 ce	
M0F4	1.566 ce	
M1F0	0.503 e	
M1F1	0.909 e	
M1F2	4.437 ab	
M1F3	3.292 bc	
M1F4	1.177 de	
M2F0	0.710 e	
M2F1	0.775 e	
M2F2	2.867 bd	
M2F3	3.259 bc	
M2F4	2.012 ce	
M3F0	0.333 e	
M3F1	1.036 de	
M3F2	3.071 bc	
M3F3	5.092 a	
M3F4	1.044 de	
LSD	1.621	
F test	S	

MAP – Months after planting ; CF- Chemical fertiliser 100:50:100 kg NPK/ha first year and 200:100:200 kg NPK/ha second year FYM – Farmyard Manure ; VC – Vermicompost; LL – Leaf Litter LSD applied to Duncan's multiple range test at 5 per cent level of significance. Means followed by same letters in a column do not differ significantly.

CF+VC recorded significantly higher leaf nitrogen content (2.58 %) compared to other fertilizer treatments. CF and CF+FYM also gave leaf nitrogen content on par with CF+VC. All the fertilizer treatments except control recorded significantly higher concentration of potassium in leaf. The leaf nitrogen content was significantly influenced with interaction treatments but phosphorus and potassium contents of leaf were not influenced by the interaction treatments. Trenching method plus CF+VC (M_1F_3) recorded significantly higher nitrogen content (2.89 %) in leaf. Control (M0F0) recorded significantly lower nitrogen content (1.28 % N) than other treatments. The higher concentration of nitrogen in plant was due to higher availability of nitrogen in soil because of high native soil nitrogen and the added nitrogen.

Nitrogen uptake by teak plant was significantly influenced by all the moisture conservation methods whereas uptake of phosphorus and potassium were not influenced significantly (Table 3). Among the fertilizer treatments, nitrogen and potassium uptake with CF+FYM and CF+VC was significantly higher (25.44 and 31.77 kg N /ha and 13.28 and 15.48 kg K_2O /ha respectively) than other treatments. Phosphorus uptake did not vary with fertilizer treatments.

Treatment combinations registered significantly higher N, P_2O_5 and K_2O content in leaf than the individual treatments (Table 3). M_3F_3 recorded significantly higher nitrogen (48.52 kg/ha) and potassium (22.32 kg/ha) uptake compared to other treatments. Phosphorus uptake (3.91 kg/ha) recorded with M_2F_3 was significantly higher than other treatments. Phosphorus uptake by the plant was very less compared to nitrogen and potassium, which might be due to very low soil pH (5.1). All the phosphorus might have been fixed in the soil. It is reported that in acidic soils, phosphorus bounds to Al^{3+} and Fe^{3+} ions and thus becomes unavailable (Jeyamala and Soman, 1999). This might be the reason why the phosphorus uptake by the plant was very low.

Among the nutrients, nitrogen content in leaf is higher than phosphorus and potassium (Singh, 1969). The higher concentration of nitrogen in leaf is attributed to better absorption by the plant. This might be due to better moisture and nutrient availability, which may help in prolonged cambial activity (Anil Mohan and Kulkarni, 1995) as evidenced by retention of green leaves for longer period of time in some of the interaction treatments (M_2F_3, M_3F_2 and M_3F_3). The prolonged activity of cambium would result in higher quantity of nutrient uptake (Priya and Bhat, 1999). The significantly higher nitrogen uptake recorded with interaction treatments supports this. Uptake of potassium was also enhanced by the moisture availability due to moisture conservation treatments and applied nutrients in the soil. Inorganic form of fertilizers are found to increase plant biomass (Rangaswamy *et al.*, 1990; Anantha Padmanabha and Nagaveni, 1991) and result in more uptake of potassium.

Table 2. Leaf nutrient content (%) as influenced by moisture conservation and fertilizer treatments

Treatments		Leaf nutrients (%)		
		Nitrogen	Phosphorus	Potash
Main plot treatments	**(M)**			
No moisture conservation:	M0	1.87 a	0.22 a	1.33 a
Trenching:	M1	2.26 a	0.23 a	1.07 a
Half ring basin	M2	2.20 a	0.21 a	1.26 a
Ring basin	M3	2.22 a	0.22 a	1.13 a
	LSD	0.59	0.13	0.39
	F- Test	NS	NS	NS
Sub plots treatments	**(F)**			
No fertilizers :	F0	1.60 c	0.20 a	0.93 b
CF :	F1	2.07 ac	0.21 a	1.19 ab
CF + FYM 10 t/ha	F2	2.39 ab	0.22 a	1.24 a
CF + VC 5t/ha	F3	2.58 a	0.23 a	1.24 a
CF + LL 2.5t/ha	F4	2.05 bc	0.24 a	1.38 a
	LSD	0.48	0.15	0.28
	F- Test	S	NS	S
Interaction (MxF)				
M0F0		1.28 e	0.04 a	0.61 c
M0F1		1.74 ae	0.29 a	1.56 a
M0F2		2.71 ab	0.26 a	1.44 a
M0F3		2.26 ae	0.23 a	1.52 a
M0F4		1.38 de	0.28 a	1.52 a
M1F0		1.51 ce	0.24 a	0.73 bc
M1F1		1.91 ae	0.12 a	1.20 ac
M1F2		2.54 ac	0.19 a	0.99 ac
M1F3		2.89 a	0.29 a	0.95 ac
M1F4		2.45 ad	0.29 a	1.50 a
M2F0		1.89 ac	0.23 a	0.98 ac
M2F1		2.59 ac	0.09 a	1.15 ac
M2F2		2.10 ae	0.19 a	1.40 ab
M2F3		2.49 ad	0.27 a	1.46 a
M2F4		1.94 ae	0.26 a	1.36 ab
M3F0		1.72 be	0.31 a	1.40 ab
M3F1		2.04 ae	0.33 a	0.92 ac
M3F2		2.23 ae	0.22 a	1.15 ac
M3F3		2.67 ab	0.12 a	1.10 ac
M3F4		2.43 ae	0.13 a	1.15 ac
	LSD	0.97	0.30	0.57
	F- Test	S	NS	NS

MAP – Months after planting; CF- Chemical fertilizer 100:50:100 kg NPK/ha first year and 200:100:200 kg NPK/ha second year; FYM – Farmyard Manure; VC – Vermicompost; LL – Leaf Litter; LSD applied to Duncan;s multiple range test at 5 per cent level of significance Means followed by same letters in a column do not differ significantly

CONCLUSION

Moisture conservation methods (trenching, half ring and ring basin methods) did not influence significantly leaf area and nutrient content in leaf. However, they significantly influenced the uptake of nitrogen. Phosphorus and potassium uptake did not differ significantly with moisture conservation methods. Fertilizer treatments CF+VC and CF+FYM recorded significantly higher leaf area and uptake of nitrogen and potassium. Phosphorus uptake was not influenced significantly by fertilizer treatments. Treatment combinations M_3F_3 and M_1F_2 recorded leaf area significantly higher than other treatments. Uptake of nutrients recorded with interaction treatments was higher than with the individual

Table 3. Nutrient uptake (kg/ha) by leaves as influenced by moisture conservation and fertilizer treatments

Treatments		Nutrients uptake kg/ha Nitrogen (N)	Phosphorus (P_2O_5)	Potash (K_2O)
Main plot treatments	**(M)**			
No moisture conservation:	M0	8.17 b	1.15 a	6.86 b
Trenching:	M1	19.67 a	1.88 a	8.35 ab
Half ring basin	M2	16.35 a	1.85 a	10.53 a
Ring basin	M3	18.69 a	1.45 a	9.27 ab
	LSD	6.91	1.05	3.23
	F- Test	S	NS	NS
Sub plots treatments	**(F)**			
No fertilizers :	F0	3.68 b	0.41 b	2.19 c
CF :	F1	7.06 b	0.82 b	4.74 bc
CF + FYM 10 t/ha	F2	25.44 a	2.41 a	13.28 a
CF + VC 5t/ha	F3	31.77 a	2.86 a	15.48 a
CF + LL 2.5t/ha	F4	10.61 b	1.42 ab	8.07 b
	LSD	7.63	1.43	4.47
	F- Test	S	NS	S
Interaction (MxF)				
M0F0		5.32 g	0.17 c	2.48 f
M0F1		6.53 fg	1.28 ac	7.42 cf
M0F2		9.10 eg	1.13 ac	6.06 bf
M0F3		13.25 dg	1.71 ac	8.83 cf
M0F4		6.49 fg	1.47 ac	9.46 bf
M1F0		2.39 g	0.41 bc	1.62 f
M1F1		6.03 fg	0.37 bc	4.38 ef
M1F2		43.13 ab	3.27 ac	16.77 ac
M1F3		35.33 ac	3.78 ab	11.49 bf
M1F4		11.21 eg	1.57 ac	7.53 cf
M2F0		4.95 g	0.63 ac	2.72 f
M2F1		8.04 fg	0.28 c	3.39 f
M2F2		23.43 cf	2.30 ac	15.99 ad
M2F3		29.98 bd	3.91 a	19.28 ab
M2F4		15.35 dg	2.17 ac	11.25 bf
M3F0		2.05 g	0.45 bc	1.86 f
M3F1		7.38 fg	1.35 ac	3.75 f
M3F2		26.09 ce	2.96 ac	14.30 ae
M3F3		48.52 a	2.05 ac	22.32 a
M3F4		9.39 eg	0.46 bc	4.07 ef
	LSD		15.25	2.86 8.95
	F- Test	S	S	S

MAP – Months after planting; CF- Chemical fertilizer 100:50:100 kg NPK/ha first year and 200:100:200 kg NPK/ha second year; FYM – Farmyard Manure; VC – Vermicompost; LL – Leaf Litter; LSD applied to Duncan;s multiple range test at 5 per cent level of significance ; Means followed by same letters in a column do not differ significantly.

treatments. Nitrogen uptake recorded with M_3F_3 (48.52 kg/ha), M_1F_2 (43.13 kg/ha) and M_1F_3 (35.33 kg/ha) was maximum and significantly higher than other treatments. Phosphorus uptake recorded with M_2F_3 (3.91 kg/ha) was significantly higher than other treatments. Potassium uptake with M_3F_3 (22.32 kg/ha) was significantly higher compared to other treatments. Moisture conservation methods conserved the soil moisture and organic fertilizers improved the soil physical and chemical properties, which in turn helped the plant to continue to grow even during dry season and absorb more nutrients in these treatments. The uptake of nitrogen and potassium was more due to moisture and nutrient availability in the soil. Phosphorus uptake was hindered by low soil pH.

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Quality Timber Products of Teak from Sustainable Forest Management pp 212-218

Non-Wood Forest Products Resource in Teak Plantations and Moist Deciduous Forests: A Comparative Study in Thrissur Forest Division, Kerala

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ABSTRACT

Non-Wood Forest Products (NWFPs) contribute to the household food security, nutrition; generate income and employment, especially to the tribal communities, support biodiversity conservation and related environmental objectives. In Kerala, among the 550 NWFP species, herbs, shrubs and small climbers constitute 322 species, growing among the lowermost stratum of the forest canopy. Moist deciduous forests, the second largest vegetation type in Kerala yield nearly 40 per cent of the NWFPs. This forest type is the home of commercially valuable trees such as rosewood, teak, irul, bijasal, etc. and was subjected to over exploitation for timber. Large tracts of this forest type were clear-felled and planted with teak, eucalyptus, etc. Out of 1,762 km^2 area of forest plantations in Kerala, 42 per cent is occupied by teak. Several NWFPs growing in the moist deciduous forests are found as undergrowth in the forest plantations. This study attempts to compare the NWFP resources of herb and shrub species in different forest types especially between teak plantations *vis-à-vis* moist deciduous forests in the Thrissur Forest Division. The measures of abundance and diversity such as density, species richness, and Shannon Wiener indices were worked out for herb and shrub species and compared between forest types. The availability of useful parts of NWFP species were also quantitatively determined and the economic value worked out. In terms of all the parameters considered teak plantations are comparable with moist deciduous forests and other plantations, and a good source of NWFPs.

Keywords: Non-wood forest products, teak plantations, moist decidous forests

INTRODUCTION

Non-wood forest products include a wide variety of products from day to day use, household articles, fodder, etc. to raw materials to industries. Though NWFPs play a crucial role in the employment and income generation to tribal and rural communities and meets a variety of their needs the past forest management policies were aimed at generating more income from timber and firewood and the NWFPs received little attention. However, during the last few decades there has been an increase in the demand for NWFPs and subsequently many NWFPs have been over-exploited disproportionate to their regeneration capacity. It is reported that there are 550 species of plants yielding NWFPs in Kerala (Nambiar *et al.*, 1985). Among the NWFPs, herbs, shrubs and small climbers comprises 322 species which grows among the lower most stratum of forests. Moist deciduous forests, the second major vegetation type in Kerala, apart from their valuable timber trees, are also the habitat of several NWFPs. About 40 per cent of the NWFPs in Kerala are reported to occur in this forests type (Basha, 1991). Thus, moist deciduous forests play a crucial role in the diversity and availability of NWFPs.

Selection felling was carried out in the past in the natural forests for the extraction of these commercially important timber such as teak (*Tectona* *grandis*), rosewood (*Dalbergia latifolia*), bijasal (*Pterocarpus marsupium*), irul (*Xylia xylocarpa*), black siris (*Albizia lebbeck/A. odoratissima*) and *Terminalia crenulata* to meet the growing demand. A substantial area was also clear-felled and subsequently planted with teak, eucalyptus, acacia, albizia, etc. In Kerala, at present out of the total area of forest plantations of 1,762 km², teak alone occupies 42 per cent. The present day forest plantations were once the habitats of valuable non-wood forest products and still have several NWFP species growing as undergrowth. The study assesses the NWFP resources growing as undergrowth (herbs and shrubs) in the moist deciduous forests, teak plantations and the plantations of other species in Thrissur Forest Division, in terms of abundance, diversity, availability of useful parts and economic value.

STUDY AREA

The study covers the Thrissur Forest Division which is situated in the Western Ghats and falls within the Thrissur Revenue District of Kerala State and lies between latitude 10°20′ and 10°56′ N and longitude 75°95′ and 76°32′ E. The area shares a warm humid climate. The area receives rain from south west and north east monsoon. The average annual rainfall for the last 10 years ranged between 2,397 mm and 3,600 mm. The temperature extremes recorded for the past few years were 19°C and 39°C. Administratively the division is divided in to three ranges viz., Wadakkancherry, Pattikkad and Machad. Of the 210 km² of forests, natural forests form 60 per cent and the rest 40 per cent is forest plantations. The dominant vegetation types in the division are southern moist mixed deciduous, west coast tropical evergreen and west coast semi-e7vergreen forests. The major plantations in the division were of teak and cashew. The other plantations include eucalyptus, acacia, bamboo and mixed plantations. In this study, for analysis purpose, plantations were divided into two groups i) teak plantations and ii) other plantations (plantations other than teak).

METHODOLOGY

In the forest cover map of the study area, grids of 1 km² were marked and identified in the field by reconnaissance survey. The number of plots and their size were obtained after a few preliminary trials and by drawing species area curve. The size of the plots adopted for enumeration are trees and saplings- 20 x 80 m for moist and semi-evergreen and 20 x 60 m for evergreen; shrubs- 5 x 5 m; for herbs, climbers and seedlings- 2 x 2 m. Four quadrates were laid down in each 1 km² grid. The plots for shrubs, herbs, climbers and seedlings were selected within the plots laid down for trees and saplings. A total of 482 plots constituting 1,928 m² in different forest types (semi-evergreen -19, moist deciduous - 194, teak plantations – 127, other plantations – 142) were laid down to assess the herb species. In the case of shrub species, the same number of plots as indicated above constituting 12,250 m² were laid down. As the number of plots for evergreen was very less, consequent to less evergreen forest available in the Forest Division, this forest type was excluded for analysis.

The number of each NWFP herb and shrub species present in quadrates were recorded. Samples of herbs each weighing 100 gm were collected from different localities of the study area. The weight of whole plant and the useful parts of herbs were measured and their average values calculated. Fresh weight of NWFPs were recorded for species which are marketed as fresh and dried weight estimated for species sold after drying. The estimated number of individuals per hectare was multiplied by the weight of useful parts (dry/fresh) that could be extracted of a given species for a plant to obtain the weight of the useful parts of NWFP plants per hectare. Wherever the weight of the produce was size dependent the estimates obtained from the regression equations were substituted suitably and yield extrapolated. However, tree species are not considered in this study for comparison.

The economic value of available quantity of useful parts of NWFPs were worked out based on the price fixed by the Minor Forest Produce Committee (MFP) of the State (for the period 2001-2003). As regards the species which are not included in the MFP list, the current price paid to the collectors by the agents or the raw drugs traders were considered.

The NWFP resources in teak plantations were also compared in terms of abundance and diversity measures following Magurren (1988) and Ludwig and Reynolds (1988), which are described below.

i) Species-abundance plot

Rank/abundance plot is a method of presenting species-abundance relationship.

ii) k - dominance plot

This is a graphical method in which percentage cumulative abundance is plotted against species rank. It is argued that diversity can only be unambiguously assessed when the k-dominance covers from the communities to be compared do not overlap. In this situation the lowest curve will represent the most diverse community.

iii) Density (No. of individuals/ha) [D] = $\dfrac{\text{Number of individualsencountered}}{\text{Total area sampled in } m^2}$ X 10,000

iv) Relative Density (RD) = $\dfrac{\text{Number of individuals belonging to species i}}{\text{Total number of individuals}}$ X 100

v) Percentage Frequency (F) = $\dfrac{\text{Number of quadrates in which species i was present}}{\text{Total number of quadrates sampled}}$ X 100

vi) Rare fraction formula

The number of species invariably increases with sample size and sampling effort. To cope with this problem, Rare fraction technique is useful for calculating the number of species expected in a sample of n individuals drawn from a population total of N individuals distributed among S species is

$$E(S) = \sum\left\{1 - \left[\binom{N-n_i}{n} \Big/ \binom{N}{n}\right]\right\}$$

where n_i=number of individuals in the i^{th} species.

vii) Species richness index

$$\text{Species richness index} = S/\sqrt{N}$$

where S = Number of species recorded

N = Total number of individuals summed over all the species

viii) Evenness index

$$\text{Evenness index} = \frac{H'}{\ln(S)}$$

where H'=Shannon's index (described below)

S = Total number of species recorded

ix) Simpson's index

Simpson's index was the first diversity index used in ecology as $\lambda = \sum_{i=1}^{s} p_i^2$

where $p_i = n_i/N$

n_i = number of individuals of the i^{th} species.

N = total number of individuals for all S species in the population

This index varies from 0 to 1, gives the probability that two individuals drawn at random from a population belongs to the same species.

x) Shannon's index [H']

H' has probably been the most widely used index in community ecology. It is a measure of the average degree of 'uncertainty' in predicting to which species an individual chooses at random from a collection of S species and N individuals belong. The average uncertainty increases as the number of species increases and as the distribution of individuals among the species becomes even.

$$H' = -\sum_{i=1}^{r}(p_i \log p_i)$$

where p_i=n_i/n

n_i = number of individuals belonging to i^{th} of S species in the sample

and n is the total number of individuals in the sample. The significant difference in diversity index values between forest types was tested using Student's t-test which is defined as

$$t = \frac{|H_1 - H_2|}{\sqrt{Var(H_1) + Var(H_2)}}$$

This test statistic t follows Student's t-distribution with v degrees of freedom, where

$$v = \frac{(Var(H_1) + Var(H_2))^2}{(Var(H_1))^2/N_1 + (Var(H_2))^2/N_2}$$

and $Var(H) = \dfrac{\sum p_i(\ln p_i)^2 - (\sum p_i \ln p_i)^2}{N} + \dfrac{S-1}{2N^2}$

xi) Similarity measure

It measures the similarity of pairs of sites, either in terms of species presences and absences (qualitative data) or by taking species abundances in to account (quantitative data). In this study, Sorenson measure based on presence-absence data was used.

$$Cs = \frac{2j}{a+b}$$

where j = the number of species common to both sites.
a = number of species in site A and
b = the number of species in site B.

RESULTS

As many as 34 different herbaceous species were encountered in the survey (Table 1). Similarity indices presented in Table 2 shows that more than 70 per cent of the species were common between different forest types considered. The species-abundance relationship as depicted in Figure 1 reveals that there were very few individuals encountered for many species in the sample plots in different forest types indicating very low abundance in the study area. The density measures of abundance status of different species are presented in Table 1 for moist deciduous forests, teak plantations and plantations of other species. The total number of individuals belonging to different NWFP species per unit area was slightly higher in teak plantations (36,535 individuals per ha) followed by plantations other than teak (35,229 individuals per ha) and moist deciduous forests (27,281 individuals per ha) in that order respectively. The common species found in all the forests types were *Piper longum, Naregamia alata, Elephantopus scaber, Hemidesmus indicus, Biophytum ssp., Cyathula prostrata, Desmodium laxiflorum, Pseudarthria viscida, Sida rhombifolia ssp.retusa, Ichnocarpus frutescens and Costus speciosa.*

Figure 2 shows that k-dominance curves are overlapping each other indicating that diversity indices should be interpreted cautiously. A comparison of number of species in each forest type for fixed number of individuals encountered is an useful exercise. For this purpose, expected number of species was calculated for varying number of individuals and presented in Figure 3 using Rare faction formula. The figure indicates that moist deciduous forest type had more number of species followed by plantations of species other than teak and teak plantations in that order respectively. Species richness index and Simpson's index values presented in Table 3 also reveal this observation. In terms of Shannon's index which incorporates evenness and species richness effectively shows that moist deciduous forest type has slightly more diverse NWFP herbs followed by teak plantations and other plantations in that order respectively. Such differences in diversity index values were found to be statistically significant using t-test ($P<0.01$).

The quantity of NWFP species and their useful parts in terms of weight (either fresh or dry according to the use pattern) are presented in Table 4 for various NWFP herb species in different forest types. The availability of useful parts of herb species are also considered in terms of economic value for comparison

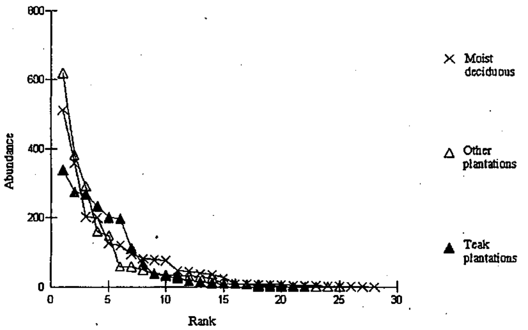

Figure 1. Abundance plot for herb species in different forest types

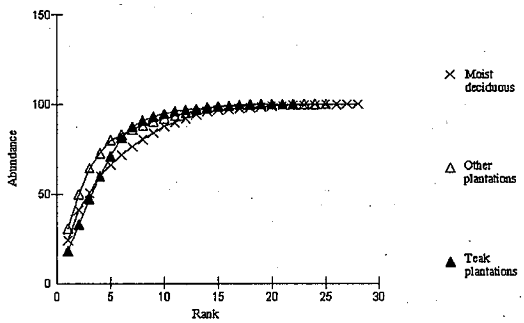

Figure 2. k-dominance plot for herb species in different forest types

Table 1. Density, relative density and percentage frequency of different NWFP herb species

Species	Moist deciduous forests			Teak plantation			Other plantation		
	D	RD	F	D	RD	F	D	RD	F
Adenia hondala	116	0.43	1.66						
Aerva lanata				39	0.11	0.25			
Amorphophallus paeoniifolius							70	0.200	0.48
Aristolochia indica	52	0.19	0.83	20	0.05	0.25	440	1.249	3.37
Asparagus racemosus	52	0.19	0.42						
Baliospermum montanum	580	2.13	2.08	158	0.43	1.00	1039	2.95	1.68
Barleria prattensis	477	1.75	2.50						
Biophytum spp.	1624	5.95	6.65	6634	18.16	10.03	18	0.05	0.24
Centrosema pubescens	335	1.23	2.91	1299	3.56	6.02	880	2.50	4.81
Costus speciosa	129	0.47	0.83	295	0.81	1.25			
Cyathula prostrata	1224	4.48	4.99	20	0.05	0.25	616	1.75	2.64
Cyclea peltata	516	1.89	3.74	610	1.67	5.51	687	1.95	5.05
Desmodium gangeticum	103	0.38	1.04	197	0.54	1.25	141	0.40	1.20
Desmodium gyrans	64	0.26	0.62				18	0.05	0.24
Desmodium laxiflorum	1031	3.78	2.70	197	0.54	1.00	18	0.05	0.24
Desmodium velutinum	103	0.38	0.42	39	0.11	0.25			
Elephantopus scaber	2603	9.54	5.41	3878	10.61	6.77	1056	2.00	4.09
Evolvulus alsinoides							176	0.50	0.48
Gloriosa superba	26	0.10	0.42						
Hemidesmus indicus	2577	9.45	16.84	4567	12.50	17.29	2817	8.00	11.06
Ichnocarpus frutescens	1546	5.67	6.03	5374	14.71	13.03	6690	18.99	17.79
Mucuna pruriens	13	0.05	0.21	20	0.05	0.25			
Naravelia zeylanica	619	2.27	5.41	492	1.35	3.26	546	1.55	2.64
Naregamia alata	4613	16.91	12.27	3957	10.83	9.02	10863	30.84	16.11
Ocimum gratissimum							176	0.50	0.48
Phyllanthus amarus	39	0.14	0.21	335	0.92	2.01			
Piper longum	6598	24.19	10.81	5256	14.39	7.52	2623	7.45	4.09
Piper spp.	103	0.38	0.21				106	0.30	0.48
Pseudarthria viscida	1005	3.69	2.91	748	2.05	2.76	563	1.60	3.13
Rauvolfia serpentina	26	0.10	0.42			0.00	18	0.05	0.24
Rubia cordifolia						0.00	35		0.48
Sida rhombifolia ssp. *retusa*	1070	3.92	5.61	2185	5.98	8.77	5106	14.49	16.10
Tinospora cordifolia							18	0.05	0.24
Tragia involucrata	39		0.42	217	0.59	1.75	511	1.45	2.64
Overall	27281			36535			35229		

D – Density; RD – Relative Density; F – Percentage Frequency

purpose and presented in Figure 4. It shows there were no notable difference in economic value for herb species between forest types. The economic value per hectare for moist deciduous forest type was Rs. 2,384, teak plantations – Rs.2,538 and plantations other than teak – Rs. 2,750. However, the higher availability of NWFP species and economic value in plantations other than teak is an unexpected trend in the study area. This might be due to large tracts of neglected cashew plantations in the division.

There were only three shrub species encountered in the sample plots. Of these, *Helicteres isora* and *Holarrhena antidysenterica* are common in all the forest types while *Solanum torvum* was found only in moist deciduous forests in few numbers. On the whole, the number of individuals of shrub species per hectare was found to be more in moist deciduous followed

Table 2. Similarity indices of herb species between different forest types

Habitat	Similarity Index
Moist deciduous forests vs. Teak plantations	84.00
Moist deciduous forests vs. Other plantations	75.47
Other plantations vs. Teak plantations	72.34

by teak plantations. The other plantations were found to have very low abundance of shrub species.

DISCUSSION

Among the 34 NWFPs enumerated from the study areas, 21 are included in the list of Minor Forest Products (MFP) which consists of 111 items by the Kerala Forest Department. About 29 species are used in the manufacture of Ayurvedic medicine on a commercial scale and their annual requirement in Kerala varies from 1490 tonnes (*Sida rhombifolia* ssp. *retusa*) to 50 tonnes (*Ichnocarpus frutescens*) (Sasidharan and Muraleedharan, 2000). The density of more light demanding species such *Sida rhombifolia* ssp. *retusa, Aerva lanata, Elephantopus scaber, Hemidesmus indicus* and *Ocimum gratissimum* were more in the plantations. *Gloriosa superba, Adenia hondala* and *Asparagus racemosus* were found only in the moist deciduous forests. The exotic species, *Centrosema pubescens* is more frequent in teak plantations and other plantations than in the moist deciduous forests. The study also shows that there are several species low in abundance in the moist deciduous forests as well as plantations, probably due to the unsustainable extraction by the collectors.

The NWFP resources were found abundant in teak plantations in density and diversity. The extent of availability of NWFP resources and their economic value in teak plantations are comparable with that of plantations of other species and moist deciduous forests. Thus, teak plantations are a good source of Non-Wood Forest Products particularly the herbaceous species which can be extracted every year in a sustainable manner. Therefore, the income from NWFPs should also be taken into account when teak plantations are valued for economic return.

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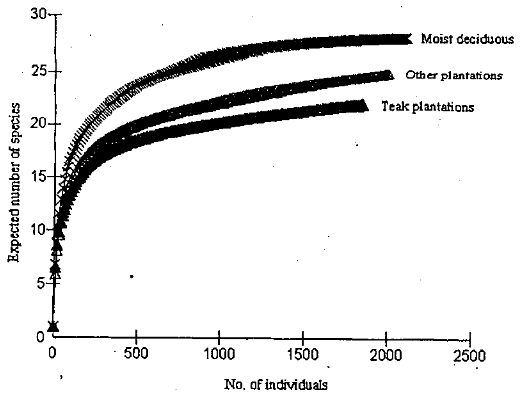

Figure 3. Rarefaction plot for herb species in different forest types

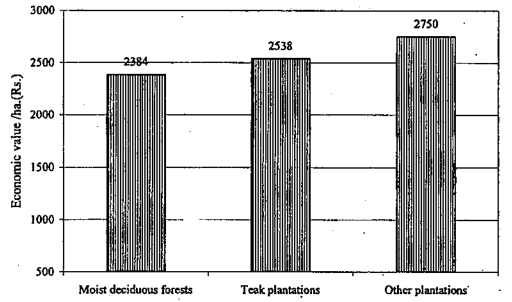

Figure 4. Economic value of NWFP (herbs) in different forest types

Table 3. Diversity indices of herb species in different forest types

Index	Habitat type Moist deciduous forests	Teak plantation	Other plantations
Species Richness index	0.61	0.51	0.56
Pielou's Evenness index	0.75	0.75	0.68
Simpson's index	0.12	0.12	0.17
Shannon's index	2.49	2.32	2.18

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Table 4. Available quantity of NWFP (herb species) in different forest types

Species	Useful part	Average weight of useful part (kg)/ha		
		Moist deciduous forests	Teak plantations	Other plantations
Adenia hondala	Root tuber	74.39		
Aerva lanata	Root		0.03	
Amorphophallus paeoniifolius	Root			20.79
Aristolochia indica	Root	0.22	0.08	1.89
Asparagus racemosus	Root	1.46		
Baliospermum montanum	Root	4.94	1.34	8.85
Barleria prattensis	Root	0.58		
Biophytum spp.	Whole plant	0.00	1.89	0.01
Centrosema pubescens	Seed/fruit	40.40	156.65	106.14
Costus speciosus	Rhizome	2.90	6.64	
Cyathula prostrata	Root and Stem	0.38 (1.98)*	0.01	0.19 (1.00)*
Cyclea peltata	Root	7.86	9.31	10.47
Desmodium gangeticum	Root	0.95	1.81	1.29
Desmodium gyrans	Root	0.04		0.01
Desmodium laxiflorum	Root	3.52	0.67	0.06
Desmodium velutinum	Root	1.20	0.46	
Elephantopus scaber	Whole plant	6.70	9.98	2.72
Hemidesmus indicus	Root	2.43	4.31	2.66
Ichnocarpus frutescens	Root	0.70	2.42	3.02
Mucuna pruriens	Seed/fruit	0.68	1.04	
Naravelia zeylanica	Root	1.98	1.57	1.75
Naregamia alata	Root	3.24	2.78	7.64
Ocimum gratissimum	Root			1.23
Phyllanthus amarus	Whole plant	0.01	0.11	
Piper longum	Root and Stem	4.92 (7.54)*	3.92 (6.01)*	1.96 (3.00)*
Piper spp.	Stem	10.84		11.11
Pseudarthria viscida	Root	0.81	0.61	0.46
Rauvolfia serpentina	Root	0.05		0.04
Rubia cordifolia	Root			0.10
Sida rhombifolia ssp. *retusa*	Root	1.52	3.11	7.27
Tragia involucrate	Root	0.11	0.62	1.46

*stem is the useful part

Table 5. Density, relative density and percentage frequency of different NWFP shrub species

Species	Density (No. of individuals/ ha.)								
	Moist deciduous forests			Teak plantation			Other plantation		
	D	RD	F	D	RD	F	D	RD	F
Helicteres isora	2718	80.32	52.83	1780	73.00	56.85	96	16.59	13.99
Holarrhena antidysenterica	660	19.50	32.83	658	27.00	29.45	482	83.41	40.56
Solanum torvum	6	0.18	0.38						
Overall	3384			2438			577		

D – Density; RD – Relative Density; F – Percentage Frequency

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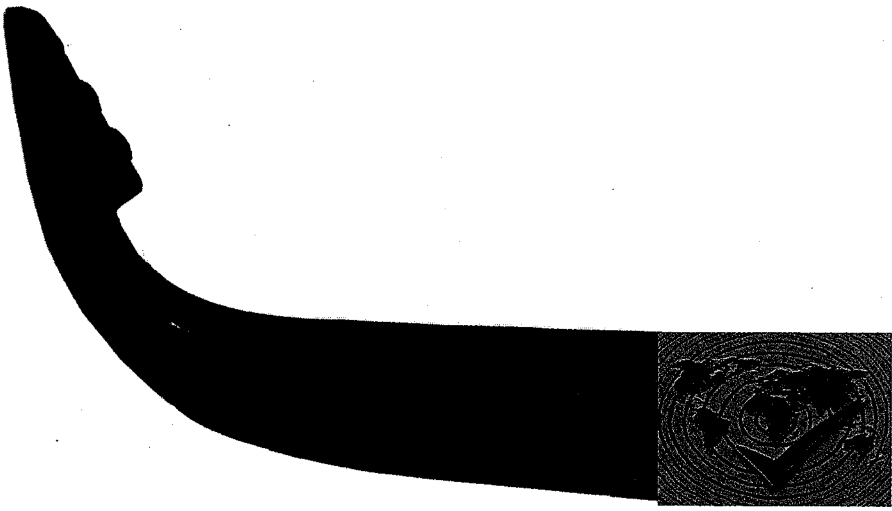
Quality Timber Products of Teak from Sustainable Forest Management



Qualities of Teak and Some Policy Issues

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ABSTRACT

Teak is a component species of the tropical moist and dry deciduous forests of the South and South-East Asian region. It is also a potential tree for raising plantations. Teak wood is used as the standard for quality rating of other timbers of India. Quality of teak products is prescribed rigidly by the market, and it essentially depends on the quality of the wood, besides the processing technology. The wood has considerable value adding and income generating potential. Teak entered the international market as early as in the beginning of 19th century. Along the way, starting in the mid 1880s, plantations of teak were raised, in order to replenish the removed stock. Currently, the availability of natural teak is limited, and supply of teak logs comes mostly from plantation sources. Teak plantations are now being raised in a large number in countries of the tropical region, outside its natural habitat. Of the total world's forest plantations of 187.1 million hectares in 2000, teak accounts for 5.7 million hectares (about 3%). It is also now grown in different scales by farmers, agriculturists, agro-foresters and investors of various types. The outlook for teak as a business enterprise raises several policy issues related to land laws, infrastructure, planting technology and systems, role of R and D, capital investment, funding sources, community involvement, private sector roles, new products and markets,market-based approaches to teak development, conflict resolution, control, and so on. From a policy point of view, apart from its physical properties, teak earns increased merit for the social, environmental and economic benefits it generates. The focus of this paper is on policy issues related to the development of teak as a quality timber.

Keywords: Teak, natural and planted, qualities and acceptance, policy issues

INTRODUCTION

The superior quality of teak (*Tectona grandis*) has been recognized in India at least for some 2,300 years. Chanakya had considered teak as the most appropriate wood for making thrones for royalty. *Arthasasthra*, dating between 312 and 298 BC contained management regulations for several valuable tree species with teak heading the list. These trees were not allowed to be extracted without the king's consent (NBS, 1971).

Troup (1921) judged teak as the most important timber tree of India. It is a deciduous tree found as a component species in the tropical moist and dry deciduous forests, occurring naturally in some parts of the South and South-East Asia region. Teak is found in India, Laos, Myanmar and Thailand; and it has naturalized in Indonesia and Bangladesh (Rao, 1991). It thrives best and reaches large dimensions in moist, warm, tropical climate. It is a good tree to be raised in plantations. Currently plantations of this species exist in 36 countries falling in the tropical regions of Asia, Africa and Latin America.

HISTORY AND CONTRIBUTIONS OF TREE PLANTATIONS

Deliberate control of plant productivity dates back to thousands of years. Olive tree management in the Mediterranean has a history of over 2,000 years. To meet the needs of human societies, as they increased numerically and progressed economically, domestication and production of genetically improved crop plants in terms of growth, yield, resistance to pests and diseases, and adjustability to varying climatic stresses became necessary. If the human race had continued with the life of hunting and gathering even as their numbers increased, there would have been no forests remaining.

In the early stages of socio-economic progress, forests were considered as an impediment and home to malarial mosquitoes, leaches and agents of diseases. This led to large-scale forest clearances in several parts. Planting of favoured forest trees in clear-felled sites was attempted as early as in the 13th century (Levingston, 1984). The need for forest plantations, to complement the natural forests, to facilitate their conservation, and to provide a sustainable source of wood and other forest products and services has been understood over centuries. With changing needs and circumstances the scale, scope, character and composition of forest plantations have undergone changes – marked by different objectives, species mixtures, harvesting cycles and so on.

The main advantage of forest plantations are that: species/provenances/clones can be chosen and growth manipulated for particular end uses; orderly layout makes low-cost tending and maintenance possible; quality of products can be controlled through better silviculture and tree improvement. They provide much higher financial yield. The superiority of plantations over natural forests as a source of timber rests primarily on their higher productivity of marketable wood. Well cared-for forest plantations are probably the next best alternative to natural forests environmentally, and in most cases better economically. A point often highlighted in favour of forest plantations is that they help to reduce the pressure on natural forests and help to ensure overall sustainability of forest management. In several cases, however, limits to the useful conversion of natural forests into plantations have been reached or exceeded. Some of the potential negative aspects of forest plantations are: the need for heavy investment and infrastructure; complexity of cost structure; tendency to rely on restricted species base; distortion of priorities affecting equity considerations and land rights; comparatively low capacity to support environmental conservation; and heavier impact of management lapses causing site deterioration. These negative aspects, often, can undermine the effectiveness of plantation programmes.

Predominance of monoculture and use of exotic species in forest plantations are major points of contention and controversy. Those who oppose monoculture and use of exotics in forest plantations, however, do not find anything incongruous in their use in agriculture. Moreover, the role of institutions and institutional instruments, mainly of policies and regulations in influencing land use (leading to misuse) is often ignored; and plantations have, often faced the fate of scapegoats.

STATUS OF TEAK

Qualities of teak trees

Teak can be grown comparatively easily, both through natural and artificial regeneration. Naturally, it grows in mixture, and its incidence in the crop composition varies. Teak is a light demanding species and it grows to considerable height with straight bole; it is reasonably resistant to light fires, grazing and other injurious agents. To attain good growth (and reasonable economic return), teak requires fertile, well-drained alluvial soils; it competes with agriculture for good land.

Qualities of teak timber

Teak timber has excellent physical properties. It is one of the most naturally durable woods. Heartwood of teak is strong, of medium weight and hardness, and outstanding in retaining shape. It has excellent shock-absorbing ability; reasonable shear, specific gravity, tensile strength and modulus of rupture; and low coefficient of expansion and contraction (Trotter, 1940). Content of sesquiterpene in the heartwood makes it less amenable to termite attack. As consumer durables, teak products store carbon for a very long time and this is an added merit. The sapwood of teak, however, is easily perishable.

The aesthetic properties of teak are its light golden brown colour, decorative grain structure and smooth surface. It can be easily seasoned and treated, has good machining properties and takes polish very well. It is an excellent utility timber; and is also very good for carving. It is considered as a model wood and used as the standard for quality rating of other common timbers of India. Teak had the status of a "royal tree" in some parts of Asia. Brandis (1872) considered that "among timbers, teak holds the place which diamond maintains among precious stones". The quality of teak timber is reflected in the high market value of the teak products. Teak of all size and age classes are utilizable for a variety of uses – as poles, posts, masts, beams, planks, panels, builders items, parquet, various types of furniture, carvings and toys. Large-scale extraction of teak timber, initially started in the early years of 19th century, was for shipbuilding – full-tree-lengths for masts, and timber for beams, boards, ribs, panels etc.

Depletion of natural teak

As a result of increased extraction of teak, and conversion of teak bearing forests into agricultural land, natural teak resources steadily got depleted. Efforts were initiated to counter the situation by raising plantations of teak in suitable areas. Teak plantations were started in India in 1839/1840, and in Indonesia, in 1880. Average annual production of teak wood from traditional producing countries, i.e., Myanmar, India, Indonesia and Thailand, is currently less than 2.5 million m^3. A significant share of this supply comes from plantation sources. Over the years, silviculture of teak (site preparation, planting materials and methods, cycle and nature of tending, maintenance regime, interplanting and under-planting, *taungya* system, crop combinations etc.) has undergone improvements. In many cases, however, repeated harvests and the impact of fire, grazing and illegal cutting have resulted in deterioration of site quality of teak areas.

During the first half of the 20th century, teak was one of the most studied species. Trials were undertaken by many countries, outside the teak zone, to introduce and promote the species. Teak was also introduced as an important component in farm forestry, agro-forestry and homestead forestry in several tropical/sub-tropical countries.

Changing pattern of wood-use

With changes in wood processing technology and emergence of new products, changes took place in the nature of wood-use. Reconstituted wood and wood-fiber products gained prominence. High cost (compared to substitutes) became an unfavourable attribute of many of the solid wood products. Demand for premium quality teak products remained comparatively low. Thus, in spite of early enthusiasm, tempo of teak planting could not be maintained; and fast growing, high yielding, short rotation plantation crops took over the lead.

Of the total area of forest plantations in 2000, globally (187.1 million ha), the share of teak plantation was only 5.7 million ha, representing about 3 per cent. According to FAO (2001a; b), 36 countries are engaged in raising commercial plantations of teak, while several others have introduced teak at least on a trial basis (Table 1).

Inadequacy of relevant information

Quantitative details on the different aspects of teak, vital for planning teak plantation development, such as age and quality classes of plantations, survival rates, growth and yield, site changes, crop combinations, rotation, relative costs and benefits,

Table 1. Details of Forest Plantations, 2000

Region	Teak		Eucalyptus		Rubber	
	Number of countries	Area (ha)	Number of countries	Area (ha)	Number of countries	Area (ha)
Africa	8	207,000	32	1,799,000	9	573,000
Asia*	14	5,409,000	16	10,994,000	12	9,058,000
Oceania	4	7,000	5	33,000	1	20,000
C.America	8	76,000	7	198,000	2	52,000
S.America	2	18,000	10	4,836,000	2	183,000
Total	**36**	**5,716,000**	**70**	**17,860,000**	**26**	**9,885,000**

* Extent of Teak Plantations in India is 2,561,000 ha. *Source:* FAO (2001)

and elasticity of demand for teak products are scarce.

Quality vs demand

Product quality is relative to other comparable products (i.e., substitutes) in terms of attributes, cost of production, and/or price. Price is, often, the proxy for quality; it is decided in the market through interaction of supply and demand and demand elasticities. Better the quality and lower the price, the demand tends to go up.

Quality-enhancing measures for teak would involve improved technology (e.g., genetic improvement and improved cultural practices), enhanced factors of production (e.g., better land and management), rational utilization of raw products (e.g., cheaper core and fancy face veneer for decorative plywood), and experimentation.

Policy influence

'Policy' generally refers to the principle that governs and guides actions directed towards given ends (Boulding, 1958). These ends reflect national aspirations. Policies contain unambiguous statements about objectives, measures and strategies to avoid arbitrariness in decisions and actions by governments and institutions. An effective policy is what is acted upon and not what is written about. Good policies support long-term sustainability. They are the hallmark of good governance.

Sectoral policies are subordinate to the operational principles enshrined in the National Constitution and higher-level policies. Policies are enforced by institutions on the basis of rules and regulations. Planning, instrumentation, plan implementation, human resource development, establishment of criteria and indicators, monitoring and evaluation, and inter-sectoral co-ordination, are all part of the policy process.

Forest sector policies

National forest policies specify principles, along with the objectives, practical measures and strategies to be followed in the conservation, management and use of the nation's forest resource, which it is felt, will contribute to the achievement of some of the broader national development objectives (Worrell, 1970). Forest policies provide the basis for legislation, regulations, plans and programmes in the sector. They define the contributions of the sector to national development and welfare, and influence the way in which organizations and individuals manage and utilize their forest/tree resources. The specifics of a sectoral policy are decided by the distinguishing sectoral features.

The plantation sub-sector (particularly specific types of plantations such as of teak) is not generally covered by a separate/comprehensive policy dealing with all policy aspects1. It is treated within, and as part of the forest policy. In some instances, forest policies specify: the importance of plantations to supply industrial raw material and fuelwood to reduce pressure on natural forests and for employment generation; the type of areas to be afforested on a priority basis; the need and importance of involving local communities and private sector in afforestation activities; and restrictions on conversion of natural forests into plantations. In other cases, the policies to be adopted are specified under the Medium Term Development Plans, long term Perspective Plans and/or specific Plantation Master Plans.

Implications of incentives

Incentives create artificial competitive advantages, and stimulate investments. In some instances, incentives are essential to achieve social or environmental goals that market forces will not otherwise deliver. In others, incentives are used to prop-up inefficient enterprises and such incentives tend to be perverse. Incentives for promoting forest plantations, among others, include: concessional credits, tax remissions, afforestation grants, price support, technical assistance, supply of cheap planting stock.

In Chile, between 1974 and 1994, 75% of the reforestation cost was granted as direct subsidy; additionally, exemptions were given on property and inheritance taxes on the reforested land. As a result, within a generation, Chile was able to create one of the world's most competitive forest resources (Clapp, 1999). It is, however, to be underlined that all distortionary subsidies represent a really serious misallocation of scarce financial resources.

Government role in plantation establishment

Almost all significant national plantation programmes appear to have been started by governments, or with government participation. More than two thirds of Japan's land area is under forests, as a result of a State-sponsored afforestation drive. The government of Indonesia has a Reforestation Fund sourced through a cess charged on harvested timber, which is meant to promote and support development of forest plantations. A number of governments, including China and India remain active participants in plantation establishment and management. In others, governments have dissolved their commercial forestry interests by privatising plantations.

Large plantation schemes require sizeable funding. Decisions about spending large amounts of public money are essentially political. This is true of direct investment by the State, and of State support to the private sector. The calculation is not simply: "is it profitable? but "who stands to benefit?" or "what will be the short-term political consequences of a yes or a no?" There will certainly be vested interests to consider, or special considerations such as creation of employment opportunities.

A number of governments have imposed embargo on clearing forest areas. India and China have imposed ban on clearing primary forests for raising forest plantations. FSC (Forest Stewardship Council) guidelines for sustainable forest management, also require that plantations should not be raised by clearing natural forests. Efforts are also on, to encourage landholders to plant trees on farms and surplus lands.

Positive and negative views

Forest plantations have attracted considerable positive attention and criticism in the recent years. Monoculture plantations, especially of exotic species have been blamed for causing environmental degradation, loss of biodiversity and social inequity (Shiva, 1996). Zobel *et al.* (1987) assert that opposition to forest plantations is mostly emotional, based on misunderstandings caused due to inadequate knowledge and scientific enquiry. Salleh (1997)

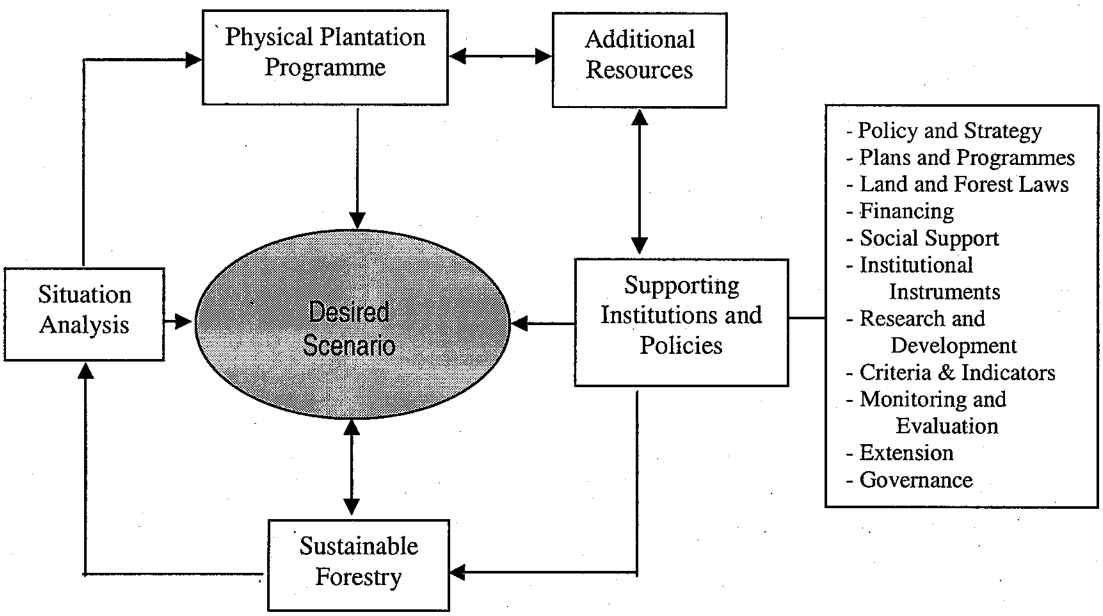

Figure 1. Diagrammatic representation of institutional/policy linkages of plantation forestry

suggests that forestry has to follow agriculture along the road to intensification of production, and that forest plantations offer the answer to many of the global environmental problems. One analysis had concluded that plantations are needed where: (1) natural forest area is inadequate (2) natural forests grow too slowly to meet forest-product demand on a sustained-yield basis, (3) natural forests are too scattered to permit economical harvesting, and (4) natural forest timber is too remotely located to be transported economically (Marsh, 1962).

Teak plantations and policy gaps

In spite of the availability of tested technology and known potential for development, one finds that teak plantations do not come up "in a big way", or they fail due to social, political and institutional (e.g., bad planning, lack of funding, inadequate protection) reasons. In common with other plantation crops, teak suffers from several chronic constraints: non-availability of suitable land, poor quality of planting materials, wrong site selection, lack of timely financing, indifference of stakeholders, corruption and illegal practices, inadequate mechanisms to safeguard investment and shareholder interests, market fluctuations and other risks, conflicts and controversies. These are often the "real world" situation; instead of assuming them away, they have to be addressed through policy measures (Fig.1).

Policy-linked shortcomings

While there are successful cases of teak plantations, both under public and private ownership, in many (if not most) cases there have been considerable shortcomings. These result from several policy-linked factors:

- Land-related factors: These are related to land types, land tenure and security, and careless attitude of public agencies and over-cautious attitude of private sector towards investments in forestry. With the ban on converting natural forests in several tropical countries, areas available for planting consist of degraded secondary forests, some of which are unsuitable for raising teak plantations.
- Problems related to financing: resulting, among others, from inadequate budget, non-availability of timely funding, financial mismanagement and high rate of interest. Area planted varies from year to year depending on availability of funds, affecting the normality and sustainability of plantation forests.

Social (and environmental) aspects covering: loss of rights and privileges of the local and forest dwelling communities; illegal and anti-social activities such as timber smuggling; legal and illegal clearing of plantations for raising agricultural crops; excessive grazing and incendiary fires; environmental impacts of the above exacerbating the social problems; and the incapability of the public institutions to address the situation.

Institutional deficiencies: These appear both in the private and public sectors. Its manifestations in the private sector are in the form of administrative hurdles, restrictions on land use, lack of research and extension support, cumbersome procedures for timber utilization (such as proof of ownership, permits for harvest and transport etc. involving harassment and bribing), lack of regulations to control shareholding plantation companies and misuse of loans and shares in others. In the public sector it manifests variously: lack of attention for site selection, use of inadequate planting materials, lack of maintenance and protection, financial mismanagement, corruption and collusion, lack of transparency and accountability, lack of MandE resulting in double/multiple counting of plant-ations, revenue fellings and overall governance failure. Moreover, social and environmental objectives of plantations such as fuelwood supply, land rehabilitation and generation of employment are often mixed up with production objectives and misused as a smokescreen to cover up the poor performance. While science-based discussions do take place, relating to silviculture, genetic improvement, site-species matching, tending schedules and so on, hardly any follow-up action happens and "business as usual" continues. This leaves a "credibility gap" affecting the forestry profession. Research papers suggest MAI of over 10 m^3 in average soils for genetically improved teak varieties, and feasibility of combined cultivation of teak with other valuable crops such as rubber and rattan for better profitability. But is it yet a field reality? In recent years, the recorded maximum MAI at final felling for selected quality II teak plantations in Kerala, India has been around 2.4 m^3/ha. Adding an estimated inter-mediate yield of 1.2 m^3/ha /yr, the maximum total MAI obtainable has been estimated at 3.6 m^3/ha (KFRI, 1997). No details are available about the overall average yield country-wise. In spite of its "excellence", teak seems to be suffering from lack of meaningful promotion. What we note here is the great gap between possibilities indicated by research and practical difficulties to move out of the default situation.

- Investment Constraints: Among the main constraints identified for investment in forestry and forest plantations in many countries are: inappropriate and inconsistent policies (and the resulting uncertainty), poor institutional capacity and difficult bureaucratic procedures (Chipeta, 1996). Private investors are interested in reasonable profit after accounting for all costs, legal and illegal, and financial safety. Non-availability of land of adequate quality and the need to incur disproportionate amount of "unaccountable" costs often dissuades private sector from investing in teak. The risks involved in long-term investment (e.g. changing consumer preferences, competition from substitutes, fluctuating demand and falling prices) are also important factors, which discourage private sector investment in teak plantations, compared to investment in short-term fast growing pulpwood plantations.

Weaknesses in policy implementation

Existence of policy alone will not guarantee success of plantation programmes. Forest policies in a number of countries suffer from a major weakness that they have been developed in isolation, solely within the forestry sector, without adequate consultations. As a result, the forest policies are routinely ignored by other sectors, which fail to see the benefits from forestry to their own objectives (Chandrasekharan, 2002).

One of the important lacunae in policies related to forest plantations is the lack of strategies to address the issue of markets. Promoting forest plantations without concurrent efforts to find reasonable markets, and facilities for value-added processing, will be counter-productive.

Opposition to forest plantations are often reactions to the manner in which large plantation schemes are promoted and implemented to the disadvantage of the poor farmers and weaker sections of rural society. These are linked to the gaps in policies and inadequate policy implementation. In such situations, forestry professionals are made to play a defensive second fiddle, and power brokers tend to gain the upper hand. The mismatch between policy and performance is thus a major institutional failure, where, in spite of institutions being in place, nothing happens. Forest plantation development requires a stable institutional and policy environment.

Need for policy research and analysis

Policy research involves scientific studies to support development (or revision) of policies. It provides relevant information for setting sound policy objectives, policy measures and strategies including institutions and instruments, to improve/optimize policy outcome and achieve policy objectives. Apart from technological aspects, policy research covers social, economic, environmental and institutional aspects.

Forest policy research is involved, among others, in situation and outlook analysis; location analysis; evaluation of policy objectives and measures; institutional structuring and mapping, equitable distribution of benefits; identifying causes for, and measures to address, illegal practices; monitoring and evaluation of policy implementation; and assessing the impacts of other policies such as of trade and land use, on forestry activities. These cover an array of factors: e.g., changes in policy environment, land ownership and tenure arrangements, production and productivity, costs and prices, market behaviour, discount rates, incentives, economic and financial benefits, benefit/cost relationship. It helps to incorporate developments in science and technology in the policy process. It can enable continuous improvements in efficiency, establishing of priorities and phasing of policy measures and activities.

However, these aspects are, often, taken for granted and neglected, and very little research goes into them. This issue deserves serious attention.

Problem analysis

Problem analysis is an important step in policy formulation/ reform. It involves analysis of factors leading to weaknesses in implementing policies (relating to plantations). Also several of the plantations are riddled with many problems such as lack of funds for maintenance, lack of detailed inventory, and poor stocking. Detailed problem analysis will help to devise suitable strategic interventions.

An important effectiveness criterion of forest policy measures should be the creation of competitive advantage, instead of simply reaping benefits from the nature-provided comparative advantage, as the latter cannot be sustained for long. Whether teak plantations (or plantations of other species) is a better/desirable land use depends on how the influencing factors are combined to produce optimum result.

Cost/benefit profiles

Cost/benefit profiles (both financial and economic; private and public2) of various alternative models (of teak plantation development) involving combinations of different provenances, rotations, thinning/tending schedules, inter-cropping etc and their merits and demerits in comparison with natural forests and other alternatives, form a useful input for making policy decisions. Cost/benefit profiling calls for research into various relevant aspects.

INSTITUTIONAL ANALYSIS

This provides the comparative merits/demerits of different institutional arrangements (private, public, community and co-operative), and their relevance for specific situations.

In the absence of meaningful policy research pitfalls are likely to plague policy implementation, and it can turnout to be economically and socially perverse and environmentally damaging. The results of policy research, being elements supporting policy decisions, need to be packaged in an easily understandable format to facilitate its effective use by decision makers.

Sustaining the pre-eminence of teak

Plantation forestry is only one of the many aspects of forest land use. Accordingly, forest (and teak) plantations are to be viewed in the holistic scheme and context of forestry. The task of fitting the various components of forestry, appropriately, into the development matrix requires 'vital imagination' based on objective assessments. The policy measures relating to forest plantations should help in the following.

- Identification and allocation of appropriate land for forest plantations, ensuring an appropriate balance in forest land use (and in overall land use).
- Defining the role and nature of involvement of public and private sectors, community organizations and co-operatives in plantation development. Considering the need for large investments, increased involvement of private and co-operative sectors is of considerable importance. Government needs only to provide a practical framework and regulatory instruments, allowing functional freedom to the investors.
- Strategic support to ensure quality (certified) seeds and improved planting stock.
- Ensuring efficient management, better market performance and improved net economic benefit. Globalisation of market for timber maintains a strong price pressure in favour of low cost producers. The inevitable consequence of this pressure is the trend towards shortening of crop rotation, which have in several cases been facilitated by advances in plant genetics and wood processing technologies.
- Improving end-uses and value-addition on plantation wood.
- Providing appropriate directions relating to the scale of plantation enterprises. Social considerations often make it necessary to have different scales of operation to support equitable participation of different categories of investors. However, plantation forestry for timber product-

ion benefits considerably from economies of scale and integration with industrial proce-ssing, thus calling for institutional innovations.

- Reducing negative social and environmental impacts and controlling illegal activities.
- Stakeholder consultation and participatory planning.
- Establishing a system for information gathering and dissemination. Public concerns and perceptions about plantations reveal that better information and effective dissemination are essential for enhancing performance of plantations.

Considering the variations found in every aspect of forest plantation development and the need for properly phasing and coordinating all the related activities, it is necessary that large plantation programmes are implemented within the framework of a plantation master plan. Such a plan will include conceptual and implementation details, with due understanding of the role of plantations in the overall forestry scene. The plan will specify the "where, how, how much, by whom, in what order and at what cost" of the plantation development schedule3. The plantation master plan should be consistent with the provisions of the overall land use plan if existing.

CONCLUSIONS

The superiority of plantations as a source of timber rests primarily on their higher productivity of marketable wood. Forest plantations are enterprises – result of human ingenuity, institutional policies and informed decisions. The deficiencies of forest plantations and tree planting ventures are to be addressed by strengthening and reforming institutions.

Commercial forest (teak) plantations should be developed and managed as a science-based enterprise following business management principles, in order to ensure sound technical practices, to avoid damaging social and environmental impacts and to deliver sustainable economic benefits.

We have relied, for too long, on the comparative advantage of natural occurrence of teak as an excellent timber. We have to manage the species efficiently, to develop a competitive advantage as well, if it is to sustain its pre-eminence.

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Quality Concerns of Sustainable Teak Wood Chain

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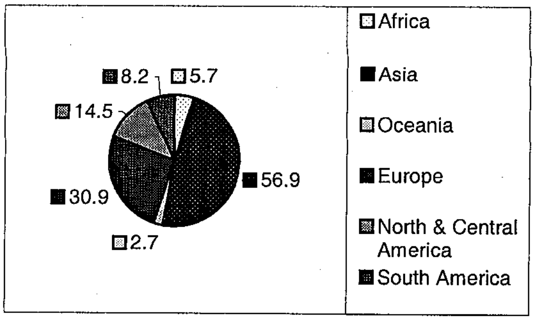
ABSTRACT

Teak is an undisputed leader of high quality tropical timbers, as a long rotation tree crop of 50-70 years. Whether it maintains superiority in fast growing short rotation plantations is a major concern of the tree growers/ investors, policy makers, traders and end-users of the teak wood chain. While highlighting the teak wood quality demands of global market, promises from teak wood farming and home-garden forestry, as sustainable options, are discussed in the paper in the light of recent research findings. Although generally teak attains mechanical maturity of timber around 20 years, the increased proportion of juvenile wood in the timber from short rotation plantations, with relatively low heartwood and extractive contents, has certain limitations for use in very durable products for which teak has worldwide reputation. However, there are enough research evidences to indicate that timber quality attributes such as density, strength, stability and aesthetic appearance of fast grown teak wood, though likely to be different, are not always inferior. With guarded optimism, it is argued that opportunities do exist for timber production of acceptable quality by applying tree improvement/genetic modification (GM) technologies coupled with collaborative research and training programmes for manufacture of quality wood products. Technological interventions in various stages of the wood chain from the multidisciplinary efforts of wood technology, biotechnology and silviculture are therefore needed for sustainable production of environmentally acceptable 'green' wood products. The adoption of appropriate processing technologies by small and medium-sized timber holders and entrepreneurs (SMEs) is also a need of the hour for marketing the value-added products from the relatively small dimensional timber coming from thinning and early harvesting of the timber crop. The other major challenges are effective mechanism of research and development as well as developing new market for 'green' products from sustainable forest management (SFM).

Keywords: Short rotation teak, maturation age, wood properties, GM tree, trees outside forest (ToF), processing technology.

INTRODUCTION

With a rapid increase over the past decade, the global forest plantation area estimated for the year 2000 is approximately 180 million ha while half of it is located in Asia with major shares from China, India and Japan and one third of global planted forests is represented by the tropical plantations (Fig. 1). The current level of potential roundwood supply from plantations is around 370 million m^3 per year, which is 25% of the global industrial roundwood production and is expected to increase to around 30-33% of total supply in the year 2010 (Whiteman and Brown, 1999). The annual global production of roundwood as well as wood product consumption are expected to increase at an annual rate of 1.7% to the year 2010 amounting to 1.9 billion m^3 of roundwood equivalent with highest rates of growth in Asia and the Pacific. While North and Central America will remain the largest producing and exporting region, it will remain behind Asia in terms of its share of global consumption. The Asian Region is expected to continue to produce more finished products than industrial roundwood and remain as a net industrial roundwood importer.

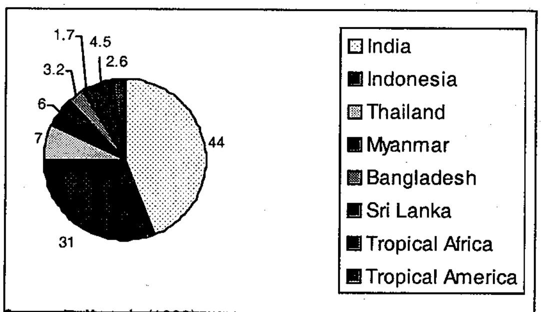


Source: Whiteman and Brown (1999)

Figure 1. Global distribution of forest plantations by main Regions in the year 1995 (million ha)

TEAK- AN UNDISPUTED LEADER OF HIGH QUALITY TROPICAL TIMBERS

Species-wise, eucalypts constitute the largest area (30%) of hardwood industrial plantations, followed by acacias (12%) and teak (7%) while pines make up most of softwood plantations. About 94% of global teak plantations are represented by tropical Asia with 44% in India and 31% in Indonesia (Fig. 2). While about 4.5% plantations are estimated in tropical Africa largely in Cote d'ivore and Nigeria, approximately 2.6% are located in central America especially Costa Rica, Trinidad and Tobago. Production of high quality wood in relatively long rotations of 50-70-year forest plantations has been the traditional practice in teak producer countries ever since the first world's teak plantation was established in India (Nilambur- Kerala) in 1840s. Now with the acceptance of farmers/small land holders in the model of industrial wood supply in many countries, viz., Malaysia, Thailand, India, Brazil and Costa Rica, shorter rotations of 20-30 years



Source: Ball *et al.* (1999)

Figure 2. Percentage distribution of teak plantations by country/regions

are being tested for veneer and saw log production for relatively quick returns (Ball *et al.*, 1999).

Teak is an undisputed leader of tropical timbers and it constitutes 75% of high quality hardwood plantations, which receives increasing attention in most of the tropical countries particularly Brazil, Costa Rica, Ghana, India, Indonesia, Malaysia, Myanmar and Thailand (Keogh, 1999). Teak is referred to as a standard timber in assessing utilization potential and end-use classification of other tropical timbers. What is *wheat to food is teak to wood* by attracting particular research attention for improvement of yield and quality in global high value timber development programme for the following unique features:

- Teak wood is an attractive, versatile and environmentally friendly raw material.
- It has worldwide reputation for natural durability and can replace preservative-treated softwoods in exterior applications like windows including garden furniture.
- It has desired strength properties with dimensional stability and can replace steel in various ways.
- It has high potential for quick growing plantation and more rapid sequestration of carbon than temperate woods.
- Environmental impacts in terms of conversion of energy requirements (and hence carbon emissions), and good and easy recycling properties at the end of teak wood product's life are much less than other materials such as PVC and aluminium.

Yet, wood quality is a major concern and it is unlikely that fast growth and carbon sequestration will benefit sales if product quality is poor.

WHAT QUALITIES OF TEAK ARE DEMANDED IN INTERNATIONAL MARKET?

The natural wood properties, specifications and supply are three critical market factors of high quality tropical timbers although quality consistency, supply regularity and dependability, promotional support and price competitiveness and stability influence the international marketing potential (Table 1).

Table 1. Critical factors in a sustainable teak wood chain

Natural properties	Specifications	Supply
Appearance	Right sizes	Regular supplies
Colour consistency	Dimensional stability	Reliable supplies
Natural durability	Moisture content	Short delivery time
Machineability	Consistency of grading	Minimum order size
Gluing and fixing	Low waste in use	Ease of buying
Dimensional stability		Honouring contracts

Source: FAO (1992)

Importance of the quality attributes varies depending on what product is marketed. For instance, weather resistance, dimensional stability and price are the predominating factors for sawnwood while wood figure (colour, grain, texture) and surface appearance are regarded as most important for decorative veneer.

KEY WOOD PROPERTIES DETERMINING THE QUALITY

Generally timber utilization aspects will be considered only at a later stage of wood chain. For a quality end-product, it is important to consider minimising the timber defects such as fluting, bole taper, knots, etc. right from the stage of seed selection (appropriate provenances / genetically superior individual trees/clones as part of tree improvement programme at grower's level. This would save considerable efforts and resource including energy at processing stage to overcome the timber defects for high quality products. This is especially true in the context of processing of solid timber products that require the minimum of conversion, unlike reconstituted products. Keogh (1999) argues that the use of as much solid wood as possible is to be encouraged especially from high quality tropical hardwood plantation like that of teak. Inferior quality wood produced through poor silviculture (i.e., timber containing knots, or timber of inferior or variable strength) or poor drying (resulting in warping) cannot expect to compete with composite products and win an extra share of the market. Before implementing the highest standards of silvicultural management for yielding the timber of desired dimensions, knowledge-base needs to be developed on effects of shorter rotation, fertiliser application, irrigation, thinning, pruning, etc. on market value of the timber.

As greater uniformity of wood is associated with straight clear bole with fewer and smaller knots, there exists opportunity for improving tree form with other desired wood properties by both genetic improvement and silvicultural practices (Bhat, 1998b). Future breeding criteria should include the following commercial properties of wood along with the acceleration of growth rate of the trees:

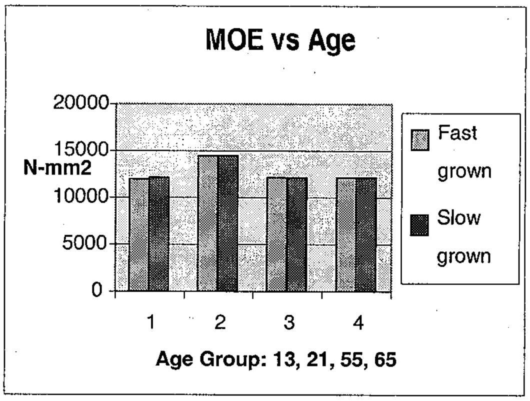
- Clear bole characteristics - reduced buttresses or fluting, which appears to be under genetic control; more knot-free (branching pattern and crown form) straighter and more cylindrical stem (including "teli" variety of teak from southern India) and desired figure (colour, grain, texture, etc).
- Denser and more durable juvenile wood (as natural resistance appears to be a genetic character).
- Uniform wood (with least within-tree variation in anatomical, physical and mechanical properties between juvenile and mature wood) and figure (colour, grain, texture)/ appearance.

PROMISES OF TIMBER QUALITY FROM WOOD FARMING

The recent research findings indicate that short rotation timber of teak is not so inferior in density and strength as to make it unsuitable for structural uses. The maturation age is attained at about 15-20 or 25 years (Bhat *et al.*, 2001.) as indicated from Indian forest plantations. The projections from the recent studies indicate the following trends:

- The productivity of short rotation teak plantations is significantly high with a mean annual increment range of 10-20 m^3/ha (Ball *et al.*, 1999).

- Without altering timber strength, plantation managers can aim at producing the logs with higher yield (larger cylinder) of naturally durable heartwood per individual tree by accelerating tree growth in short rotations with judicious fertiliser application/genetic inputs in suitable sites (Bhat, 2000).
- Teak can produce the timber of optimum strength in relatively short rotations of 21 year-old forest plantations (Fig. 3).
- Fast growing provenances/clones can be selected for teak management without reducing wood specific gravity (Bhat and Indira, 1997). However, matching the provenances for specific site conditions and product requirements appears to be most crucial in tree improvement programmes (Bhat and Priya unpublished)
- With lower heartwood and extractive contents, natural decay resistance of juvenile wood from farm land is lower than that of mature wood (Bhat and Maria Florence, 2003) despite its comparability to the central part of even very mature trees of forest plantations.
- Although wood figure, in terms of colour, grain and texture, of farm grown trees is likely to be different, it should be acceptable in the market in view of reduced supply of conventional quality timber in future and (Bhat, 2000; Bhat *et al.*, 2001).
- Wider ring due to faster growth in teak yields higher proportion of latewood (with greater yield of fibres), although exceptions were also noticed in some Indian provenances (Bhat and Priya, 2004.).



Source: Bhat and Indira (1997)

Figure 3. Timber stiffness (Modulus of elasticity) in fast and slow grown trees in four age groups of 13, 21, 55 and 65 years respectively from Nilambur

HOW DIFFERENT IS THE TIMBER QUALITY OF HOME GARDEN TEAK

The preliminary findings of a research project indicate that log dimensions are generally greater and defects less in the home garden teak trees of wet zone than in drier zone and forest plantations in Kerala (Bhat *et al.* unpublished). Whereas wood figure (colour and grain) with darker streaks of extractives which influence timber price, are often better in the homesteads of drier locality in Kerala than in wet zone and forest plantation (Fig. 4). While no significant wood density differences were noticed, timber strength difference was not of practical value. However, planting site with edaphic factor and its interactions with the genetic set up of the trees will have decisive role in influencing the quality of wood from homesteads and plantation localities (Bhat *et al.* unpubslihed; Indira and Bhat, 1998).

PRODUCTS FROM SMALL DIMENSIONAL TIMBERS OF JUVENILE TEAK

Sustainable choices of timber supply from trees outside forests (ToF) especially homesteads and farmlands will control the future market with more juvenile wood than in the past. This is evident from the projected figure of 80-100% of juvenile wood at breast height level in cultivated 20-year-old trees in contrast to 25% of 60-year old trees (Bhat *et al.*, 2001).

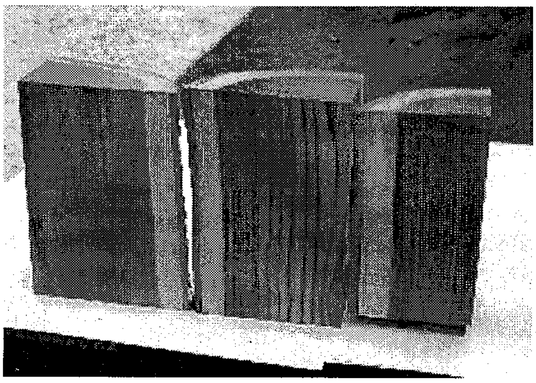


Figure 4. Wood figure from home garden teak from wet (left) and dry zones (middle) in comparison with forest plantation (right) in Kerala

Compared to mature wood, it is characterised by wide rings, short fibres, small diameter and low percentage of vessels, high percentage of cell wall, wide microfibrillar angle and relatively low or almost similar mechanical properties. While the average timber stiffness (modulus of elasticity) and bending stress (modulus of rupture) in juvenile wood are 85% and 82% respectively of the mature wood value, the longitudinal compression strength is similar. With relatively small fibrillar angle of 15° average value and with the scope for genetic selection of individual trees, teak juvenile wood has potential for desired dimensional stability (Bhat *et al.*, 2001). The juvenility in plant-ation grown teak extends up to 20-25 years depending on various factors such as wood property, growth rate, individual tree and plantation site (Locality) although generally trees attain mechanical maturity by 20-21 years (Fig.5) (Bhat, 2000; Bhat *et al.*, 2001).

The studies on the utilisation of teak thinnings from Indonesia, Malaysia and Thailand indicate that juvenile wood could be used for furniture making although some defects such as blisters, cracks and knots merit attention in training the manufacturers (Sutopo, 1992; Sahri, 2003; Doungpet, 2003). Because of moderate weight, appropriate strength, dimensional stability, durability, good working and finishing qualities as well as desired figure (colour, grain and texture), teak is recognised as the best timber for manufacture of furniture and cabinet making in India.

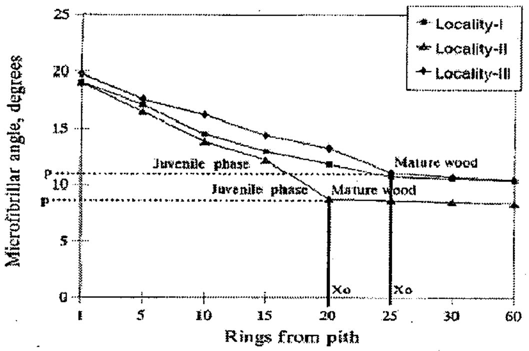


Figure 5. Age demarcation (Xo – critical point of age) between juvenile and mature wood formation as determined from the wood property of microfibrillar angle in three plantation localities in Kerala.

A considerable quantity of teak timber is peeled and sliced for decorative veneers. Beyse (1991) showed that sliced veneer of good quality could be produced from 25-year-old plantations in Brazil, which yielded 320-330 m^3/ha.

The study (Tan *et al.*, 1992) on gluing with phenol resorcinol formaldehyde adhesive for both interior and exterior structural glue-lamination showed that relatively young wood from plantations was acceptable for interior structural applications according to the Malaysian Grading Rules. Karnasudirdja (1989) conducted studies on strength of glue-laminated timber made from three wood species including teak with six species combinations. Teak was the strongest solid wood in bending and compression tests, followed by kapur and meranti. Laminated samples of the same species were generally not as strong as their solid wood counterparts, except for laminated kapur, which had greater bending strength parallel to the grain and greater compressive strength than solid samples. Based on mean shear strength values, mixed species laminates were stronger than self-species laminates, with the teak/meranti and teak/kapur combination strongest.

The tests on physical and mechanical properties of particleboards showed satisfactory results. The feasibility of fabricating technically sound cement-bonded particleboard from 10-year-old juvenile teak wood grown in Nigeria has been shown by Badejo (1989). The mill studies from Thailand report about 51% of sawn wood recovery from 20-year-old teak trees with a diameter range of 9-20.5 cm (Sangkal, 1995). Sawing trials on small timber for furniture stock and strips gave satisfactory results in plantation grown teak of Ivory Coast (Durand, 1983). The two major factors that influenced sawn wood grade and recovery were unsound hollow knots and deep flutes in the logs.

PROCESSING OF TEAK WOOD FROM TREES OUTSIDE FORESTS (TOF)

As the transport costs and growth rates tend to be the critical factors in plantation profitability, mobile technology needs to be applied for sawing and drying in growing/felling sites for precise dimensional products required for the market. This will facilitate considerable savings and fetch higher prices for the products of small-timber holders. Modified equipments in processing for sawn wood/ veneer recovery from small diameter logs have been suggested for many plantation grown timbers. For instance, peeling lathes should be capable of handling logs up to a minimum diameter of 7 cm while modified vertical band saws can process small diameter logs more efficiently (Damodaran and Xavier, 1992; Sivananda, 1992).

Processing technology for small timber holders

The opportunities seem to exist for technological interventions in both plantation and processing sites for more efficient use of wood by improved quality and market value (Fig. 6). For instance, small portable or mobile sawmills (with a capacity of 5000 m^3 log intake) with portable solar kilns and preservative treatment plants (for sapwood), that can be easily moved from site to site during thinning or final felling operations, may be appropriate for improved utilisation of small timber (FAO, 1981). This can facilitate the supply of sawn wood requirements of rural communities, building contractors, and furniture manufacturers of remote areas besides promoting the handicraft potential of the country by making best use of small dimensional materials in toys/ wooden souvenirs by encouraging rural artisans. This may promote the supply of sawn wood to meet the small timber demands of rural communities from road-side/railway development and agroforestry plantations. The building contractors and furniture manufacturers of remote areas will be the major users in addition to the handicraft industries, which employ skilled rural artisans.

Erecting a preservation plant, easily accessible to the felling/thinning sites, with the possibility of using "simple" methods of preservation (with local know-how), would enhance the durability of poles and sapwood portion of converted timber. Simple dipping of poles in trenches filled with preservatives and covered in polythene sheets (sap displacement technique) would give adequate protection as shown by the Institute of Wood Science, Bangalore. Based on the work done in Indian Plywood Industries Research and Training Institute, simple cost-effective prophylactic and end-coat treatment techniques are available in India. The code of practice as per the Bureau of Indian Standards (IS, 9104) provides guidelines for protection of logs in felling site, during transportation and storage.

Installation of cost-effective *nomad* solar kilns with an annual capacity of about 200m^3 timber in remote areas would be appropriate to meet the seasoning requirements of small dimensional wood in village level (Plumptre and Jayanetti, 1996).

Glulam and jointed structures

Recently, selected processing sectors in many teak producer countries, including India, have introduced semi-automatic finger-jointing machines that are manufactured locally with imported cutters, or have planned to invest on automatic imported machines for manufacture of jointed and glue-laminated structures. Often poor quality fingers and weak joints were noticed due to the vibrations of cutter spindle and movement tables.

Attention should be focused on low-cost mechanisation in general and the finger jointing, glulam and peeling and ultra-sonic veneer grading techniques in particular. Related to this, strict quality control, both internal (by the manufacturer) and external (e.g., by a standards institution), is a need of the hour to gain acceptance for finger-jointed timber and to maintain confidence in the product (Bhat, 1999). Standards or codes of practice are an integral part of most external quality control systems. The thrust areas of technology transfer include: development of glue spreading devices and gluing technology, non-destructive testing and criteria for engineered uses (laminated timber/veneer; light-frame construction) and non-engineered uses, optimum length of joints and long finger-jointed members, new production techniques and equipment.

CHALLENGES AHEAD

While the timber quality is a crucial factor, the major challenges to sustainable teak wood chain include the external threats to productivity from pests and diseases, climatic changes, biotic and abiotic (soil and water) interactions including the site management with nutrient manipulation and fertiliser responses of small holdings (AICAR, 2000).

Research and development

As many of the research findings are only indicative of the potential of teak for specific conditions, many aspects of the timber quality including genetic modification of teak for desired timber dimensions, figure (colour, grain, texture), natural durability and strength of fast grown juvenile wood pose several R and D challenges. For instance, despite the acceptable features of 20-year-old juvenile wood, bending stiffness (modulus of elasticity) of 5-year-old thinning material has much lower bending stiffness (only 51.7 % of mature wood) (Bhat *et al.*, 2000; 2001). The relatively low heartwood proportion and extractive contents with possibly low natural decay resistance is another limiting factor of juvenile wood as compared to the traditional long rotation teak. Integrated wood research with novel biotechnology and silvi-culture would however offer promises with guarded optimism.

Developing new market

Teak timber being a biological product is very responsive to changes in the environmental conditions. Since the properties of cultivated teak invariably differ from those of natural forests and the traditional long rotation plantations, a new and a different market is to be developed for both semi-finished and other new end products such as finger-jointed and glue-laminated structures besides furniture, flooring, decking, kitchen utensils, etc (FAO, 1992).

Training and processing skill

Processing the timber including sawing and drying demand immediate training programmes for improving the productivity and reducing the waste. End products, where aspects of design and quality are of importance should be developed, rather than trying to substitute traditional end uses such as boat trim and decking, in the case of teak, with less suitable plantation grown wood.

Sustainable management

There is a growing environmental concern and the global trend is to go for 'green' products. The tropical

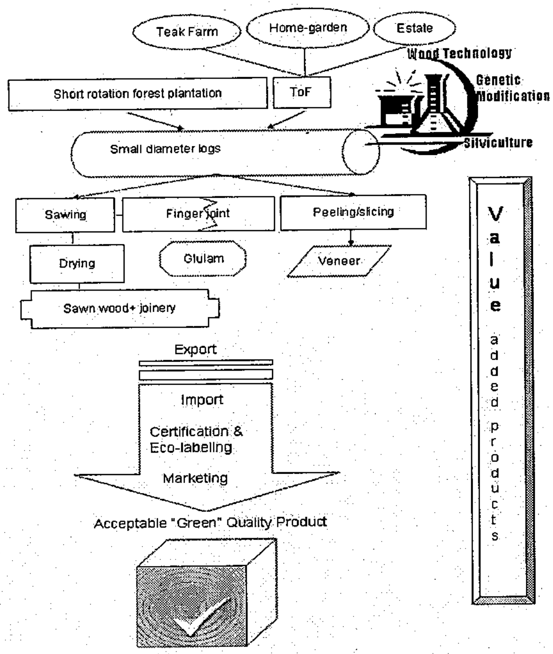


Figure 6. Arbitrary model of technological interventions for quality products in sustainable teak wood chain

high quality teak has many advantages over temperate products and other synthetic products. As certification with Eco-labeling is likely to become an increasingly important issue in the future many teak producer countries will have the stiff challenges of getting adopted to the newer SFM criteria. While long rotation plantation management is to be maintained with long-term sustainable principles for traditional qualities, short rotations may offer dividends and quick returns on plantation investment.

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High Input Plantations of Costa Rica

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ABSTRACT

Linking forest management to requirements of timber industries is fundamental for development in forestry and forest-based industry. Relationships of silvicultural activities with wood quality are often limited to size-related characteristics, such as DBH. Restrictions set by international markets (e.g. minimum log dimensions, heartwood content and wood defects) limit seriously the marketing options of several forest companies in Costa Rica and many other countries in the area. Therefore, efficient management practices are urgently needed to lead not only to a maximization of per-hectare volume but also for the production of desirable individual-tree dimensions and high quality commercial timber. This paper should help foresters to choose the most adequate management practices to suit their particular goals (i.e., specific wood properties, total yield, commercial volume, rotation periods). The paper discusses topics like aboveground biomass and the applicability on stand density management, wood quality (heartwood, density) of young and advance aged plantations, effects of stand density on wood quality based on the results from a thinning trial, effects of stand density on growth and yield, preliminary pruning programme, pruning intensity and timing and total and merchantable volume equations.

Keywords: Wood quality, merchantable volume, aboveground biomass, thinning, pruning, teak market, volume equations

INTRODUCTION

Tectona grandis has gained a worldwide reputation on account of the attractiveness and durability of its wood. Market demands have prompted the establishment of plantations within and beyond its native countries (Hoare and Patanapongsa, 1988; Monteuuis and Goh, 1999; Bhat, 2000). In Costa Rica, *T. grandis* was introduced in 1940 (Keogh *et al.*, 1978). Teak planting was prompted at the beginning of 1980 by the Costa Rican government, effort that led to a reforestation area of 40 000 ha by the year 1999 (Arias and Zamora, 1999).

Despite all the efforts invested in planting activity [i.e., 5.7 million hectares planted worldwide till the year 2000 according to FAO (2000)], teak timber resources currently available are far below the needs of the huge worldwide market demand (Ball *et al.*, 2000). Increased yield, higher uniformity and shorter rotations are strong incentives for developing *T. grandis* intensive managed plantations. However, no adequate data are available for teak timber grown with intensive silvicultural practices (Bhat, 1998). Although teak is an established high-value timber tree for commercial planting, the resulting timber may turn out to be different in quality and yield from what is expected (Tze, 1999).

Evidences of similitude in wood mechanical properties between young (21 years) and old (65 years) *T. grandis* trees offer scope for reducing the rotation age of this fast-growing species without affecting timber strength. Nevertheless, the available data on the effects of spacing and thinning regimes on wood quality are insufficient for designing an efficient management strategy (Bhat, 2000).

The aim of the present work is to summarize the main results obtained in a series of studies on stand dynamics of *Tectona grandis* plantations in Costa Rica. The present work presents main relationships between different tree characteristics; results of studies of stand management, and a group of equations, which would be of great help for developing stand growth scenarios for high-input management.

METHODOLOGY

The present work compiles results from management-related studies carried out by the authors and incorporates them into high-input management recommendations for *T. grandis* in Costa Rica. These studies are basically of:

- Aboveground biomass and the applicability on stand density management (Pérez and Kanninen, 2003a)
- Wood quality (heartwood, density) of young and advance aged plantations (Pérez and Kanninen, 2003b)
- Effects of stand density on wood quality, results from a thinning trial (Pérez and Kanninen, 2003c)
- Total and merchantable volume equations (Pérez and Kanninen, 2003d)
- Effects of stand density on growth and yield, results from a thinning trial (Kanninen *et al.*,2003)
- Preliminary pruning program, pruning intensity and timing (Pérez *et al.*, 2003)

For the different studies listed above, over 20 plantations were selected from different sites and regions in Costa Rica, representing different climatic conditions, plantation densities (initially between 1111 and 2500 trees ha^{-1}, actually between 170 and 1600 trees ha^{-1}), and ages (5 to 47 years). One or two plots of 400 m^2, with 50 to 80 trees each, were established on each plantation. From these plots, a total of 112 trees were felled for the different studies.

In the case of the thinning trial, the experimental design consisted of randomized complete blocks, with 8 treatments and 3 replicates. The trial consisted of different thinning intensities (Control, 25%, 40%, 50%, and 60%) tested at two different timings (4 and 6 years of age).

In the case of the pruning trial, the experimental design consisted of randomized complete blocks, with 4 treatments and 3 replicates. The trial consisted of four different pruning intensities (Control and pruning of all branches up to 3, 4, 5 meters of total height) executed at year 2.

RESULTS

Relationships between tree components, such as the crown width vs diameter at breast height (DBH), increment of crown diameter with increasing DBH (Fig. 1a), or the foliage biomass as a function of increasing stand density (Fig. 1b), were studied as possible tools to help the management of tree stands under competition.

The proportion of heartwood increased with increasing age, while the proportion of sapwood and bark decreased (Fig. 2a). Wood dry density increased slightly with age (Fig. 2b) presenting a higher correlation with age at the base of the tree ($r = 0.61$) than at the base of the crown ($r = 0.51$). Dry density was statistically different ($P<0.05$) only between 8-year-old trees or younger and 47-year-old trees.

After the application of the different treatments in the thinning trial, differences in DBH began to be evident, i.e., increasing with increasing thinning intensity (Fig.3a). The basal area (BA) at year 4 ranged between 14.6 and 18.2 $m^2\ ha^{-1}$ (Fig. 3b). The thinning with the highest intensity (60% of the standing trees) reduced the BA in 48%, decreasing from 15.9 to 8.2 $m^2 ha^{-1}$. At year 6, when the same treatments were repeated 2 years after, the BA before thinning for the treatments without intervention yet ranged between 23 and 26 $m^2\ ha^{-1}$. After the thinning, the BA decreased to 13.1 – 22.4 $m^2\ ha^{-1}$ (Control remained at 26 $m^2\ ha^{-1}$). Treatments applied at year 4 recovered the extracted BA sooner than those carried out at year 6, both after a period of 2 years.

Accordingly, heartwood volume (m^3) was found to vary inconsistently with thinning intensities, as well as within each treatment. The stem form factor

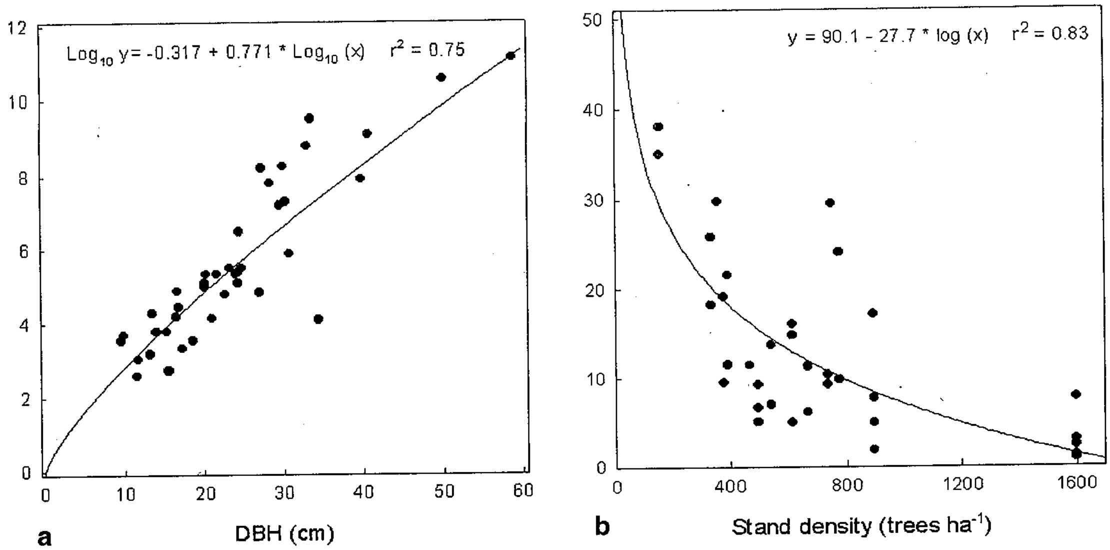


Figure 1 Relationship between a) crown diameter with DBH, and b) foliage dry weight with stand density of *T. grandis* plantations in Costa Rica.

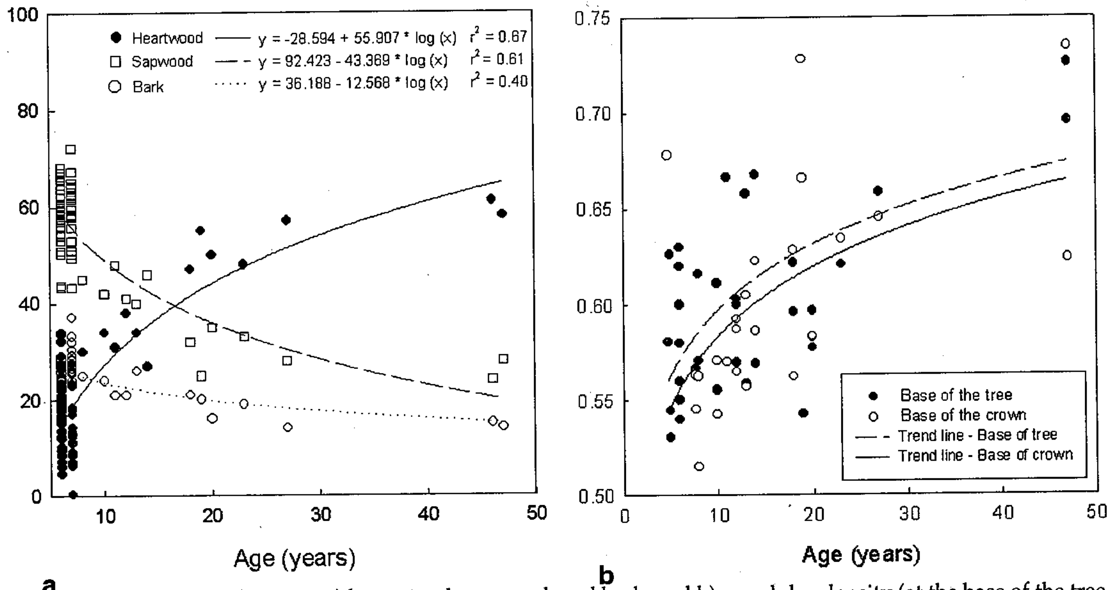
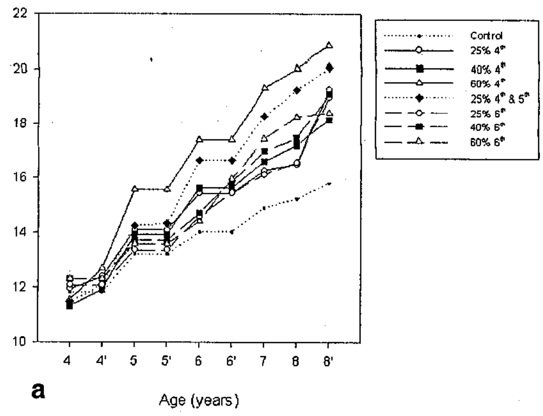


Figure 2. Relationship between a) heartwood, sapwood, and bark; and b) wood dry density (at the base of the tree and at the base of the crown) with age for *T. grandis* in Costa Rica.

presented also an inconsistent variation with stand density. Wood basic density (g cm^{-3}) was significantly higher in the 25% thinning intensity performed at year 4 than in the other treatments. From trees harvested in different regions of Costa Rica, linear and non-linear regression analyses were used to model the relationship of total volume with DBH (testing an equation reported by Chakrabarti and Gaharwar, 1995), and with DBH and total height (testing equation reported by Clutter, 1980):

$$\ddot{O}(v) = -0.0884 + 0.0297 * DBH$$
$$r^2 = 0.99 \qquad \text{(Model 1)}$$



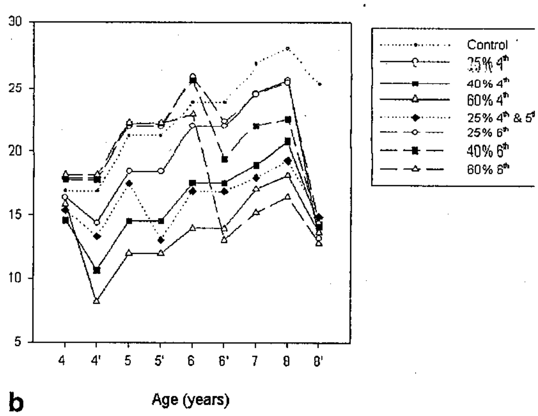


Figure 3. Stand diameter (a) and stand basal area (b) before and after the thinning interventions (') from year 4 to year 8 for the different treatments implemented in the thinning trial of *T. grandis* established in Costa Rica. Legends for each treatment refer to the intensity and timing of the thinning.

$$v = 0.00007319 * (DBH)^{1.5588} * (H)^{1.2103}$$
$r^2 = 0.99$ (Model 2)

The study also included merchantable volume equations for any minimum top diameter or bole length. Model 3 was fitted using a non-linear regression procedure, with v, dm, and DBH as independent variables. Merchantable volume equations of this type have been used by Burkhart (1977) and Clutter (1980):

$$vm = (-0.0884 + 0.0297 * DBH)^2 * (1 - 0.7839 * (dm)^{2.4149} * (DBH)^{-2.4175})$$
$r^2 = 0.98$ (Model 3)

where, vm: merchantable stem volume (m3) to a top diameter dm
dm: upper stem merchantability limit (expressed as a minimum diameter in cm)
DBH: diameter at breast height (cm)

Model 4 was used for the development of variable-bole length merchantable volume equations. Merchantable volume equations of this type are reported by Avery and Burkhart (1983), and Kozak *et al.* (1969):

$$Vm = (p/4)*(DBH)^2*(0.000014*h + (0.000274/2)*(h^2/H) + (-000331/3)*(h^3/H^2))$$
$r^2 = 0.99$ (Model 4)

Where, vm: merchantable stem volume (m3) to a top height h
DBH: diameter at breast height (cm)
h: upper stem merchantability limit (expressed as merchantable height in m)
H: total tree height (m)

Independent of site quality, our studies indicate that the first pruning in *T. grandis* must be carried out when the stand reaches a total height of 4.0-5.0 m. In the case of Costa Rica, this occurs at the age of 2-3 years. A second pruning should be carried out when the stand reaches between 9.0 and 10.0 m of total height, pruning up to 4.0-5.0 m. Finally, a third pruning should eliminate all the branches up to a height of 7.0 m when the stand reaches 12 m of total height.

Hubert and Courrand (1988) and Hochbichler *et al.* (1990) consider that in order to make the activity of pruning economically profitable, a tree should reach by the time of harvest 3 times the size that presented when pruned, referring by size to the diameter at pruning height. A projection of stem diameter at two possible pruning heights and four different rotations is presented to exemplify and analyze this criterion (Table 1).

Considering the previous suggested criterion, the actual diameter at the height of 7.0 m should reach at least 21.9 cm at the final rotation. According to the projections of Table 1, this diameter is feasibly obtained on high quality sites with 15 years or more and on medium quality sites at rotations of 20, 25, or 30 years for teak in Costa Rica.

Local/international market requirements ask for

Table 1. Projection of stem diameter at different tree heights for T. grandis on medium and on high quality sites, and for different rotations. H = Total height (m); DBH = Diameter at breast height (cm); D_7m = Stem diameter (cm) at tree height of 7.0 m.

Site quality	Variable	Rotation (years)				
		At pruning	15 years	20 years	25 years	30 years
High	H DBH D_7m	12.013.07.3	24.533.824.7	28.140.030.9	30.644.435.3	36.154.044.9
Medium	H DBH D_7m	12.012.06.3	20.727.018.0	23.632.022.9	25.635.626.5	29.943.234.1

Table 2. Dimensional and quality requirements, uses, yield, and prices to be found in the local market for *T. grandis* in Costa Rica.

Final Market	Requirements	Price US$/ m³	Product	Yield (%)
Local	- Min. 20cm diameter on the lower end - 4-5 m straight bole - >12 years - Pith on one side only	63 - 160	Floors, ceiling, timber, general construction, parquet, etc.	50 - 60 (Loss due pith eccentricity 20 - 50%)
International + Local	- Age > 20 years	160 - 530	- Furniture (only heartwood) - Parquet (local consumption)	15 – 45
International + Local	- Age > 18 years	130 - 360	- Parquet for exteriors (only heartwood) - Boardfeet (local consumption)	-----------

certain quality and dimensional characteristics of timber products. In Costa Rica, the local market is consuming teakwood of all dimensions and ages. However the best prices are paid for the largest and oldest trees, from which mainly heartwood and wood free of defects is being processed and sold to international clients. A brief description of the requirements and prices currently used in Costa Rica is presented in Table 2.

DISCUSSION

The relationship between DBH and foliage biomass is linked to the relationship between crown area and DBH. This can be used to determine the possible maximum plantation density of the stand at certain age. For example, assuming a criterion of maximum crown area occupancy, the maximum stand density could be subjected to a desired minimum mean DBH.

The present study indicates that teak in Costa Rica presents a heartwood proportion of 55% of the total volume at 30 years, increasing logarithmically with increasing age and consequently with DBH. Arce (2001) found heartwood proportions of 33-37% in 10-year-old teak grown in a dry region of Costa Rica. The average values of wood dry density found in this study are at similar level to those reported elsewhere for plantation grown teak (Baillères and Durand 2000; Betancur *et al.*, 2000; Bhat, 2000). On the other hand, other studies report no significant differences in wood density between young and mature *T. grandis*, hence rotation period of fast-growing tree species can be reduced without affecting timber strength (Bhat, 1998; Bhat *et al.*, 2001).

The thinned plots differed from the non-thinned ones, presenting up to 5 cm difference in DBH and 2 m in total height at year 8. The plots thinned at year 4 recovered better than those thinned at year 6. Applying this result to individual tree growth, a preliminary conclusion is that the best thinning regime is either to carry out the thinning at year 4 and remove from 40 to 60% of the trees, or at years 4 and 5 and removing each year 25% of the initial number of trees (heavy thinning better than light – early better than late).Changes in stand density improved the quality of *T. grandis* trees, depending on the intensity and timing of the thinnings. Although not statistically significant ($P<0.05$), heartwood volume and the heartwood / sapwood ratio were greater on high-intensity thinned treatments. Stem form became more cylindrical after high-intensity and early-executed thinnings. Wood basic density increased with increasing stand density.

The volume equations tested in this study fitted the observed data well. Other models from the literature tended to overestimate the stem volume, especially at DBH e" 30 cm. The volume equations chosen in this study are more accurate on smaller trees (DBH <30 cm and total heights <20 m) than on larger trees, and more accurate on plantations with less than 1000 trees ha^{-1} than on denser stands.

According to the present results, on medium and high quality sites the pruning of *T. grandis* in Costa Rica can be economically feasible for rotations of 15 years and more, if performed adequately and at a precise time.

Current characteristics and prices set up for Costa Rican teakwood correspond to a Grade 4 in many of the international market grading systems. In order to improve current grading, Costa Rican teakwood should be sold with higher quality (wood free of knots and bends, less taper, more heartwood) and of greater size and age (DBH greater than 30 cm, age greater than 15 years at least). This would imply, however, that the silvicultural treatments, such as thinning and pruning, are carried out timely and adequately.

However, the main objective should be to simultaneously develop two lines of action for Costa Rica. Firstly, develop and execute adequate and timely silvicultural interventions for teak plantations, which currently is not the case. Secondly, develop new products and markets using small diameter teak instead of competing with advance-aged teak produced in other countries.

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Quality Timber Products of Teak from Sustainable Forest Management pp 243-249

Some Wood Quality Issues in Planted Teak

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ABSTRACT

Assessment of the wood qualities of planted teak in relation to different growth conditions is a pre-requisite to maximize the tree potential by genetic improvement and silvicultural methods. In the context of promoting timber production in fast growing teak plantations, the present study tries to show the variability in growth and relationships between growth rate and selected wood properties, including growth stress, based on the samples collected from plantations in Indonesia and India. Planted teak has wide variations in the growth rate. During the initial stage of the growth, up to 10th year, all trees showed a faster rate, i. e., 3 - 9mm/year. After 10 years, they grew at almost a constant rate up to 40-50 years, and subsequently the growth rate decreased gradually, i. e., 1.5 - 7.3mm/year, even though they still continued to grow after 60-70 years. The relationship between the heartwood ratio and the diameter is divided into two linear relations. The heartwood ratio rapidly reached 90 per cent at around the diameter of 20 cm and increased slightly at larger diameter, regardless of the different provenance trees. The level of growth stress was considered to be lower than some other fast-growing species and is not affected by the growth rate. Also, the density at outermost part of trunk is not affected by the growth rate nor the tree age. The density increased towards the bark by 5-6 cm from pith and then stabilized at the age 10 -12 years. On the other hand, the microfibril angle decreased towards bark until 10-12 years. From these observations, it is expected that the planted teak forms mature wood around the age of 10-12 years. The results imply that growth acceleration by silvicultural treatments such as fertilization does not always adversely affect the wood qualities in teak.

Keywords: Growth stress, Wood quality, Litter dynamics, mineral nutrition, N-fixing woody perennials, site quality deterioration, species mixtures

INTRODUCTION

Tropical man-made forests accomplish rational consistency in the maintenance of global environment through their carbon sinks and the sustainable supply of forest resources. Raising the value-added products from man-made forest encourages forest plantations. According to the FAO data, the area of man-made forest in the tropical countries is estimated to be about 55 million ha (FAO, 1997) including 1.6-2 million ha of teak plantation (Oo and Hlaing, 1998). Teak is the only multi-purpose timber planted extensively in the tropics although it comes next to eucalypts, pines and acacia in the extent of global plantations. Teak is preferred for its high quality timber owing to its moderate density, high dimensional stability, high durability and ornamental wood figure. Expectations from fast growing planted teak are high because of great demand for wood accompanied by partial trading prohibitions on naturally grown teak. It is important to add value to the timber of planted teak by improving the wood quality through biotechnology, silvicultural control and processing techniques. However, all these will rely mainly on the effects of growth rate on wood quality. Although a number of studies have been conducted on teak timber management aspects, only a few deal with wood qualities in relation to the growth conditions (Bhat, 2000). In the present paper, some wood qualities of planted teak are discussed with particular reference to growth rate.

MATERIALS AND METHODS

Tree samples

Six trees of teak (*Tectona grandis* L. f.) from the age group of 16 years, ten each from 38 and 39 years were randomly selected from a site of forest in Sumedang, West Java in addition to six trees of 76-year-old stands located in Cepu, Central Java, Indonesia. Both forests represent the plantations managed by Perum PERHUTANI in Indonesia. Diametrical strips prepared from discs of 5, 41,55 and 63-year-old teak planted in Nilambur (Kerala), India were used for comparison of the heartwood ratio.

Released strains measurement

Growth stresses were estimated from the released strain induced by the release of growth stress (Okuyama *et al.*, 1981). Released strain was measured on standing trees by setting 10-15 measuring points around the periphery at breast height of each tree. Foil-strain gauges of 8 mm gauge length, Minebea type E-8-12 T11, were attached on the xylem surface using cyano-acrylate type adhesives. The released strain induced by kerfs made around the strain gauge was detected by a multi-strain meter, Kyowa UCAM-1A.

Growth rate

Growth rate was defined as annual increment in breast height diameter. Annual rings were counted with the naked eye. A 5-cm thick disk, including the points where the release strain measurement was conducted, was taken from every tree. Growth rings were easily distinguished from the false rings based on the distinctness and completeness of the ring.

Heartwood ratio

To determine the heartwood ratio, 10-15 radii of a disk from the pith to the outermost part where the released strain measurement was conducted, were measured. At the same time, the radii of the heartwood portions were also determined. The area of heartwood and total of section were calculated from the radii. The heartwood ratio is the ratio of heartwood area to the total area.

Mean microfibril angle

Mean microfibril angle was evaluated using the X-ray diffraction method. Six to ten air-dried samples, 0.2-mm thick of tangential section sliced along the surface of each measuring point were prepared. MFA was then determined using modified Cave's method (Yamamoto *et al.*, 1993b).

RESULTS AND DISCUSSION

Annual increment

Fig. 1 shows the positions of annual rings on the radius of teak planted in India, West Java and Central Java. Generally all curves show a mild convex shape. During the initial stages of the growth, all trees exhibited a faster growth rate. This is represented by mean annual ring width of 3-9 mm, up to the 10th year. Between the 10th and the 30th year, it was 2.5-8.3 mm while beyond the 30th year, ring width was 1.5-7.3 mm. Because of the small number of samples, the growth rate could not be compared between planting sites. Nevertheless, we can say that planted teak had wide variation in the growth rate. It is said that in West Java teak grows faster than in Central Java due to the difference in rainfall. Nonetheless, in some 40-year-old teak trees, the growth rates from these two areas were the same.

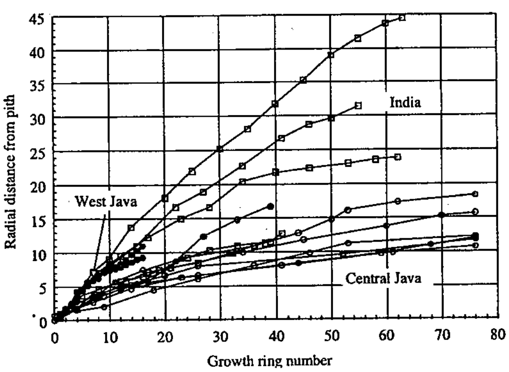

Figure 1. Radial positions of annual rings of teaks planted in India, West Java and central Java.

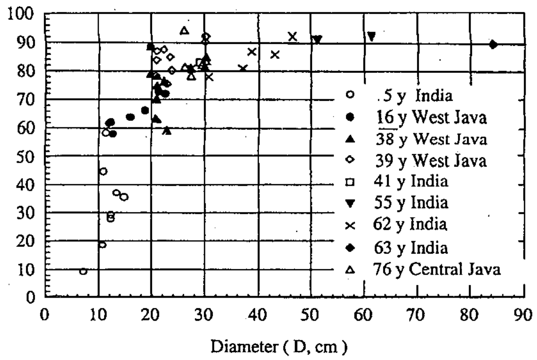

Figure 2. Relationship between heartwood ratio and diameter

HR1 = 4.8 D - 22, HR2 = 0.07 D + 84.5

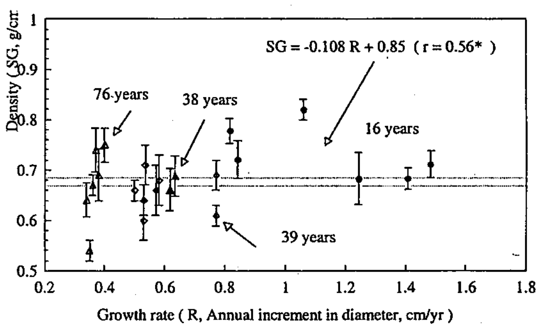

Figure 3 Relationship between density and growthrate. Note: Dotted lines show the confidence interval of average at 95% level

Heartwood ratio

Larger proportion of heartwood is preferred by end users because of its high durability, dimensional stability and darker color with various extractives (Sandermann and Simatupang, 1966). Fig. 2 shows the relationship between heartwood ratio and the diameter of the tree at various ages. A clear transition can be seen at around diameter of around 20cm. Two linear curves can represent this relation. For younger trees, the heartwood ratio (HR) increases linearly with the diameter (D) and reaches 90 % of heartwood ratio at a diameter of 20cm. This is described by the regression equation HR= 4.8 D – 22. While for the older trees, the heartwood extends slowly as given by the equation HR= 0.07 D + 84.5. All data are on the same lines regardless of provenances studied. Within the same age, the heartwood ratio increased as the diameter increased. Therefore, the heartwood ratio depends not on the tree age but on the diameter. This indicates that the faster the growth rate, the larger the heartwood ratio. This is very evident in younger trees while for older trees; the rate of increment is relatively low as reported by Bhat (2000). According to Ferguston (1934), in younger teak trees, from 1-20 years, wider sapwood is formed with an increase in diameter. On the other hand, in trees older than 60 years, uniform sapwood is formed compared to its large increase in diameter. The present data supports his results.

Density of xylem surface

Fig. 3 shows the relationship between air-dry density on the surface of xylem and the growth rate of individual teak stands. The density showed a large variation among trees, with a range being 0.54-0.84 g/cm^3. Nevertheless, it did not depend on the tree age or on the growth rate. In 16-year-old trees, the large difference in diameter demonstrated a wide variation in the growth rate with a range of 0.8 - 1.5 cm/year. It was subsequently confirmed that only 16-year-old trees had negative correlation between growth rate and density. This explains why the earlier data were conflicting with each other. For instance, Chowdhury (1952) and Bryce (1966) reported that the faster grown teak formed lighter wood, while Bhat (1995) did not find any significant difference between fast and slow grown teak. From this it is evident that young trees such as16-year-old trees, produce lighter wood than slower growing ones; whereas comparing among older trees the density is uniform regardless of the growth rate. Trees up to a diameter of 20cm produce low-density wood and subsequently they produce wood of uniform density afterwards as shown in Figure 7(a).

Released strain

Most planted fast growing species have high growth stresses that cause heart splits and crooking at sawing. Even in planted teak heart split usually occurs as shown in Photo.1 in the case of trees without girdling treatment. This means that the growth stress cannot be out of consideration also in planted teak. Fig. 4 provides all data showing the relationship between the longitudinal released strain and the distance of xylem surface from the pith at each measuring point. Negative values depict contraction meaning tensile growth stress was present at that point. The range was between -0.0005 and -0.16%, while the confidence interval of average

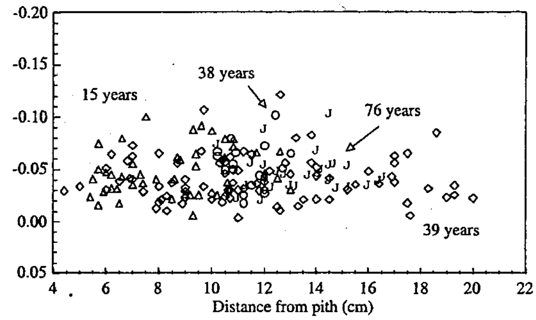

Figure 4. Relationship between released strain and distance from pith (after elimination).

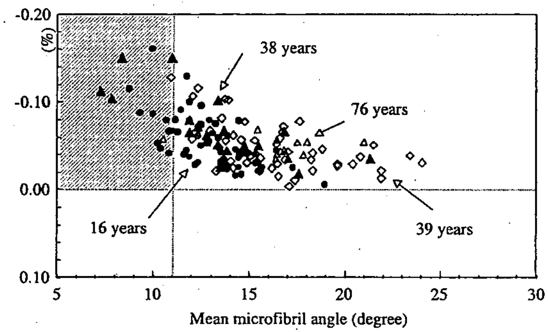

Figure 5. Relationship between released strain and mean microfibril angle

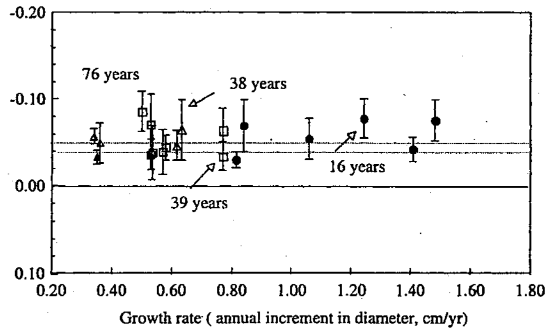

Figure 6. Relationship between longitudinal released strain and growth rate for individual trees after eliminating the values for tension wood
Note: Dotted lines show the confidence interval of average at 95% level.

was between -0.0506 and -0.0615%. These values are smaller than that of some hardwood species in temperate and tropical zones (Wahyudi *et al.*, 1999; 2000). This suggests that fewer defects such as heart checks and crooking are likely to occur during sawing (Okuyama and Sasaki, 1979). Nevertheless, heart checks were usually observed when non-girdled teak logs were crosscut during felling as shown in Photo1. Fewer heart checks of teak would be attributable to the relaxation of residual stress inside log after the girdling treatment.

Considerable variation was observed in the released strains. Younger trees, 16- and 38-years-old, showed larger dispersion than 76-year-old trees that gave a more uniform value. Furthermore, at 10 measuring points on the girth of the trunk, within-tree dispersion was larger than among-tree dispersion. This phenomenon was due to the existence of tension wood (Okuyama *et al.*, 1994).

The growth stress has close relation with microfibril angle. Smaller the microfibril angle (MFA), the larger the negative longitudinally released strain. This is because microfibrils in the cell wall generate large tensile stress in the axial direction during cell wall maturation. Even though, the tensile force is uniform along the axial direction of the microfibrils, the amount of tensile stress in the longitudinal direction in the cell wall depends on the MFA. The smaller the MFA, the larger the tensile stress created along the cell axis (Yamamoto *et al.*, 1992; 1993). Therefore, larger released strains are detected in region of smaller MFA.

Figure 5 shows the relation between longitudinally released strain and mean microfibril angle. The negative released strain (tensile stress) was large in the small MFA region, gradually decreased toward 15 degrees, and then became flat in regions of large MFA. Hardwoods have small MFA in the upper part of the inclined stem or the branches regardless of whether gelatinous fibers occur or not. Large tensile growth stresses exist at regions of small MFA. This tensile stress generates a force large enough to support the inclined stem and branch, directing it upward controlling the shape of the tree (Yoshida *et al.*, 1999).

Microscopic observations on the measuring points where strain was high and MFA was small did not show any gelatinous fibers. Therefore, further observations should be made to confirm this because Bhat (1995)previously noticed gelatinous layer-like tissues in teak. Nevertheless, it is also possible that teak is similar to wood containing tension wood but without any gelatinous fibers, e.g., *Magnolia obovata* (Okuyama *et al.*, 1990) and *Liriodendron tulipifera* (Okuyama *et al.*, 1994).

In order to investigate the effect of growth rate on the released strain, the relationship between strain and growth rate of normal wood alone should be considered by eliminating the data in the tension wood.

Released strains of tropical fast-growing species such as *Paraserianthes falcataria* and *Acacia mangium* increased gradually as the MFA decreased at less than 12 and 11 degrees, respectively. Tension wood was observed in the specimens obtained at the region of MFA less than 10 and 8 degrees, 2-3 degrees smaller than where the released strain began to increase (Wahyudi *et al.*, 1999; 2000).

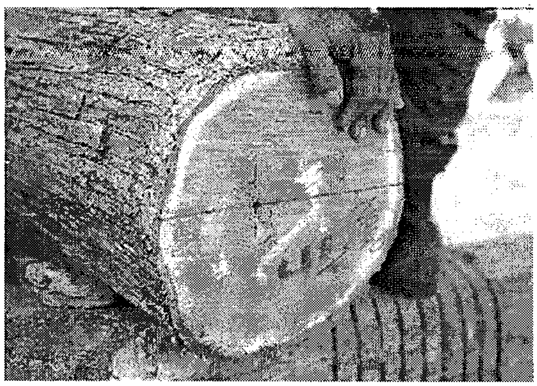

Photo 1. Heart split in a 38-year-old planted teak without girdling treatment

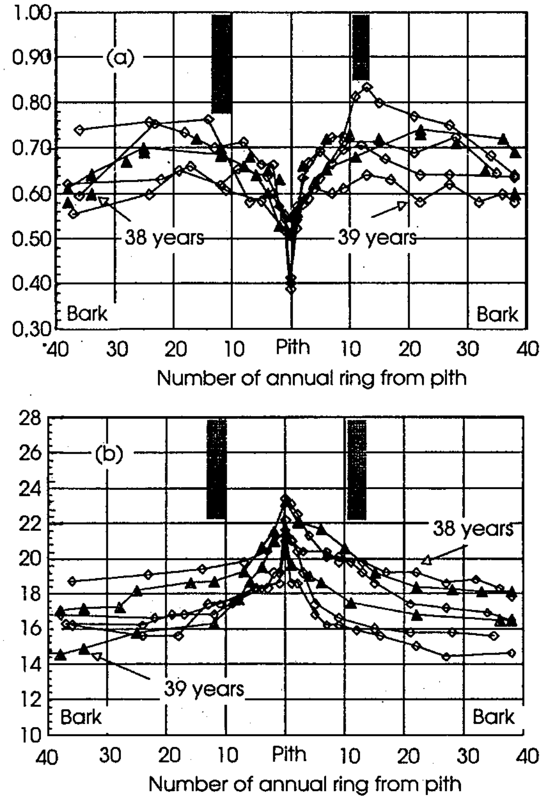

Figure 7. Radial distributions of density and mean microfibril angle

In teak, following the above examples, the transition point between normal wood and tension wood was considered at 11 degrees of MFA, which is 3 degrees smaller than where the released

Strain began to increase

Fig. 6 shows the mean values of released strain for individual trees and their standard deviations after eliminating the values at tension wood. The horizontal axis indicates mean annual growth rate. It reveals that not only fast growing young trees but also slow growing old trees generate a uniform growth stress in their normal wood. The average was –0.046%, the confidence interval at 95% level was between –0.0407 and –0.0493%. This means that the growth stress of planted teak is not affected by the growth rate. This is true also in the case of *Cryptomeria japonica*, a plantation grown softwood (Okuyama *et al.*, 1981).

Gerard *et al.* (1995) reported that younger *Eucalyptus* spp. generated slightly larger strains than older ones, but younger trees were more prone to form tension wood than older ones. Therefore, when the released strain is measured at random, there is a possibility to detect larger released strain in younger tree than in older trees. However we can say in general that the released strain is not affected by the growth rate as it is common in most fast growing species (Wahyudi *et al.*, 1999; 2000).

Estimation of maturation age

Since the utilization of short rotation and high density plantation trees increased, knowing the wood properties of juvenile wood became important especially in softwood species. This is also true for the fast growing tropical hardwood species.

Juvenile wood and mature wood formations do not depend on the tree age but on the cambial age. Therefore a tree that is old enough to form mature wood simultaneously forms juvenile wood at the upper part of the tree. Basically, the characteristics of juvenile wood in hardwoods are similar to those of softwoods. The juvenile wood is characterized by short wood fibers, large MFA, thin cell wall and low density. Moreover, their shrinkage along the lateral direction is high, and their strength properties are lower than normal wood. Thus, juvenile wood causes problems in the processing of timber (Zobel and Sprague, 1998). According to Bendtsen and Senft (1986) formation of juvenile wood starts from the 5th to the 20th annual ring.

Figs. 7a, b indicate the region of juvenile wood in 38-,39-year-old teak. That is, a second-degree curve can represent the radial distribution of density as shown by Bhat *et al.* (1989). It is low around the pith and increases steeply towards the periphery. After displaying the highest value around 11th annual ring, density decreases gradually or remains more or less uniform towards the bark. On the other hand, MFA shows the maximum value around the pith and decreases steeply up to the 11th annual ring from pith and then more slowly toward the 20th annual ring before remaining constant towards bark.

It is difficult to decide the precise maturation age of teak based only from the above results. Yet, it was estimated that the maturation age in five 38-year-old trees, starts from the 10th to 12th year. This conforms with the estimate made by Bhat (2000) for Indian teak which was about 12-15 years although juvenility was often noted to extend up to 20 or even 25 years in fast grown trees (Bhat *et al.*, 2001).

CONCLUSION

The effects of growth rate on the heartwood ratio; density and surface released strain coming from growth stress were investigated in teak planted mainly in Indonesia and India. Further, the maturation age was estimated based on the radial distributions of wood density and microfibril angle. The main findings are the following:

1. The formation of heartwood depends on tree diameter, i.e., the heartwood proportion of young trees increases abruptly up to 90% at the diameter of around 20 cm. Then it shows a slower increase. It can be said that faster the growth rate, larger the heartwood proportion in plantation grown teak.
2. Density of older trees is not affected by growth rate while in the case of young trees around 16 years fast grown trees have lower density than slower grown trees.
3. The released strain, excepting the tension wood, is not affected by the growth rate.
4. Maturation age of planted teak was estimated around 12-15 years based on the density and microfibril angle distributions across the stem.

In order to know the best silvicultural condition for producing high quality of timber, comparative investigations of wood qualities are required in relation to the provenance, climate, soil and growing conditions throughout the tropical region. The radial distributions of density, microfibril angle and heartwood ratio in the tree trunk and the maturation age appear to be good indicators of timber quality.

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Myanmar Teak: Quality and Exports

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ABSTRACT

Myanmar is a supplier of forest products, of which teak from natural forests plays a major role. In order to ensure sustainable harvest, Myanmar Selection System (MSS) has consistently been applied. Myanmar is committed to Sustainable Forest Management (SFM), and enabling conditions to achieve SFM have well been put in place. In view of achieving SFM and better market access, a Timber Certification Committee (TCC) has been established. Regarding timber certification, documentation of basic framework has been started. Myanma Timber Enterprise is the only State Economic Enterprise authorised to harvest timber, and the private sector is allowed to process and export value-added timber products. Not all teak grown in Myanmar is identical in properties. In exporting veneer and sawlogs, Myanmar has 4 quality classes or grades. It is noticed that log quality has been declining since the 1970's. With the deterioration in log quality, production of teak squares and other high quality end products is also observed to decline. Likewise, annual export of teak conversion has been reduced to more than half during the 1990s. However, export of secondary processed wood products (SPWPs) has gradually increased in the same decade. Disparity in tariff rates on the same product encourages importing countries to purchase teak in log form. Export of teak SPWPs from the private sector has increased since around 1997-98. Notwithstanding the limitations in woodworking technology and trained personnel, export of teak in log form would remain an important means of earning hard currency for wood-based industry development. To strike a balance between log exports and wood industry, development is considered most judicious. Myanmar is striving to industrialize the wood industry. Enhancement of teak quality and export of SPWP within the shortest period is the final goal.

Keywords: Myanmar Selection System, Sustainable Forest Management, timber certification, wood quality, log exports, wood industry

INTRODUCTION

Myanmar's natural teak forests are found within 25° 30′ N and 10° N latitude. Forestry, with more than 50% of the country's total land area of 676,577 km^2 under forest cover, has been an important sector in terms of social, economic and environmental dimensions. Myanmar is an agro-based economy and about 70% of the 52 million inhabitants live in rural areas. The country has been a supplier of forest products and the revenue from the forestry sector is roughly about US$ 300 million annually. Of the forest resources, teak plays a major role and will continue to be so as the forests are systematically managed and are still in a comparatively good condition. (Shwe Kyaw, 2000)

Myanmar Selection System (MSS) has been consistently applied since around 1900. For sustained yield production, the MSS employs a 30-year felling cycle, which provides sufficient time span for forests to accumulate increment ensuring viable harvest, at least without any reduction in the forest capital. Silvicultural treatments such as gap planting or enrichment planting, regeneration, improvement felling, thinning, climber cutting and weeding are the routine operations to ensure the expected increment. Although the MSS is a proven system for over 100 years and is still being applied, conditions and stand structures in some forest areas of the country are undergoing degradation due to invariable social problems stemming primarily from population growth and infrastructure development.

This trend is similar to that prevailing in many of the timber producing countries in the tropics. In view of restoring the degraded forests, establishing forest plantations (since around 1980), forming community forests (since around 1995) and regenerating the forests by natural means and enrichment planting have been increasingly emphasized and implemented. With a view to achieving Sustainable Forest Management (SFM), Myanmar has drawn up and promulgated Myanmar Forest Policy (1995), Forest Law (1992), Protection and Conservation of Wildlife and Wild Plants Law (1994) and Community Forestry Instructions (1995) as well as Criteria and Indicators (C and I) for Sustainable Management of Natural Production Forests in Myanmar at both national and Forest Management Unit (FMU) levels. There is in existence, a National Code of Forest Harvesting Practices in Myanmar.

Timber Certification Committee (TCC) has been functioning in Myanmar since 1998. It comprises forestry professionals, specialists, and retired heads of the institutions under the Ministry of Forestry (MOF). A non-governmental organisation, Forest Resources Environment and Development Association (FREDA) is also a member. The goal of setting up the TCC is to take an essential role in developing timber certification scheme in Myanmar in cooperation with all stakeholders of forestry. The Forest Department and the Myanma Timber Enterprise have, in collaboration with other relevant organizations, developed major tasks with regard to timber certification. Actions include among others drawing up C and I for SFM for Myanmar; pre-assessment checklist for forest management certification; working procedures and practices on Chain of Custody for Forest Products according to guidelines from international bodies including Société Général de Surveillance (SGS), which is accredited by Forest Stewardship Council. (Myat Thin, 2001)

Table 1. Movement in some common timbers of Myanmar

Species	Movement %	
	Tangential	Radial
Teak – *Tectona grandis*	1.2	0.7
Gurjan – *Dipterocarpus* spp.	3.3	2.0
Kuruing – *Dipterocarpus* spp.	2.5	1.5
Mahogany – *Swietenia macrophylla*	1.3	1.0
Oak – *Quercus* spp.	2.5	1.5
Persimmon – *Diospyrus virginiana*	3.4	2.0
Pyinkado – *Xylia dolabriformis*	2.1	1.7
Rhodesian teak – *Baikiaea plurijuga*	1.6	1.0
Rosewood – *Dalbergia latifolia*	1.0	0.7

Myanma Timber Enterprise (MTE) is the only State Economic Enterprise authorised to harvest both teak and other species of wood. Since 1993 the private sector is allowed to process and export value added timber products. State Timber Board (STB), and Timber Corporation (TC) are forerunners of MTE. Teak from natural forests accounts for more than 95% of the teak exported from Myanmar.

QUALITY OF TEAK WOOD

Teak is widely used in shipbuilding, decking, launches, boats, deckhouses and weather doors. It is considered to be one of the most durable timbers lasting more than seven hundred years in some dry sites, and more than twenty-five years in contact with the ground. Teak makes excellent furniture (both indoor and outdoor), door and window frames, and good flooring material because of its durability and stability. Extractives present in the heartwood are believed to be responsible for its durability. (Soe Tint *et al.*, 1995) Teak is an exceptionally stable timber to changes in atmospheric temperature and humidity. From Table 1 it is evident that movement in teak is minimal which is almost equal to rosewood. It is said to be moderately refractory and is not liable to check, split and warp. The wood can be air-dried kiln-dried without much problem. Except the teak from the dry parts of Myanmar, the rest is quite easy to work with. The silica content in teak varies up to 1.4 per cent. Teak from northern Myanmar is inferior in quality as compared to that from other parts of the country as it is usually cross-grained (Tint and Kyu Pe, 1995).

Teak is one timber that has comparatively more defects than many other species. Therefore, in trade, timber with lesser number of defects is deemed to be of better quality and fetches a higher price. Both teak logs and sawnwood are graded into various qualities by calculating the defects found on them. Properly graded timber fetches higher prices than ungraded timber. (Tint and Kyu Pe, 1995)

Table 2. Influence of precipitation on teak wood characteristics

High rainfall areas	Low rainfall areas
-large diameter	-smaller diameter
-irregular annual rings	-more regular annual rings
-low wood density	-higher wood density
-dark colour	-light colour
-bee holes present	-bee-holes absent
-usually non-striped	-black striped
-suitable for sawnwood	-suitable for veneering

There is considerable variation in quality of teak coming from different parts of Myanmar. MTE has an established system of marking logs with special hammers showing the Forest Division, to enable easy identification of the source of the logs. Teak logs coming from various areas were studied at the logyards in Yangon. The studies were based on conformation of the logs; regularity of annual rings; colour and texture of the wood; presence or absence of black stripes; typical defects; all of which influence the quality and price of the wood. Table 2 shows the general characteristics of teak from heavy and light rainfall areas. (Thein Aung *et al.*, 2001). As areas producing higher quality teak logs have been identified, more care is now being taken to preserve and increase the teak trees growing there. Replanting in theses areas is also done.

TEAK LOGS

Myanmar exports two types of teak logs namely, veneering logs and sawing logs. Grades for veneer quality logs comprise: Special, First, Second, Third, and Fourth Quality. Sawing quality logs comprise: Sawing Grade-1 (SG1), Sawing Grade-2 (SG2), Sawing Grade-3 (SG3), and Sawing Grade-4 (SG4). Teak logs are priced and sold according to the average grade of the parcel or lot. A parcel may comprise twenty-five pieces generally. But in higher grades the number of logs in a parcel may be as few as four or five.

Grading rules for teak veneer logs

Veneer logs are graded using a set of rules namely 'Grading Rules for Teak Veneer Logs'. Grades or qualities covered by these rules are Special, First, Second, Third, and Fourth. In Myanmar teak trade the words 'quality' and 'grade' are used interchangeably.

Grading rules for teak saw logs

People started noticing that the quality of logs harvested became poorer and poorer starting from mid-seventies. With production of more sawing logs, a new set of grading rules for sawing logs was drawn up in 1998 to accommodate the new trend in log sales. Table 3 indicates the proportion of veneer quality logs and sawing quality logs produced by the Myanma Timber Enterprise throughout the previous decade. It is seen that the quality of the logs declined significantly during the ten years. Years shown are financial years (FY) and quantity is shown in m^3.

Reasons for quality decline

It is worth noting that the population of Myanmar according to 1973 census was 28.89 million (Anon., 1995) and in 2003 it grew up to 52.43 million. Increase in population has put a heavy demand for timber and an enormous pressure on forestland for agricultural purposes and infrastructure development; thereby causing degradation of natural forests and dwindling stocks.

Myanmar faced internal insurrection immediately after independence in 1948, and this situation lasted for almost four decades. Insurgency thrived in densely forested areas, thereby creating constraints in systematic harvesting of teak logs. Over-cutting, including illicit felling, occurred in many areas and consequently rapid deterioration of quality of teak harvested became noticeable as years went by. Virgin forests in the North are now cut for teak logs while the forests in central Myanmar are being retained. As shown in Table 2, central Myanmar forests with light rainfall yield better quality logs and the forests newly exploited yield poorer logs.

Price vis-à-vis quality

Paradoxically, the prices rose even as the quality of the logs declined. The buyers reciprocated every upward escalation in price, with more rejections. And as these rejections were needed to be disposed off, new grades had to be created. Only three grades of veneer

Table 3. Quality composition of export quality teak logs produced at depots in Yangon (m^3)

Year	1st& 2nd	3rd	4th	SG-1	SG-2	SG-3	SG-4	ASST	TOTAL
1990-91	155	2133	9668	44516	54088	31696	65666	0	207922
1991-92	13	331	4682	14780	37499	6448	57688	0	121441
1992-93	20	430	5854	14972	44474	10206	167468	0	243425
1993-94	2	329	4660	19584	50026	7364	120227	0	202192
1994-95	16	635	4538	36227	53291	10661	134210	0	239578
1995-96	0	229	3251	21535	49423	7009	152579	0	234025
1996-97	4	140	2155	10082	26874	5900	162787	13599	221540
1997-98	0	72	1832	7371	22604	4828	117070	18481	172258
1998-99	0	-	1517	3177	16481	1748	97785	174388	295096
1999-00	0	23	976	2322	8678	1994	71780	236034	321808
TOTAL	210	4322	39132	174566	363438	87854	1147261	442502	2259285

Source: Export Statistics,Myanmar Timber Enterprise.
Note: Veneer logs- 1st, 2nd, 3rd, 4th Qualities; Sawing logs- SG1, SG2, SG3, SG4; Assorted (Asst)

quality logs namely, first (four star), second (three star) and third (two star) were available up to 1973. In 1978 the Sawing Quality (now SG1) and Unsorted (SG3) were introduced. In 1988 Sawing Rejection quality (now SG2) and Saw Mill Rejection quality (SG4) were introduced into the market. In 1996, yet another grade called 'assorted' joined the group of sawing logs. Grade names became inconsequential as lower grades nowadays fetch higher prices than the better grades of yester years. Average prices for these items are shown in the Table 4. The average price of this 'assorted' grade in 1996-67 was US$ 410/ m^3 and is higher than the price of SG2 in 1990 i.e., US$ 403/ m^3. The table also shows that the price of a SG-2 log in 2000 is the same as a Third Quality log in 1990. (Nwe Nwe Aung, 1998)

TEAK CONVERSIONS

Teak conversions are teak sawnwood and comprise: squares; posts, decks, boards, planks, flitches, and scantlings. Grading rules for grading teak squares and other sawn timber (conversions) have been in place since 1950. The nomenclature for conversions is given below in Table 5.

Teak squares

Squares (please see specifications above) are not dimension stock and are mainly meant for re-converting into smaller sizes. They are, therefore, judged by the general quality of the wood, and the probable loss, chargeable to visible defects under normal sawing methods. Most squares nowadays, are of 'market quality'. First and second quality are also available, but comparatively in a smaller quantity.

Grading rules for teak conversions

The grading rules for teak conversions now in use were prepared by the Forest Department. Scantlings are exported today as Special, First, and Second Quality. Special and Better Quality is the export quality for teak boards, planks, decks and flitches. There is no standardisation of quality names among teak exporting countries. For example, First European Quality (FEQ) and Middle East Quality (MEQ) are used by many Asian exporters and some private Myanmar exporters. In Indonesia teak sawnwood is grouped into five quality classes, namely; Primary, First, Second, Third, and Fourth. (Anon., 2000)

Quality-wise production of sawn teak wood

Quality-wise and commodity-wise production statistics are given in Table 6 to indicate the decline in the grades and the high priced specifications during a period of ten financial years from 1992- 03.

Secondary processed wood products (SPWP)

As secondary processing is a capital intensive and highly technical industry, Myanmar exports of SPWP are very small in quantity. These products are mainly floorings, parquet, lam parquet, and moldings. The grades mainly are, 'A' grade, 'B' grade, and 'C' grade. In Indonesia moldings cover floor, wall, door, and garden table specifications, and grades are Prime, Standard and Local.

Myanmar teak exports

MTE, as producers, has to fulfill the raw material requirements of the private industries in addition to its major responsibility as foreign exchange earner. Tables 7 and 8 show exports by the state sector. Present day markets are mainly India and Thailand. As teak is indigenous to India, Myanmar, Thailand and Laos PDR, natives of these countries price teak above other species. (Saw Eh Dah and Shwe Baw, 2000) India and Thailand import teak for domestic use as well as for re-export to USA, Europe and the Middle East. Singapore is only a transportation hub

Table 4. Average FOB prices for teak logs during 1990-2000 (US$/m3)

Quality	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00
First	1985									
Second	1260	2236	2638		3094	3056	2889			
Third	998	1864	1972	2053	1888	1960	2042	2018	1771	2154
Fourth	750	1053	1104	1251	1371	1493	1619	1669	1619	1786
SG-1	489	700	726	919	1075	1108	1126	1119	1242	1337
SG-2	403	492	513	696	830	899	887	838	910	996
SG-3	329	392			680	631	573	548	457	433
SG-4	286	398	387	528	681	647	583	568	548	587
Assorted							410	442	378	392

Table 5. Specifications for teak conversions

Specification	Measurement	Grades Available
Squares	10" and up x10" and up x 10′ and up	F, II, M
Posts	6"/9"x6"/9"x6' and up	F, II, M
Planks	Avg: (3.5" x 8" x *')	S and B
Boards	0.5"-2" x Avg: (8"x8')	S and B
Flitches	3"and up x 7"and up x 6'and up	S and B
Decks	2"-3"x4", 5"x10'and up	S and B
Scantlings	0.5"-5"x1"-6"x1'and up	S, F, II

Note: S and B (Special and better); S (Special); F (First); II (Second); M (Market)

Table 6. Quality-wise production of sawn teak (m^3)

FY	Squares	Posts	D/F/P/B	Sctg. F and up	Sctg. II	Sctg. III	Total
93-4	8116	1368	340	8536	13485	9950	41795
94-5	12230	2062	574	9061	13028	6565	43520
95-6	11448	2023	342	6558	10874	5334	36579
96-7	8138	1561	172	5022	9342	5103	29338
97-8	7095	1018	148	7340	8784	5621	30006
98-9	7091	931	372	5898	7064	5685	27041
99-0	3122	1133	146	4474	7694	6359	22928
00-1	6654	1303	104	4925	8632	5128	26746
01-2	6548	1796	87	7242	10209	5730	31612
02-3	6479	1716	67	7221	9068	7209	31760

Source: Export Statistics, Myanma Timber Enterprise
Note: D/F/P/B- stands for decks, flitches, planks and boards all Special and Better Quality; Sctg. F and up stands for scantlings First Quality and Special Quality; Sctg. II stands for scantlings Second Quality; Sctg. III stands for scantlings Third Quality (normally for local use); Squares and posts are roughly Market (75%) and Second (25%)

Table 7. Commodity-wise export of teak by the statesector (m^3)

YEAR	LOG QTY	%	CONVERSION QTY	%	TEAK PRODUCTS QTY	%	TOTAL
1990-91	148032	79	36942	20	1326	1	186300
1991-92	110243	71	44453	29	862	1	155558
1992-93	221416	80	52441	19	2219	1	276076
1993-94	209338	85	35213	14	2870	1	247421
1994-95	138717	79	32990	19	2866	2	174572
1995-96	260030	88	31689	11	3608	1	295327
1996-97	210386	87	28283	12	3816	2	242485
1997-98	=186361	88	21241	10	3237	2	210839
1998-99	276671	92	21839	7	3371	1	301881
1999-2000	396295	95	15715	4	3468	1	415478
	2157489		**320804**		**27643**		**2505936**

Source: Export Statistics, Myanma Timber Enterprise

in the trade though it uses a substantial quantity of floorings in construction.

Selling logs means more earnings?

Referring to the tables on the price of sawn teak and teak logs, the price of 'assorted quality' log would be \$ 392 per m^3. The average price per m^3 for teak conversions during 2002-03 is US\$ 780. Considering the recovery rate to be 50% (actual recovery at MTE sawmills varies around 47%), the sawn teak should fetch a net price of at least US\$ 784 per m^3 to cover the cost of raw material only.

Tariff relief under the Generalised System of Preferences (GSP) from USA and EU is no longer applicable to Myanmar since 1997. Tariffs in many countries remain high for SPWP compared to tariffs for primary products like logs and sawnwood. Such a disparity in rates would favour domestic processors from importing countries to import raw materials at lower rates of duty.

Until 1988 all trade was handled by state entities, timber was no exception. Budget constraints hampered the development of the industry. Even though there was an increased demand for sawn teak from many areas, sluggish state-owned mills were unable to meet the demand. In that way MTE lost foothold in some of the primary processed wood markets. Hong Kong SAR was the biggest market for flooring material. MTE was unable to supply the specifications in time and finally this market switched over to other species. It will take time and

Table 8. Export of teak to selective major markets (state sector) (m^3)

Year	India		Thailand		Hong Kong		Singapore		Europe		China	
	Log	Conv	Log	Conv	Log	Conv	Log	Conv	Log	Conv	Log	Conv
90-91	88736	3371	13745	1908	23035	7822	10856	13406	4279	4003	7218	3147
91-92	43483	112	1089	780	18772	3510	7798	18698	2128	4150	5441	7694
92-93	112199	140	16776	2695	28838	6401	9369	15506	4986	9764	6084	7599
93-94	74075		58556	7325	19555	4038	22869	9726	5045	5454	1199	2834
94-95	38840	347	33736	5555	15280	5419	23180	11220	4410	3412	2104	2661
95-96	33327	536	77861	4228	12649	3682	35249	12293	5209	2124		1887
96-97	47810		81023	3443	10206	3437	25924	11826	2457	3993	362	
97-98	106447		35789	3252	5953	2538	19051	9969	4779	1742	2961	
98-99	130954	431	87093	3669	14639	2198	15091	6457	11403	1149		
99-00	239033	279	87262	3839	14386	2766	13471	6461	5724	1537	7425	134
	914904	5216	492930	36694	163313	41811	182858	115562	50420	37328	32794	25956

Source: Export Statistics, Myanma Timber Enterprise

Scandinavia use teak mainly for decking and furniture. Major markets for teak finished products are USA and Europe.

Table 9. Export of Wood Products (Private Sector)

Year	Value US$ million
1997-98	24.060
1998-99	67.598
1999-00	66.481
2000-01	60.845
2001-02	150.713
2002-03	84.140

Source: Customs Department

money to regain the market. This could apply to the loss of market in Europe for teak conversions. Europe used to be, and still is, a major market for quality teak for making furniture and boat decking.

To combat this loss of productivity and market foothold, the Ministry of Forestry has adopted joint production schemes at the state owned mills and factories in conjunction with experienced foreign companies. It also provides encouragement to foreign investors to form "100% foreign investment companies" and to create joint ventures in the private sector.

In most countries exporting timber products the role of the private sector is more dominant. In Myanmar the private sector complements the state sector by exporting value added items. Figures show the private sector shipped out 37818 m^3 of teak S4S and 4197 m^3 of teak SPWP during FY 2002-03. Table 9 shows the participation of the private sector in the export scenario. Exported value is from both teak and non-teak products.

CONCLUSION

Myanmar has quality teak wood. Need for hard currency necessitates the sale of good logs. This led to the supply of remaining poor grades to the local industries, leading to the production of poor quality wood products. Poor wood products fetch less money. This in turn leads to putting more logs to make up the loss in revenue. Sell more logs and face criticism or sell fewer logs and get less revenue. Whichever way one chooses, it looks like a "catch-22" situation.

The woodworking technology is not very advanced in Myanmar. Lack of systematically trained workers and appropriately modern machines would not help Myanmar to become a leading exporter of high-end teak products. Meanwhile, the present policy of balancing the sale of only good quality logs to obtain the money needed to upgrade the industry, and developing both the industry and the human resources at the same time would appear to be most judicious. To export value-added products within the shortest possible time is the final goal of Myanmar.

Teak from the natural forests of Myanmar will remain very much in demand. To this end Myanmar is dedicated to the preservation of its teak forests and committed to the of quality teak.

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Assessment of Some Wood Characteristics of Teak of Brazilian Origin

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ABSTRACT

Technical information about naturally grown teak (*Tectona grandis* L f.) and Asiatic plantation teak is available. The situation is quite different with regard to technological research data on teak managed in incidental plantations and short rotations in Latin America and Brazil, in particular. This study aims to provide new technical data on Brazilian teak. Chemical composition, fibre length distribution, mechanical and physical properties and natural durability were determined to assess the quality of Brazilian wood. The analyses were performed on heartwood and sapwood materials of two 22-year-old trees and one 14-year-old-tree. The analysis showed significant extractive content in the heartwood in particular, and also high lignin content. The fibre length was rather low, probably due to relative juvenility. Static bending tests for MOE and MOR confirm that the wood has already become mature, comparable with high quality teak. The average equilibrium moisture content at fibre saturation point gave low values, probably due to high extractive content. Determination of maximum shrinkage and shrinkage from green to 12 per cent moisture level showed that the wood has a high dimensional stability. Considering the results obtained, it can be assumed that Brazilian teak does not differ from the high quality Asiatic teak, and that, it might be suitable for the same range of end-uses.

Keywords: Characteristics, physical properties, mechanical properties, natural durability, extractives, fibre length, heartwood, sapwood

INTRODUCTION

High quality tropical hardwood production in plantations is a challenge because long rotations are often not economically viable while short rotations may lead to low quality wood with high incidence of defects. Teak may be considered as an exception and its cultivation, almost everywhere in the tropics, has a long history. Although teak is a native of continental Asia (India, Myanmar, Thailand and Laos), teak plantations currently exceed 2.2 millions ha in the tropics including Africa, Central America and the Asia Pacific, with an annual increasing rate of 100,000 ha (FORSPA, 1999). This is because teak is a high-value timber having a wide range of end-uses due to its natural decay resistance and favourable dimensional stability in changing moisture conditions, and also because teak plantations yield with mean annual increments of 10 to 12 m^3 per ha. Economic reasons lead to apply short rotations of 20-30 years to the new teak plantations instead of the traditional rotation of 50-60 years. It appears fundamental to assess the economic returns of investments on such intensively managed teak plantations, and this means to forecast the quality of timber that can be produced.

Information about wood quality and natural durability of teak are then important parameters for marketing the product and promoting new investment on teak plantations.

Technical information and research data on naturally grown and plantation grown teak from are relatively abundant. Very different is the availability of such data on teak managed in short rotation plantations in Latin America, and in particular Brazil, where the first industrial teak plantation is now around 35 years old. The present study aims to provide some new technical data on Brazilian fast growing teak and, in order to do so, chemical composition, fibre length distribution, physical and mechanical properties, and natural durability were determined. All these analyses were performed, according to the standard methods on heartwood and sapwood samples by selecting from the same age of three different trees. In this way it was possible to assess the variation of wood characteristics from pith to bark.

MATERIALS AND METHODS

All the wood samples tested were obtained from three teak (*Tectona grandis* L. *f.*) trees. These trees were cut from a small teak plot growing in West of Cuiabá, a city located in the Southern part of the State of Mato Grosso in Brazil. The plot is at a short distance from the present 30-year-old teak plantation managed by Cáceres Florestal, and from the more recently started 8-year-old plantation of Floresteca Agroforestal. Although the trees are not part of the mentioned plantations, there are no substantial differences in soil and climatic conditions among the three growth locations. Three different capital letters, A, B and C have been given as names to the three teak trees in order to distinguish and identify the tested material. For all the trees the second log was selected, ranging 120 to 220 cm above the ground level. Age and diameter of the three sample trees are given in Table 1.

Table 2. Location and coding of the different zones investigated in the teak logs.

	Growth ring zones			
	Core	*Heartwood*		*Sapwood*
Tree A	2 – 5	8 – 11	14 – 17	18 – 21
Zone code	A 1	A 2	A 3	A 4
Tree B	2 – 5	8 – 11	14 – 17	18 – 21
Zone code	B 1	B 2	B 3	B 4
Tree C	2 – 5	7 – 9	-----	11 – 13
Zone code	C 1	C 2	-----	C 3

The logs were divided into four (from trees A and B) and three (from tree C) longitudinal zones of different ages within the same tree and almost the same ages in different trees (see Table 2). By doing so, material was obtained from the real juvenile period of the trees (up to 5 growth rings from the pith); the other age limit was formed by growth rings in the sapwood. Two other sample locations in the heartwood of the older trees provided material: one from the growth rings situated half-way, and the other from the outer zone of the heartwood. In the younger tree only material of the outer heartwood zone was tested. The results of the investigation into natural decay resistance of this material, were already reported (Laming and Sierra-Alvarez, 2001)

Anatomy

Radial, tangential and transverse sections, 20 μm thick, were cut on a sliding microtome from small Brazilian teak wood blocks (10 x 10 x 10 mm). Sections were stained with a 2% solution of safranin for microscopic examination of anatomical characteristics. Vessel diameter was measured using an image analysis software, Win CELL (Regent

Table 1. Characteristics of the sampled logs of three teak trees

Tree code	Age (yr)	Diameter (cm)	Sapwood	
			Number of rings	Width (cm)
A	22	36.5	5	3-5
B	22	39.0	5	3-5
C	14	30.0	3	5

Instruments Inc., Quebec, Canada). The fibre length was determined on macerated wood samples according to TAPPI methods (Technical Association of the Pulp and Paper Industry, Atlanta, GA) by a Kajaani FS-200 analyser (T 232 cm-85).

Chemical analysis

Wood for chemical analysis was prepared by chipping sample stakes sawn from every zone of each tree, followed by milling in a wood mill. The wood meal obtained was then sieved through a 1 mm mesh-screen and utilised for chemical analysis (TAPPI T 257 OM and TAPPI T 264 om-88). In this way the fine particles permitted a complete reaction of the wood with the reagents used in the analysis. The extractive content was measured in two solvents: ethanol-cyclohexane (by a modification of T 204 om-88) and hot water (T 207 om-88).

The concentrate of lignin was divided in two components (T 222 om-88): acid-insoluble lignin (Klason lignin), extracted by 72% sulphuric acid and acid-soluble lignin, measured by spectrophoto metric method based on absorption of ultraviolet light at 280 nm. The holo-cellulose content was estimated according to the chlorite method described by Wise *et al.* (1946). The pH of the wood was calculated in hot water (T 252 om-90). Ash percentage was also determined (T 211 om-85). Wood composition values were expressed as percentage on oven-dry wood weight taken to the nearest 0.0001g by analytical balance. All chemical analyses were performed in duplicate per each single zone and the reported data are mean values with corresponding standard deviations.

Mechanical testing

Mechanical testing was conducted on stakes (20 x 20 x 360 mm^3) obtained from the zones A3, B3 and C2, representing the outer part of the heartwood. After conditioning in a climate chamber for two weeks to constant weight (approx. equilibrium moisture content of 10 - 12%), the modulus of rupture (MOR) and the modulus of elasticity (MOE) were determined by 3-points bending with a Zwick test bench, according to the German standard DIN 52 186 "Flexure Test on Wood".

Physical properties

The physical properties determined here are: density, hygroscopicity and hysteresis loop and dimensional stability, i.e. shrinking and swelling.

Density

This was determined, on weight to volume ratio, at three different wood moisture contents. The weight was determined by means of an analytical balance with a precision of 0.0001g, and the volume of the samples was calculated by the real dimensions of the wood blocks measured with a calliper with a definition of 0.01 mm. *Air-dry density* was determined after conditioning of wood specimens in a climate room at conditions of 22°C and relative humidity of air (RH air) of 65% to constant weight (10 days) so as to reach an equilibrium moisture content (EMC) of 9% to 11%. The *oven-dry density* was calculated after oven-drying the specimens at 103 ± 2°C for 48 hours. The *basic density*, being the ratio of oven-dry weight in fully swollen volume, was calculated after conditioning wood blocks at 98% of RH air and 25°C inside the conditioning containers.

Shrinkage and swelling

The methodology was adapted from Rijsdijk and Laming (1994). Teak samples were conditioned at 10 different RH values, from 10% to 100% at constant temperature (25°C) till constant weight is attained. This was possible by using laboratory-conditioning containers in which the RH air value was created and maintained stable by means of different chemicals in water saturated solutions, according to ISO 483-1988 (E) standards. Test sticks of about 1 meter of length and transversal dimensions ranging from 17 x 17 to 25 x 25 mm^2 were sawn along the grain for 10 zones having the sides running radially as much as possible in order to attribute the dimensional changes to the radial and tangential directions. Defect free sticks were then sawn to obtain cross-cut samples 5 mm thick. Zone A 1 was not tested because no more material was available. Shrinkage was calculated on the basis of fibre-saturation-point (FSP) conditions (after the 98% RH air at 25°C conditioning) and expressed in percent of those dimensions. Swelling was calculated on the basis of the dry conditions (after the 22% RH air conditioning), and was expressed as percentage of the dimensions determined under those conditions. All the values of radial, tangential and axial shrinkage and swelling reported in this research are averages of the 10 or 20 samples tested for each zone with the respective standard deviation.

Equilibrium moisture content (EMC)

The value of EMC at the various RH values of air was calculated from the data obtained in the shrinking and swelling tests.

Hysteresis curve

This was plotted on the basis of the statistical values for the series of test pieces for each climate and for desorption as well as adsorption of moisture. The standard deviations were also calculated.

RESULTS AND DISCUSSION

Chemical composition

The results of the chemical analysis are presented in Tables 3-4.

Cyclohexane-ethanol extractive was found to be the largest fraction of wood extractives in Brazilian teak. This fraction included fatty acids, resin acids, waxes, tannins and colouring matter. Their percentage on the dry weight of wood ranged from 7.2 to 9.8% in the heartwood zones and 3.2 to 5.0% in the sapwood. Hot water extractive consisting of carbohydrates, proteins and inorganic salts amounted to 0.6 to 2.5% of the dry weight.

All the three trees showed the same pattern of variation in the extractive content from the core to the cambial region. For the older trees there was an initial increase in the total extractive content from the inner to the outer heartwood reaching its maximum in the transformation zone of heartwood-sapwood. In the sapwood extractive content was 37% (tree A) to 59% (tree B) of the maximum value. The younger tree C showed a different trend, in fact, extractives were higher in the inner part of the heartwood with 10.9% decreasing to the sapwood to 5.0%. The range of total extractives content in the heartwood of the three trees was between 7.8% and 11.9%. This range is to be considered normal for teak wood. Holocellulose and lignin contents determined are presented in Table 4.

The lignin content ranged from 37% to 41% in the sapwood and from 37.4% to 42.7% in the heartwood zones.

Generally, in hardwood the holocellulose content varies from 71.0% to 89.1 % of the dry- weight. Brazilian teak showed a holocellulose content of 75.7% to 78.8%. Both lignin and holocellulose

Table 3. Extractives in the three Brazilian teak trees.

Tree Zones	Extractives (%)				
	Cyclohexane-ethanol		Hot water		Total
	Mean	SD	Mean	SD	Average
A 1	7.15	0.12	0.62	0.07	7.77
A 2	9.17	0.29	0.83	0.02	10.00
A 3	9.81	0.26	1.02	0.05	10.83
A 4	4.99	0.29	1.65	0.04	6.64
B 1	7.91	0.22	1.22	0.04	9.13
B 2	8.85	0.21	0.87	0.03	9.72
B 3	9.54	0.01	2.38	1.58	11.92
B 4	3.63	0.06	1.04	0.05	4.67
C 1	7.39	0.33	2.50	0.13	9.89
C 2	8.68	0.34	1.90	0.00	10.58
C 3	3.24	0.19	2.23	0.04	5.47

SD = Standard deviation

Table 4. Chemical compounds of the three Brazilian teak trees.

Tree Zones	Lignin (%)				Holocellulose (%)	
	Acid-insoluble		Acid-soluble			
	Mean	SD	Mean	SD	Mean	SD
A 1	41.70	3.36	1.03	0.08	78.78	0.42
A 2	38.35	0.33	1.04	0.03	77.98	0.53
A 3	40.80	0.08	0.95	0.01	76.54	0.38
A 4	40.13	0.37	1.00	0.03	78.15	0.55
B 1	38.89	3.42	0.98	0.08	77.63	0.27
B 2	37.33	3.46	1.10	0.04	78.68	0.43
B 3	41.07	1.55	1.12	0.19	78.08	1.11
B 4	39.94	0.07	1.10	0.01	77.65	1.20
C 1	37.51	2.24	1.13	0.02	75.68	0.63
C 2	38.62	1.21	1.02	0.01	76.17	0.63
C 3	36.10	0.06	0.95	0.02	75.82	0.61

SD=Standard deviation

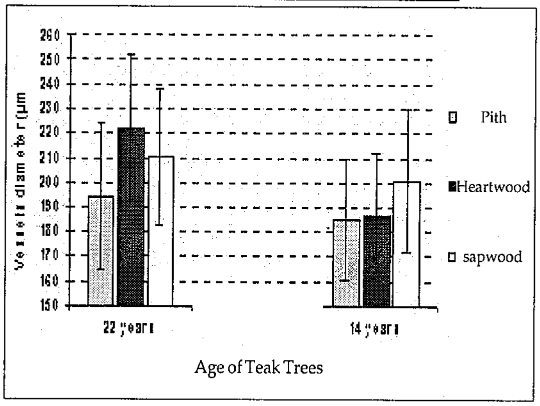

Figure 1. Variation of earlywood vessels diameter along the radial direction in Brazilian teak of 22-years and 14-years-old.

Table 5. Fibre length characteristics (mm) of the three teak trees.

TreeZones	Weighted average fibre length, mm
A 1	0.98
A 2	0.84
A 3	0.99
A 4	1.15
B 1	1.03
B 2	0.98
B 3	1.08
B 4	1.13
C 1	0.90
C 2	1.21
C 3	1.18

contents did not present big differences within the three trees even if the younger tree C had 1 to 2% less than the older two. The variation in these two chemical compounds was not particularly notable in the radial core-sapwood direction.

Ash content and pH of Brazilian teak were also measured. Ash contained all the inorganic constituents of wood as calcium, potassium, magnesium and other minerals, and its content was dependent on environmental factors such as site and climate. Ash content ranged from 0.7% to 2.8% on the dry-weight basis.

The pH value, ranging from 4.6 to 6.7, had the same pattern for all the three analysed trees showing a little increase of acidity from pith to outer heartwood. This happens because in tropical wood the pH value is influenced by the acid extractives content. For the same reason the pH value was increasing in the three sapwood zones to moderate acid values, 5.5 to 6.7.

Anatomical features

Teak is a ring-porous species; earlywood clearly distinguished from latewood by larger vessels, and is marked by thick-walled latewood fibres. Vessel diameter variation in early wood is shown in Figure 1. Vessel diameter is one of the most significant anatomical indicators of demarcation between juvenile and mature wood in teak, and an increase of this parameter along the radial direction (see

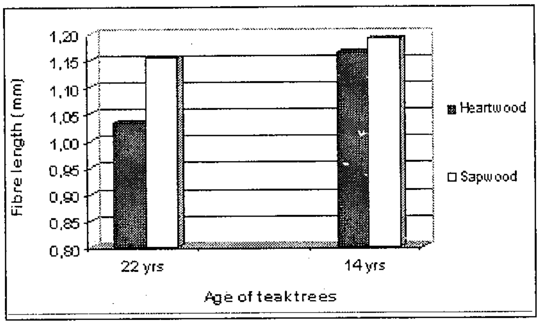

Figure 2. Variation in fibre length in 22- and 14-year-old Brazilian teak.

Figure 1) indicates a juvenile phase of growth (Bhat *et al.*, 2001).

In both hardwoods and softwoods, rotation age and growth accelerating treatments such as fertilisation and irrigation have effects on anatomical features of wood, and among them, fibre length often presents a smaller average length (Haygreen and Boyer, 1996). The primary function of the longitudinal fibres is to give mechanical support to the tree, so their length influences the strength properties of the wood material.

The Kajaani FS-200 analyser measured automatically the length-weighted average fibre length, which is to be assumed as the most significant index of fibre length. Fibre length of two zones (B2 and B3) was measured by means of a microscope and a projector and the observations confirmed that no fibres in the teak samples were shorter than 0.3 mm if not broken, so the mean values obtained by the Kajaani measurement have been corrected. Table 5 reports the weighted average fibre length of each zone of the trees, whereas Figure 3 reveals variation between heartwood and sapwood of different age.

The pattern of variation in fibre length within the same tree shows a small difference between the two 22- and 14-year-old trees. In trees A and B, fibre length seems to decrease initially from the pith outward and then to increase again in the heartwood reaching a maximum value in the sapwood. The C tree is also close to the normal pattern; in fact even if the fibre length in the sapwood is shorter than in heartwood, the difference is just 0.03 mm.

Mechanical properties

Teak is used for structural purposes in house constructions as well as in boats and ships. In order to assess if Brazilian teak has the required strength properties for those end-uses, MOR and MOE of the trees concerned were determined in static bending tests. The determined values are shown in Table 6.

These results confirm that the elasto-mechanical properties even with a fast growth rate, are not inferior to those of long rotation or natural-grown teak. Literature reports that naturally grown and plantation grown teak present the same variability of wood mechanical properties and, in particular, a wide range of MOE and MOR values going from 8600 to 13400 N/mm^2 for the first one and from 58 to 148 N/mm^2 for MOR (Trockenbrodt, 1999). Teak tree A and C present high values of MOE and MOR, which are closer to the upper limit than to the average range. This fact could prove the theory that teak attains mechanical maturity at a relative young age, around 21 years (Bhat, 1998) or even earlier considering the high values shown in tree C.

Physical properties

The wood density values of the Brazilian-grown teak analysed in this study are the density at EMC at 65% RH, the oven-dry density, and the basic density (ratio of oven-dry weight to volume in green state). The density values reported hereafter are the mean values of 10 samples per zone in each tree.

Table 6. Strength properties of Brazilian teak at different ages

Zone	**Age** (years)	**Modulus of elasticity (N/mm^2)** Mean	SD	**Modulus of rupture (N/mm^2)** Mean	SD
A	22	12892	611	152	11
B	22	9062	395	114	5
C	14	11787	223	137	7

SD = Standard deviation

Figures 3-5 reveal that there is a distinct pattern variation in density within the trees from pith to bark in both age-categories, with an initial increase from the pith reaching a maximum in the outer part of the heartwood and decreasing then in the sapwood. This decrease is possibly due to the lower extractive content in this zone (Tsoumis, 1991). In both younger and older trees the density in the sapwood is equal or slightly higher than in the pith.

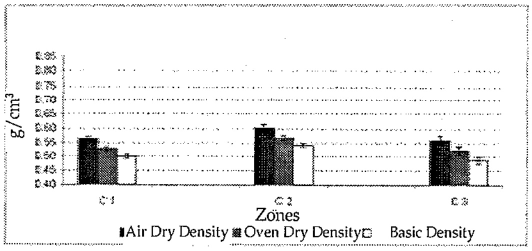

Figure 5. Variation of density along the radial direction, from pith (C1) to bark (C3), in Brazilian teak tree C (14-years- old).

Hygroscopicity

This is an important property because it affects most of the other moisture sensitive characteristics of wood, such as density, dimensional stability and mechanical properties. A clear insight into this is urgently needed for a rational utilisation of a 'new' timber to be introduced on the market. In order to assess the hygroscopic behaviour, the EMC at ten different RH conditions, was determined. Test specimens were conditioned in such a way that for each RH value (10%-98%), half of them were adsorbing and the other half desorbing moisture. In this way, after determination of the EMC of all specimens, it was possible to determine the hysteresis loop as shown in Fig. 7. The magnitude of hysteresis is expressed by the adsorption/desorption ratio at equal RH. Generally, for wood this ratio is constantly varying from 0.74 to 0.88, depending on the species (Tsoumis, 1991). The teak investigated in this study presents the average ratio of 0.93 or 0.94.

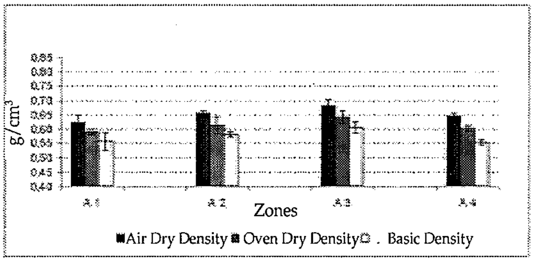

Figure 3. Variation in density along the radial direction, from pith (A1) to bark (A4), in Brazilian teak tree A (22-year-old).

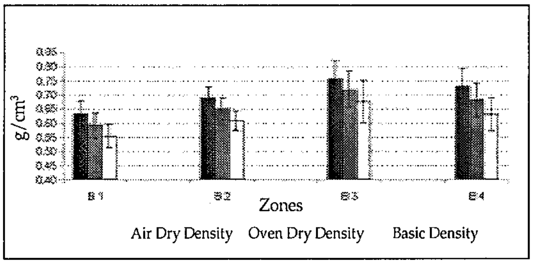

Figure 4. Variation of density along the radial direction, from pith (B1) to bark (B4), in Brazilian teak tree B (22-year-old).

Stability aspects of the raw material are getting opportune below the FSP. The results show that the average FSP is at 19.7% moisture content, fairly in between the 18% as found by Haygreen and Boyer (1996) and the 22% by Rijsdijk and Laming (1994). This low FSP is due to the high extractive content of teak. Species with relatively high extractive contents, in fact, show a relatively low FSP, for the reason that extractives occupy some sites in the cell wall material that otherwise would attract water (Haygreen and Boyer, 1996). Investigation on the variation in EMC at FSP showed no substantial differences between the trees although within each single tree along the radial direction, there

Table 7. Mean values of Brazilian teak wood density: air-dry, oven-dry and basic density.

Origin and age	Density at 65% RH (g/cm^3)		Oven-dry density (g/cm^3)		Basic density (g/cm^3)	
	Mean	SD	Mean	SD	Mean	SD
Tree A (22 y)	0.652	0.027	0.612	0.026	0.574	0.028
Tree B (22 y)	0.702	0.071	0.661	0.069	0.617	0.068
Tree C (14 y)	0.576	0.023	0.538	0.024	0.508	0.025

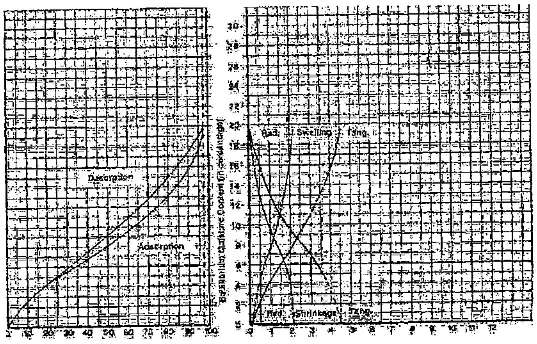

Figure 6. Hysteresis loops and shrinkage and swelling curves in Brazilian teak

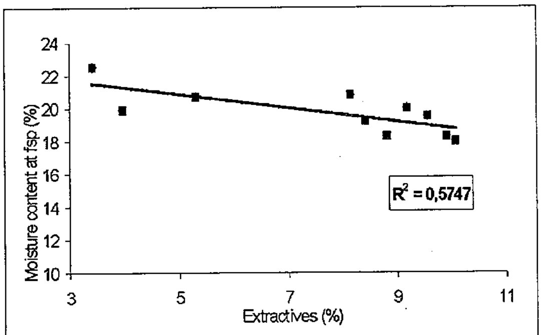

Figure 7. Correlation between pith-to-bark variation in moisture content of Brazilian teak wood at FSP (%) and extractives content (%) along the same direction.

was variation from pith to bark (Table 8).

Although small variations do exist, in both age categories the same pattern was observed: EMC at FSP was relatively high near the pith and decreased in the mature heartwood to some extent before rising again in the sapwood. In the sapwood, the lipophyllic extractive content is usually lower. This relation between EMC at FSP and the extractive content has been confirmed from the correlation analysis

Shrinkage and swelling

Teak was reported to present shrinkage, from the green state to oven-dry condition, of 2.5 to 3.0% in the radial direction, 3.4 to 5.8 % in the tangential direction (Trockenbrodt, 1998) and 0.6% in the axial direction (Tsoumis, 1991). In Brazilian teak maximum values of shrinkage stay within the ranges mentioned above, being 1.8 (B1) to 4.4% (A4) the radial variation, 3.4 (B1) to 5.3% (A4) the tangential one and 0.2 to 0.6% of

Table 8. Equilibrium moisture content at fiber-saturation-point in three teak trees and its variation along the radial direction

Tree zone	Equiibrium Moisture Content at fibre saturation point (fsp)(%)
A2	19.5
A3	18.0
A4	20.7
B1	20.8
B2	20.0
B3	18.3
B4	19.9
C1	19.2
C2	18.3
C3	22.5

longitudinal shrinkage. Zone A4 shows relatively high dimensional variation, but the standard deviation between the tested samples of this zone is also rather high, so can be assumed that this does not present anomaly. Shrinkage of teak from green to 12% moisture content was reported to be 0.7 to 1.5% in the radial direction and 1.1 to 2.5% tangentially (Trockenbrodt, 1998). As Table 9 shows similar trend, Brazilian teak is not different from natural or plantation grown teak of Asia in this respect.

CONCLUSIONS

Results of anatomical, chemical, physical and mechanical analysis demonstrate that Brazilian teak from the Mato Grosso region present desired quality characteristics. Recorded chemical composition particularly extractive content, density values and average fibre length are quite favourable and not so different from values reported from other countries. Static bending tests confirmed that strength maturity has already been attained in 14- and 22-year-old trees. Brazilian teak has also been demonstrated to have a good dimensional stability, with normal values of shrinkage reported for plantation teak. Because of small differences between the tangential and the radial dimensional changes, no particular deformations could be anticipated in construction applications. In terms of strength and dimensional stability, Brazilian teak could have the same wide range of end-uses, including the structural applications, as the normal high-quality marketable teak.

Table 9. Shrinkage values of Brazilian teak from fibre saturation point to 10-12% moisture content and the ratio and difference between tangential and radial shrinkage at 57% of RH

Tree Zones Difference	Radial (%)		Tangential (%)		Ratio	
	Average	Stdev	Average	Stdev	Average	Average
A 2	0.74	0.16	1.70	0.25	2.30	0.96
A 3	0.72	0.29	1.57	0.26	2.17	0.85
A 4	1.31	0.18	2.51	0.34	1.92	1.20
B 1	0.85	0.11	1.49	0.37	1.76	0.64
B 2	0.74	0.21	1.45	0.24	1.95	0.70
B 3	0.68	0.91	1.59	0.22	2.34	0.91
B 4	1.30	0.18	1.36	0.36	1.05	0.07
C 1	0.77	0.50	1.34	0.53	1.75	0.57
C 2	0.59	0.38	1.57	0.21	2.65	0.08
C 3	1.24	0.87	2.70	0.51	2.18	1.46

Although teak material under analysis comes from only three trees growing in irregular plot, the main findings can provide a reasonable forecasting on quality and natural durability of the teak growing in the neighbouring plantations under similar environmental conditions. However, considering the fact that management techniques determine the plantation wood products, additional studies should be performed on trees growing within a stone's throw distance from commercial plantation to confirm the expected natural durability and wood properties.

ACKNOWLEDGEMENTS

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Characterisation and Extension of Juvenile Wood in Plantation Grown Teak (*Tectona grandis* L.f.) from Ghana

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ABSTRACT

For qualitative and quantitative characterisation of juvenile wood, heartwood of 18 teak trees, between 10 and 32 years age, from 5 plantations in Ghana was studied with regard to the radial variations in growth ring width, vessel diameter, microfibril angle (MFA), natural durability (ND), density, sorption behaviour, compression and bending strength, and modulus of elasticity (MOE bending). The results are compared with those obtained from four 81 to 314 - year - old trees from natural stands in Myanmar. Significant differences between from plantations and natural stands. The natural durability study confirmed the attribution of teak as stipulated in DIN EN 350-2, i.e., teak from natural stands conforms to ND class I, while plantation timber varies from ND class I to ND class III. In 10 out of 18 plantation trees, the outer heartwood was more durable than the inner heartwood. Six plantation trees were rated very durable (class I) and two, only moderately durable (class III) throughout the heartwood. Mean density and related strength values did not differ significantly between plantations and natural stands. However, radial trends were different in that the wide-ringed plantation timber followed the pattern typical of diffuse-porous woods and the narrow-ringed natural stand timber, that of ringporous woods. The proportion of juvenile wood based on natural durability, physical and strength properties was negligible in timber from natural stands but was fairly high in the plantation timber. Although no biological boundary between juvenile and mature wood exists, for practical purposes, a virtual boundary based on natural durability variation can be set at about 7 cm radial distance from the pith, corresponding to an average of 4.5 growth rings and 12 per cent of total stem volume. If this proportion is eliminated from calculations, the overall properties profile of the remaining volume improves significantly, i.e. average strength is clearly higher and the proportion of very durable wood (ND class I) increases from 55 to 85 per cent.

Keywords: Tectona grandis, plantation-grown timber, Ghana, juvenile wood, wood properties, variation

INTRODUCTION

Plantation-grown teak (*Tectona grandis* L.f.) has been the subject of numerous .ternational markets, the economically important question - how does plantation-grown teak compare to old-growth teak of natural stands has been raised repeatedly by wood trade and industry, and has been addressed by researchers in some instances. The results of many investigations agree each other in some aspects and less incongruent in others. Indeed, overall congruence and general conclusions thereof cannot really be expected since the variables with known and/or suspected impact on wood properties (genetic stock, site conditions, growth rate, tree age, silvicultural treatment, etc.), sample size, and test methods employed differ widely from one study to another. Eventually, however, the sum of past, present, and future investigations may yield a fairly accurate property profile of plantation-grown teak, and how it compares with that of old-growth timber from natural stands.

The present study represents one step forward towards consolidating our knowledge on property profiles of plantation-grown teak and encompasses, perhaps more so than many of the previous studies, a large number of biological, physical, and technological parameters to obtain better insight into mutual dependencies of individual properties, their intrinsic radial variation and, as particularly emphasised in this paper, their diagnostic power for a fairly reliable and practicable definition of juvenile wood that would enable sawmillers to effectively separate lower quality material from higher quality timber to improve marketing and sales economics.

MATERIAL AND METHODS

Eighteen trees from five plantations in Ghana were studied. For comparison, butt ends of four commercial trees from old growth natural stands in Myanmar were included in the investigation. The details on the exact location, site characteristics and tree age of the Ghana plantation material were given earlier by Schmitz (2001). The commercial logs of the trees were cut in to two 1.4 m-long sections (lower and upper), which were then sawn into flitches (as export of roundwood from Ghana was prohibited) and shipped to Hamburg for further processing. The properties determined cover a wide range of anatomical, physical, biological, and mechanical parameters of which only those deemed important for the definition of juvenile wood are presented and discussed in the context of this study on:

- natural durability (screening and full tests; procedures adopted from DIN EN 350-1 [1994], N34 CEN TC 38/WG 23 [2000], and DIN EN 113 [1996]; test fungi: *Coriolus versicolor* ("white rot") and *Coniophora puteana* ("brown rot")
- density, bending and compression strength, MOE bending (DIN 52 186 [1978]; DIN 52 185 [1976]);
- Micro fibril angle (MFA) by means of x-ray diffractometry (SilviScan2, Evans, 1999).

RESULTS AND DISCUSSION

Natural durability

Here only the results obtained with the white rot fungus *Coriolus versicolor* under full test regimen (EN 113) are presented. The brown rot fungus *Coniophora puteana* did not cause significant mass loss, and the results from the more rapid screening tests with few selected trees did not differ markedly from those obtained from the full tests.

Natural durability, though quite variable within and between trees of the Ghana material, displayed rather distinctive radial trends. Fig. 1 depicts the mass loss caused by white rot and its wide variation from near 0% (durability class 1) to a maximum of 50% (durability class 5) along the radius from pith to the heartwood-sapwood boundary over a distance of approximately 15 cm, corresponding to an average of 20 growth rings (years). On the contrary, mass loss of the Myanmar trees varies to a much lesser degree with a maximum around 5% near the pith region (Fig. 2).

However, these findings cannot be generalized in the sense that Ghana plantation teak is so much less durable than Myanmar teak. For nearly all individual mass loss values above 25% are attributable to the innermost heartwood and, in particular, to one individual tree (plantation II, tree C) as shown in Fig. 1. Heartwood from other individual trees, particularly the two selected from the Amentia plantation provenance trials, proved very much superior in terms of natural durability (class 1-2). For comparison, data on average mass loss and natural durability classification (DIN EN 350-1) of all trees tested are given in Table 1.

Accordingly, none of the plantation trees rates on average lower than durability class 3. However, mean values do not tell the entire story since individual portions of trees have to be attributed to

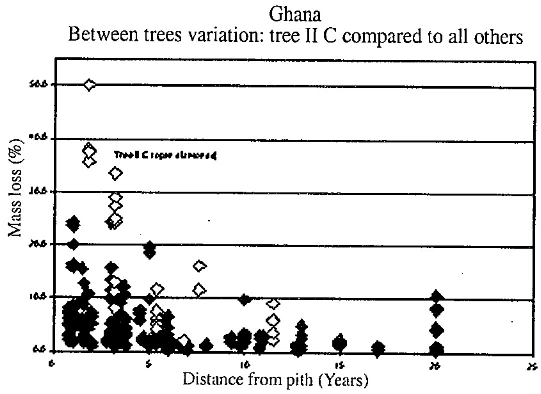

Figure 1. Mass loss caused by *Coriolus versicolor* depicting data of tree II C vs. those of all other trees

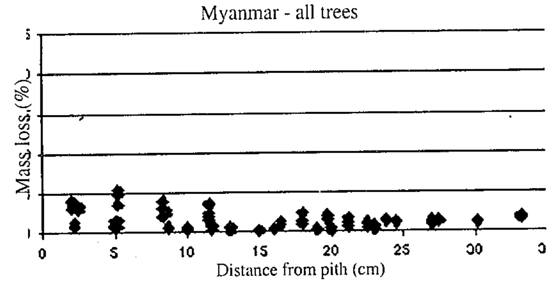

Figure 2. Mass loss caused by *Coriolus versicolor* for the entire Myanmar sample

lower durability classes as shown in Fig. 3a (specimens) in comparison with 3b (whole tree averages). And if, as is often the case, the weakest link in a chain constitutes the platform for quality assessment, the heartwood portions (primarily from the region close to the pith) attributed to durability classes 4 and 5 would lastly determine the quality customers are prepared to pay for.

Density and strength properties

Wood density and strength properties (bending, compression, MOE's) were determined at three positions along the tree radius, i.e., inner heartwood (close to the pith), intermediate, and outer heartwood (close to the heartwood-sapwood boundary), except with small diameter trees for which no intermediate or sometimes no outer heartwood values were determined. Density-strength correlations are shown in figs. 4 (Myanmar) and 5 (Ghana), the corresponding data for the plantation-grown teak from Ghana are summarized in Table 2.

In most general terms, some exceptions permitted, the radial variation of density and corresponding strength properties follows established patterns. Density increases very gradually from inner to outer heartwood, and with it bending as well as compression strength and the corresponding moduli of elasticity. The Ghana timber density was on average approximately 5% lower than that of the Myanmar timber.

The radial variation of density and strength properties typically shows two separate data collectives for inner and outer heartwood as exemplified in Fig. 6 for bending strength of the Ghana material. The two peaks are distant enough

Table 1. Mean mass loss and attribution to durability classes (EN 350-1) of all studied trees

Origin	Plantation	Tree	n	Mean mass loss [%]	Durability class (EN 350-1)
Myanmar		A	27	1.6	1
		B	24	2.0	1
		C	21	0.3	1
		D	18	0.3	1
Ghana	I	3021	10	4.5	2
		3047	15	1.6	1
	II	A	18	4.1	1
		B	18	4.7	2
		C	24	17.2	3
		D	17	1.4	1
	III	A	15	4.5	1
		B	13	0.7	1
		C	15	7.7	2
		D	12	0.6	1
	IV	A	5	10.4	3
		B	10	15.7	3
		C	12	4.9	2
		D	6	6.3	2
	V	A	13	1.1	1
		B	18	4.1	1
		C	22	3.2	1
		D	10	1.3	1

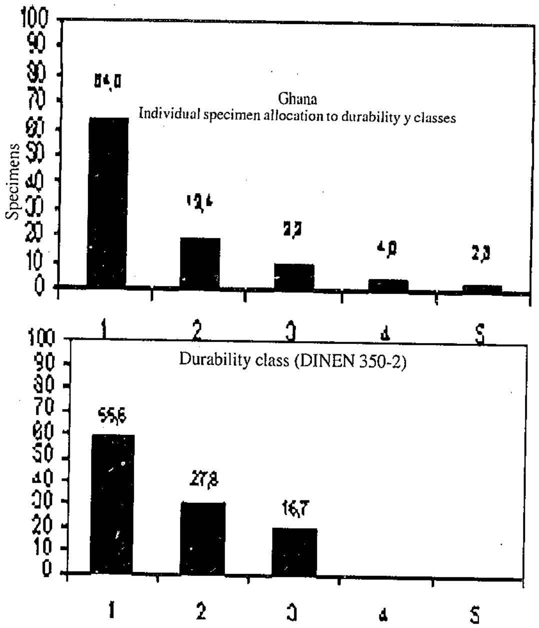

Figure 3. a) Distribution of durability classes for individual specimens (Top) b) Distribution of durability classes for tree averages.

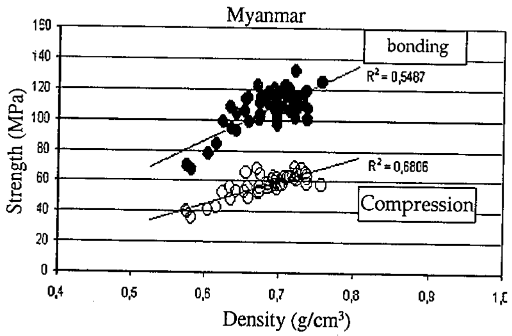

Figure 4. Density-strength correlation for old-growth Myanmar timber

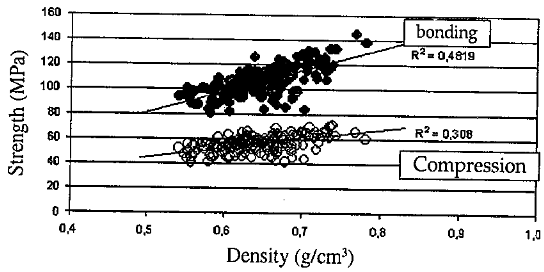

Figure 5. Density-strength correlations for plantation-grown timber of Ghana

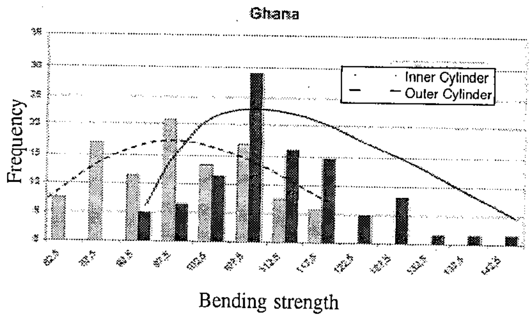

Figure 6. Frequency distribution of bending strength values determined for inner and outer heartwood of teak grown in Ghana plantations

to warrant interpretation as a radial trend, (density and) strength increasing proportionally with distance from the pith, a trend that conforms to the general pattern observed in diffuse-porous hardwoods. Contrary, in the Myanmar material density is highest in the innermost heartwood (wide rings) and thus follows the pattern anticipated for ring-porous hardwoods (viz. corresponding data for *Robinia pseudoacacia* – Richter *et al.*, 2003).

However, the differences in strength appear much more pronounced than can be predicted from those observed for density. Therefore, in an additional experiment the microfibril angle (MFA) frequently indicated as a factor of significant influence on strength properties (Zobel and van Buijtenen, 1989; Zobel and Sprague, 1999: Evans and Ilic, 2001; Bhat *et al.*, 2001), was determined.

Microfibril angle (MFA)

The MFA was determined from cores of selected trees with a resolution of 5 mm, each recorded value constituting a mean based on 100 measurements at 50 μm intervals. The results, as shown for selected trees from Myanmar and Ghana in Figs. 8—10, give evidence of a) very little variation in the old-growth tree from Myanmar, and b) an enormous variability within and between the plantation-grown trees, some with quite pronounced trends (microfibril angle sharply and continuously decreasing from pith to bark, e.g., Ghana tree IIIA), others without a distinct trend, e.g. Ghana tree VC.

Changes in microfibril angle along the tree radius have been measured and discussed occasionally in

Table 2. Density and selected strength properties (means,) as a function of radial position in the tree

Plantation	Tree	Radial position	n	Density	Strength		MOE	
					Bending	Compression	Bending	Compression
				[g/cm³]	[MPa]	[MPa]	[MPa]	[MPa]
I	3021	inner heartwood	4	0.587	96.9	52.6	11834	13760
		intermediate	8	0.559	98.6	52.3	12245	14629
		outer heartwood	7	0.614	108.7	61.6	13339	17283
	3047	inner heartwood	6	0.669	102.0	52.1	11483	13644
		intermediate	3	0.716	125.1	61.0	13060	15779
		outer heartwood	6	0.748	126.6	67.3	14393	17507
II	A	inner heartwood	4	0.571	91.5	45.2	9124	10404
		intermediate	6	0.616	105.5	55.3	11115	13795
		outer heartwood	5	0.608	103.4	54.0	10758	13192
	B	inner heartwood	3	0.609	96.8	48.9	8978	9876
		intermediate	4	0.643	107.6	56.2	11230	13861
		outer heartwood	4	0.626	104.6	49.5	9596	10369
	C	inner heartwood	4	0.608	88.4	47.7	9256	11804
		intermediate	5	0.624	95.8	47.3	9725	12442
		outer heartwood	4	0.635	107.4	58.3	11822	15740
	D	inner heartwood	1	0.667	105.3	47.3	9212	12693
		outer heartwood	2	0.673	118.0	58.5	11018	13054
III	A	inner heartwood	1	0.664	108.1	50.6	11432	10270
		intermediate	6	0.679	116.7	59.3	12370	14349
		outer heartwood	6	0.645	110.5	58.5	11547	13181
	B	inner heartwood	4	0.678	113.8	58.0	11867	12031
		intermediate	5	0.659	109.9	61.0	11712	13153
		outer heartwood	4	0.633	100.6	55.1	10050	12101
	C	inner heartwood	2	0.586	88.0	53.7	11475	15655
		intermediate	7	0.614	103.2	56.1	11027	14006
		outer heartwood	2	0.663	100.6	60.5	11749	14307
	D	inner heartwood	1	0.717	111.7	65.9	13396	16630
		intermediate	3	0.731	125.4	63.8	12139	14418
		outer heartwood	6	0.718	124.5	64.2	12212	14702
IV	A	inner heartwood	3	0.683	85.3	42.7	6551	7797
	B	inner heartwood	6	0.639	100.4	53.7	12336	14664
	C	inner heartwood	5	0.609	96.15	47.8	8819	10433
	D	inner heartwood	1	0.664	103.9	50.3	9986	11140
V	A	inner heartwood	1	0.705	115.0	65.3	11887	14619
		outer heartwood	4	0.679	110.3	56.9	11034	12691
	B	inner heartwood	2	0.651	97.5	56.0	10813	14616
		outer heartwood	3	0.686	106.1	53.4	10260	11960
	C	inner heartwood	4	0.652	107.2	55.8	10983	13103
		intermediate	2	0.669	103.2	54.3	9843	11325
		outer heartwood	4	0.633	104.8	57.8	10501	12490
	D	inner heartwood	3	0.628	97.7	56.1	10111	12677
		intermediate	1	0.694	126.5	63.2	11825	14458
		outer heartwood	5	0.679	120.6	61.2	12281	14087

earlier reports (Bhat *et al.*, 2001) with a continuous decrease from about 20° in the youngest formed wood to a fairly stable 8° to 12° at age 20 to 25. For the Ghana material such a stable trend was the exception rather than the rule (only 4 trees, example in Fig. 7) and the respective thresholds varied widely from tree to tree, i.e., stabilization between 5 and 20 years at an angle from 8° to 17°. In all other trees microfibril angle variation was equally large but no defined trends were evident (Fig. 9).

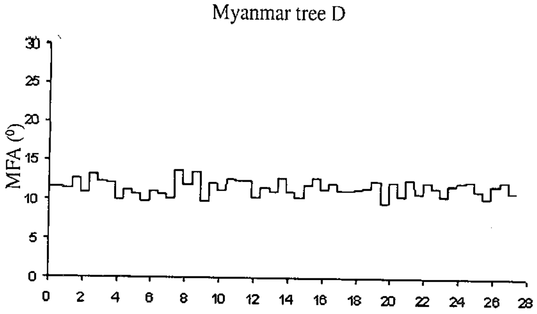

Figure 7. Microfibril angle of Myanmar tree D depicting rather small within-tree variation without visible trend from pith to bark

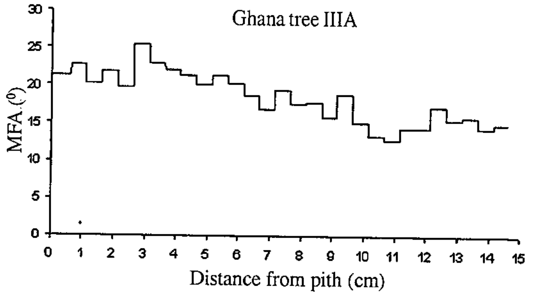

Figure 8. Microfibril angle of Ghana tree IIIA depicting fairly large within-tree variation but following a pronounced trend decreasing from pith to bark

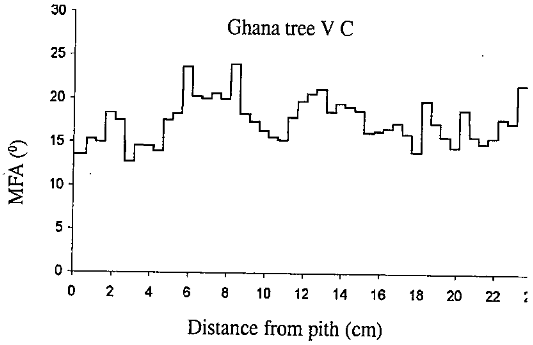

Figure 9. Microfibril angle of Ghana tree VC depicting a fairly large within-tree variation but no pronounced trend from pith to bark

CONCLUSIONS

The principal conclusion from this research is that for the plantation-grown teak from Ghana nearly all parameters are far too variable to be safely used for a plausible definition of a juvenile-adult wood boundary. About the reasons one can only speculate.

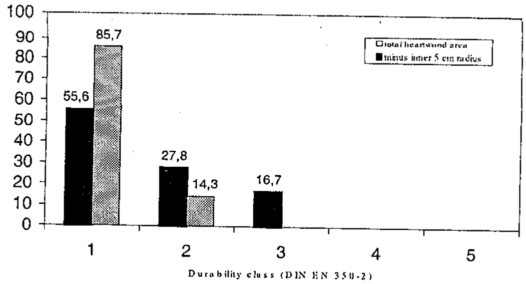

Figure 10: Changes in durability class attribution (tree averages) by excluding inner heartwood (5 cm radius) from the calculation

One may be the relatively young age of the plantation trees with growth dynamics different from that of older trees. Judging from the overall similarity of the two trees from the Amentia plantation provenance trials one can also assume that differences in genetic stock play a major role as a cause for the observed high variability.

The one exception to this apparent rule is natural durability. It is equally variable but in nearly all Ghana trees follows a fairly well defined trend. Following the original purpose of this study, i.e., setting a meaningful boundary between lower (juvenile) and higher (adult) quality wood that can be easily transferred into sawmilling practice, the following steps were taken: After some trial and error, an artificial boundary was set at a radial distance of 5 cm from the pith encompassing an average growth of about 4½ years. When all individual specimen values for natural durability within this boundary are statistically excluded from tree averages, the proportion of trees attributed to durability class I increases from 56% to 86%, that in durability class II is reduced from 28% to 14%, and none is left in durability class III (Fig. 10).

Hence, by means of a very simple sawing pattern that separates an inner beam measuring approximately 10 by 10 cm², the total heartwood volume can be processed into, and marketed as, two quality grades with corresponding price differences. The larger volume (outer heartwood) meets the minimum quality requirements for construction timber under exterior exposure (durability class I—II), the smaller volume (inner heartwood) could be destined strictly to interior use such as flooring (pre-fab parquet), simple furniture, and other indoor end uses which do not require large cross-sectional dimensions. Though self-explanatory, it shall be emphazised again at this point that, since the juvenile wood volume does not increase any further with age, the older the trees are allowed to grow the higher is the volume of the more profitable grade 1 timber (adult wood).

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Teak Production, Processing and Utilization in Nigeria

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ABSTRACT

Teak is an exotic wood species, introduced in Nigeria around 1889. It has since become well established as one of the two most popular exotic commercial timber species grown in many parts of southern Nigeria, the other species being *Gmelina arborea* Roxb. A study, involving market and literature surveys, was conducted to obtain information on the current status of teak production, processing and utilization in Nigeria. Findings indicated that teak is a plantation-grown timber only in government-owned forest reserves of Nigeria. There is no accurate information on the current total teak population in the country. In 1994, the total planted area was 39055 hectares. By 1996, this decreased to about 32966 ha, due to over-exploitation. Nigerian teak is moderately hard, strongly scented, dark golden yellow in colour when freshly cut and light brown when dry. The stems attain Diameter at Breast Height (DBH) of over 30 cm within 30 years. Stands on good forest sites attain acquire a Mean Annual Increment (MAI) up to 17.5 m3. The current average stumpage price is US$28. Teak is used as round wood and also locally processed into different items by the wood industries in Nigeria. The most common end uses, in the order of magnitude of usage are furniture for domestic consumption and export, telegraphic poles, floor parquettes, fuelwood and charcoal. Therefore, teak in Nigeria generates raw materials for local wood industries, creates employment opportunities and contributes to the country's foreign exchange earnings.

Keywords: Teak production, processing, end-uses, Nigeria.

INTRODUCTION

Teak (*Tectona grandis* L.f.) occurs naturally only in India, Myanmar, the Loa's People's Democratic Republic and Thailand. It is, however, naturalized in Java and Indonesia (Pandey and Brown, 2000). It is also panted throughout tropical Asia, many parts of tropical Africa, and some parts of Latin America (Pandey and Brown, 2000; Krishnapillay, 2000). Nigeria was the first country outside Asia where teak was introduced between 1889 and 1902. (Horne, 1966; FORMECU, 1990; Oluwalana, 1997; Pandey and Brown, 2000).

The first teak seed was imported into Nigeria from India while subsequent ones came from Myanmar. The first 750 ha of teak plantation was established in 1890 at the Olokemeji forest reserve in the then Western Nigeria, now part of Ogun State (FORMECU, 1990; Oluwalana, 1997, Pandey and Brown, 2000). Further stands were established in the Gambari forest reserve in 1912. Teak was planted widely in many other parts of Nigeria from 1915 onwards. It is now planted nationwide. A significant number of teak trees were planted across the country in the 1960s and especially in the western part during a national drive for afforestation of the 1970s and 1980s. The World Bank, the African Development Bank, the Federal Government of Nigeria and some State Governments jointly funded many of such projects (Sanwo, 1983; Oluwalana, 1997).

By 1994, there were about 39,055 ha of pure and mixed teak plantations in Nigeria, most of the plantations being concentrated in the high forest and Guinea savanna zones of the country (FORMECU, 1990). There were about 651 ha of teak trees at premier teak plantation site in Nigeria, the Olokemeji forest reserve, alone in

1997 (Oluwalana, 1997). By the year 2000, there were about 132,500 ha in tropical Africa (Krishnapillay, 2000). With about 70,000 ha, Nigeria has the largest (52.7%) teak plantation in Africa (Table 1). In terms of the extent of teak plantations outside Asia, Cote d'Ivoire is second to Nigeria (Krishnapillay, 2000; Maldonodo and Louppe, 2000).

One hundred percent of Nigeria's teak and other plantations are currently owned, controlled and maintained by the respective State governments on whose lands they are located. Harvesting is, however, left in private hands. Teak exploitation generates raw materials for the local sawmilling, furniture and building industries. It also provides employment opportunities for numerous people and generates substantial earnings for the governments at both the state and the national levels in forms of fees, royalties and export duties. The objective of this study was to obtain and document information on the current status of teak production, processing and utilization in Nigeria.

MATERIALS AND METHODS

Market and literature surveys were conducted to obtain information on the current status of teak production, processing and utilization in Nigeria. In conducting the market survey, several visits were paid to places such as the University of Ibadan teak plantation, Forestry Research Institute of Nigeria (FRIN), Jericho Hills, Ibadan, timber markets, furniture workshops, wood preservation establishments, and other teak users within Ibadan metropolis in Oyo State, Nigeria. At each location, oral interviews were conducted with the operators to elicit requisite information. The literature survey involved paying visits to libraries to consult available documents (both published and otherwise) on Nigerian-grown teak.

Table 1. Established teak plantations in Africa in 2000

Country	Plantation Size (ha.)	Percentage of Total (%)
Nigeria	70,000	52.7
Cote d'Ivoire	52,000	39.3
Sierra Leone	3,000	2.3
Tanzania	3,000	2.3
Togo	4,500	3.4
Total	132,500	100.0

Source: Krishnapillay (2000), Maldonodo and Louppe (2000)

RESULTS AND DISCUSSION

Characteristics of Nigeria-grown teak

Nigeria-grown teak is moderately hard, strongly scented, dark golden-yellow when freshly cut, and light brown when dry. There is a sharp colour differentiation between the heartwood and the sapwood. The sapwood is usually narrow, having a colour ranging from white to pale yellow. The heartwood is typically light to golden brown in colour. The grain varies from straight to interlocked. The wood is ring porous and exhibits a coarse and uneven texture. The bole may be flutted or sometimes have slight butt swell. On dry shallow soils, the tree may be twisted with heavy undesirable branching (Sanwo, 1983). The wood is durable and exhibits a rather rapid drying rate. It exhibits moderate movement, is amenable to cutting, and has very good general working qualities (Oyetunji, 1999).

Teak production

Teak is the oldest plantation species in Nigeria. It is available only in the forest reserves, where much of the planting is still carried out by government agencies or as part of externally assisted afforestation or reforestation projects. It is also the most sought-after exotic species (Adeyoju, 1975; Omole, 1996). It lends itself to easy plantation establishment. It is commonly established from stump (Sanwo, 1983). Nigerian-grown teak performs well in plantations under favourable conditions unlike other some other popular commercial Nigerian hardwood species such as *Milicia excelsa, Khaya ivorensis, Khaya grandifolia,* and *Entandrophragma* species, all of which have proved to be not amenable to plantation growing. Some of the problems associated with plantation growing of these species include slow growing rate, susceptibility to mortality when established on cleared land, and vulnerability to pests and diseases (Pandey and Brown, 2000).

Table 2 shows the level of availability of teak in different States in Nigeria in 1994. The total stand area was 39,064 ha. (Akande and Adeofun, 1999).

Table 2. Level of teak availability in different States of Nigeria in 1994

State	Stand Area(ha)	Merchantable Area (ha)	Exportable Volume (m^3)
Benue	1,500	300	9,000
Edo	2,954	1,500	105,000
Kaduna	1,613	500	15,000
Ogun	6,840	3,000	180,000
Ondo	16,133	6,400	320,000
Oyo	10,024	6,000	270,000
Total	**39,064**	**17,700**	**899,000**

Source:Adeofun and Akande (1999)

Ondo State had the largest teak plantation (16,133 ha.), followed by Oyo (10,024 ha.) and Ogun (6,840 ha.) States respectively. About 4.5% of the global teak plantations were located in Nigeria and Cote d'Ivoire in 1995 (Pandey and Brown, 2000).

Teak productivity

Teak is deciduous in areas characterized by alternating wet and dry seasons, but non-deciduous in areas that are constantly wet (Sanwo, 1983). Growth of teak is influenced largely by the twin factors of rainfall and depth of soil, both of which vary from one geographical location to the other in Nigeria. Yields obtainable from the various teak plantations are, therefore, quite variable. It is observed that the Mean Annual Increment (MAI) of the trees aged between 5 and 9 years ranged from 0.95 $m^3 ha^{-1}$ for 3 year old trees at Gambari to 9.77 $m^3 ha^{-1}$ for 9 year old trees planted at Onipe.

Anon (1964) and Sanwo (1983) reported that teak stands on good sites in the rain forest regions often attain a MAI of up to 17.5m^3 ha^{-1}, while in the savannah forest region, it may attain a MAI of about 6 m^3 ha^{-1}. Renes's study (1978) involving Nigerian-grown teak trees aged 8 to 61 years showed that 12-16-year-old plantations gave the maximum MAI in both low and high quality soils in Western Nigeria, the values being 11.05m^3 ha^{-1} and 14.95m^3 ha^{-1} respectively (Table 3). Pandey and Brown (2000) had noted that teak usually exhibits an early peak of MAI between 6 and 20 years. A study by Akinsanmi and Akindele (1995) showed that the performance of teak in the dry high forest area of the Nigeria was comparable to what Krishnapillay (2000) reported by for teak grown in Mata Air Station, Perlis, Malaysia. The mean diameter at breast height (DBH) and tree height at 15 years were 24.5 cm; 18.6 m respectively in Nigeria, and 25 –35 cm; 22-25 m respectively in Malaysia.

Table 3. MAI of Teak Grown in South-Western Nigeria

Age Group (years)	MAI[1] (m^3/ha/yr)	MAI[2] (m^3/ha/yr)
8-10	10.9	13.6
12-16	11.0	14.9
53-61	6.9	8.6*

Site Condition: Sandy soil, gravel soil,Top slope, poorly drained soils. Loam to clay soils, none to moderate gravel.
*Including thinning yields, estimated at 50% of final crop.
[1] Low Quality Site [2] High Quality Site
Source: Renes (1978)

Teak harvesting

Teak plantations are situated in government-owned forest reserves in at least six out of the 36 states that make up the Nigerian federation (Adeofun and Akande 1999). All of these plantations are licensed to timber contractors for exploitation. To operate in a teak plantation, timber contractors are required to have necessary capital to procure logging facilities and transportation vehicles. All the states have essentially similar regulatory guidelines regarding forest concession allocation.

Various assessment models are used to arrive at charges to be paid by timber contractors. These include stumpage, Out Turn Volume (OTV) and unit area charge. The most common one is stumpage. The State Governments control stumpage prices and these vary

1. The exchange rate of Nigeria Naira (N) to US$ in 1990 was 10 Naira to US$1.
2. The current exchange rate of Nigeria Naira to US$ is 125 Naira to US$ 1.

Table 4. Projected supply of teak products from 14 teak plantations in Ogun State

Year	Sawlog[1] ('000 m³)	Sawnwood ('000 m³)	Poles[2] ('000 m³)	Others[3]	Total Vol.[4]('000 m³)
2000	702	330	1,373	183	2,258
2001	738	347	1,444	192	2,374
2002	774	364	1,514	202	2,490
2003	811	381	1,585	211	2,607
2004	846	398	1,655	221	2,723
2005	882	415	1,725	230	2,839

[1] Diameter 30 cm and above [2] Diameter 20 cm to 29 cm [3] Diameter below 20 cm and others [4] Excluding sawnwood
Source: Oluwalana (1997)

from one State to another. This variation accounts for greater teak exploitation in States that charge cheaper prices, thereby leading to mass removal of teak stands (Omole, 1996). Ondo State was charging the minimum stumpage price of ₦750 (US$ 75)1 for teak in 1990 while most of other five States were charging ₦1500 (US$ 150) (FORMECU 1990). The current average stumpage price is ₦3000 (US$ 24)2. Hence while the stumpage price has increased by 100% in local currency in 12 years, it has decreased by about 84% in US Dollars. The implication of this is that foreign investors have now virtually taken over teak exploitation in Nigeria.

Problems associated with teak exploitation in Nigeria include illegal felling, over-exploitation without replacement of felled trees, and unstable government policies, arising from the political instability witnessed in the country, particularly between 1983 and 1999. Oluwalana (1997) reported that about 90% of the teak plantations sited in Ogun State were been exploited without replacement. Many other teak plantations in the country need rejuvenation and, in some cases, re-establishment as they have either been or are currently being heavily exploited.

Teak conversion in sawmills

Teak is usually sawn for both high-grade lumber and volume recovery on mobile horizontal bandsaws in Nigerian sawmills. These machines are relatively light and are prone to frequent breakdowns. The quality of lumber produced is also usually poor (Olorunnisola, 1997; 1998). The average conversion efficiency from teak sawlogs on these machines is about 47% (Oluwalana, 1997). This is about 11% lower than the average value of 58% obtained for other common local wood species (Olorunnisola, 1997). The advantages of mobile horizontal bandsaws, however, include simplicity of design and operation and minimum maintenance requirements. The circular saws that are commonly used for re-sawing operations (crosscutting, edging and trimming) have a disadvantage with relatively large saw kerf. The present infrastructure in the Nigerian sawmilling industry is ill suited to processing small diameter logs. This situation is hindering the development of a local market for teak from thinnings.

Local utilization and marketing of teak

Teak is utilized in Nigeria, in diverse ways. Trees having a basal diameter ranging from 10 to 25 cm are used as poles; while stems having diameter at breast height (DBH) greater than 30 cm, a minimum length of 3.7 m and a minimum top diameter of 23 cm are converted to sawn timber. Stumps, unsuitable butt ends of inferior quality, tree branches and crooked stems are typically cut into pieces and either converted into charcoal or sold as firewood in urban markets near production centres, given teak's relatively high calorific value (Omole, 1996, Ezekiel, 1997). Common local uses of teak timber include furniture making, joinery and general carpentry works, floor parquet production, flush door manufacturing, as poles for electricity transmission and land telephone lines, as struts in buildings, and as beams in bridge construction (Omole, 1996; Ezekiel, 1997; Areghan, 2001). A survey by Quadri (2000) of 30 furniture workshops in Osun State Nigeria showed that teak is one of the most popular and most expensive timber species used for furniture making.

Local non-wood uses of teak include the leaves as wrapping material, dye making and pharmaceuticals. These products are less profitable than timber logs, as they have much lower market value. They are, nevertheless, quite useful.

Teak export

Of all plantation-grown exotic timber species available in Nigeria, i.e., Gmelina (*Gmelina arborea* roxb.), Eucalyptss (*Eucalyptus* spp.), and Pine (*Pinus* spp.), teak appears to have the highest demand in the world market. There is, however, no current and accurate record on the total volume of teak processed for export annually in the country.

The Federal Government of Nigeria banned the export of teak and other species (except *Gmelina*) in the round wood on January 1, 1988. Hence, currently, teak export can only be legally accomplished when traded as semi-processed furniture components, (i.e., rough-sawn or clean-sawn billets), or furniture parts (Adeofun and Akande, 1999, Sanwo, 1999). Sawn billets are usually produced in three length categories: 1.86m (6 feet), 3.72m (12 feet) and 4.96 m (16 feet) respectively for loading into cargo containers whose capacities seldom exceed 500 cubic meters.

The bulk of Nigerian-grown teak is exported to Singapore, Belgium, Lebanon, and many Asian and West African countries, where it commands a selling price ranging between US$ 150 and US$ 250 in 2000 (Maldonaldo and Louppe, 2000). Problems associated with teak export include relatively poor quality of lumber produced by many of the local sawmills and the relatively primitive nature of sea transport business in Nigeria, exemplified by relatively poor packaging and containerisation, inadequate quality control, relatively poor overseas marketing services, and poor documentation (Sanwo, 1999).

Projected teak supply

Data was not available for review on the projected supply of various end products from teak plantations nationwide, except from the fourteen teak forest reserves in Ogun State. As shown in Table 4, pole sized logs account for about 61% of the total projected annual teak supply from 2000 to 2005, while sawlogs, poles, and other products account for rest 39% (Oluwalana, 1997). Unfortunately, domestic outlets for small diameter teak logs are largely limited to electricity and telephone poles, a sector in which concrete is posing a major challenge as a substitute material, given its less susceptibility to decay and bush fires. Poles also attract lower market values than sawnwood. The subsequent harvesting of many of the teak poles for conversion in the local sawmills results in huge wood wastes in view of the unsuitability of the conversion machines.

CONCLUSION

Since its introduction to Nigeria a little over a century ago, teak has remained one of the most popular exotic timber species, highly favoured by both Nigerians and foreigners alike. As shown in this paper, Nigerian-grown teak is amenable to plantation growing. It is utilized locally in diverse ways, and commands great respect in the international market. Its exploitation generates raw materials for local wood industries, creates employment opportunities for indigenes, and generates revenue for the government.

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Is Deoxylapachol, the Allergenic Agent in Teak, a Potential Threat?

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ABSTRACT

The causes of desirable and undesirable properties of teak wood are reviewed and the causes and occurrence of health injurious effects are highlighted. In industrialized countries, teakwood is considered as one of the most common sensitizers in the wood industry. Since the first report in 1896 on teak allergy and its sensitizing constituents, it was shown that air dried wood dust did not have primary irritant effects, whereas moistened dust produced toxic reactions. Native teakwood dust is therefore, the substance of choice for patch testing to diagnose teak allergy. In a study in Norway during late 1950s, out of 112 teak workers, 18.7 per cent showed allergic skin reaction to native wood dust. The diagnosis of allergic contact eczema was reported in 12.5 per cent, and 6.2 per cent were considered to have latent allergy. In total, 46 persons, including 41 per cent of the workers at the furniture plant were affected by teak dust. It was also seen that 13 patients who were allergic to teak dust showed cross reactions to Brazilian Rosewood, even though it was never used in that factory. Deoxylapachol, the primary sensitizer in teak, is about 100 to 200 times stronger as allergenic compound than lapachol. Deoxylapachol and other allergenic benzoquinones and napthoquinones can be detected in a simple way using the Craven test. This method enables to screen logs or specimens with latent allergenic properties. During the last 15 years, no cases of teak allergy were reported, although the amount of utilized teakwood is still high. This may be due to the better hygienic situations in the various industries which utilize teakwood. Its high incidence in Norway in the late 1950s was due to poor hygienic conditions in the furniture plants there.

Keywords: Wood extractives, allergic compounds, working safety

INTRODUCTION

It is now accepted that the desirable and less desirable properties of teak are dependent on wood extractives (Simatupang *et al.*, 1995). The desirable properties are high natural durability, good dimensional stability, gold brown color after short exposure, good workability, good abrasion resistance to its modest density, good hydrophobic properties making teak suitable as ship's deck planks and prevention of rusting of iron nails embedded in teak wood. Natural durability against wood destroying insects, especially termites, is mainly due to anthraquinone derivatives, viz. tectoquinone. The active principles against wood destroying fungi are still yet to be knnown. Some evidences show that the decay active ethanol extract and non-active caoutchouc act synergetically to render teakwood decay resistance (Yamamoto *et al.*, 1998). Earlier it was considered that the good dimensional stability of teak was due to the caoutchouc (Sandermann and Dietrichs, 1959). This compound occurs in the cell lumen as well as in the cell wall (Yamamoto *et al.*, 1998). Puth (1964) observed that the good dimensional properties were still retained after extraction of thin teak specimens with petroleum ether removing caoutchouc. A successive extraction with ethanol to remove more polar compounds reduced the dimensional stability markedly. Puth (1964) supposed that the polar extractives in the cell walls act as bulking materials improving the dimensional stability, a phenomenon already known in other wood species. Higgins (1957) and Puth (1964) supposed that in addition to the wood extractives a high lignin content may improve the dimensional stability. The lignin content of teakwood is 30%. The bulking effect of wood extractives may impair the supply of air and moisture to the wood destroying fungi leading to its decay resistance (Bavendamm, 1944).

The less desirable properties of teak are inhibition of hardening of lacquer due to radical polymerization, occurrence of calcium phosphate inclusions and inducing dermatitis and allergic reactions. The causes and occurrence of these health injurious effects are reviewed in this paper.

Health hazard

The use of wood is steadily increasing. More and more wood species, hitherto not widely utilized, are now finding their way to the market. In the industry wood is worked up into various finished and semi-finished products. Various processes such as sawing, planing, boring and sanding are required to modify the dimension and form of the original logs into the required products. Saw dust, shavings, splinters and bristles can damage the skin mechanically which is followed by infections. Fine dust can cause irritations of the mucous membranes of the nose, throat and eyes, and even can effect inner regions of the respiratory tract. They also can produce more or less severe lesions of the skin. It is known that certain kinds of wood species can cause general symptoms of illness such as headache, nausea, vomiting and cardiac arrhythmia. The commonly affected persons are those who are employed in the wood industry as carpenters, cabinet makers, lumberjacks, sawmill operators, paper mill workers. Hobby wood workers are seldom affected. Last but not least, a kind of rare cancer of the nasopharynx, adenocarcinoma, may develop in woodworkers, induced after several decades by steady contact with the fine wood dust. Certain kind of wood species, e.g. beech and oak, are allegedly to cause such phenomenon (Hausen, 1981).

Most of the proven cases of health hazards due to wood or wood products are allergic reactions of the skin, designated as contact dermatitis. To a lesser degree and also not yet extensively examined in details, are respiratory disorders (Hausen, 2000). Finished wood articles or solid wood are seldom recognised as the source of contact dermatitis. In rare cases it may occur after prolonged contact with wooden bracelets, necklaces, knife-handles, wooden shoes (clogs) and musical instruments such as the mouthpiece of clarinets, flutes and recorders or the chinrest

Table 1 Indonesian and Malaysian wood species which can be injurious to human health

Trade name	Scientific name	Health hazard	Active compound
Kuku	*Pericopsis* spp	Asthma	Not known
Salimuli	*Cordia subcordata*	Allergy, dermatitis, asthma	Cordiachromes (benzoquinone derivatives)
Mahogany	*Swietenia macrophylla*	Allergy, dermatitis, asthma	2,6-Dimethoxybenzoquinone ?
Jati	*Tectona grandis*	Allergy, dermatitis, asthma, rhinitis	Deoxylapachol, Lapachol (naphthoquinone derivative)
Keruing	*Dipterocarpus alatus*	Asthma, rhinitis, urticaria	Not known
Meranti merah	*Shorea* spec.	Allergy, dermatitis, asthma	Not known
Sonokembang	*Pterocarpus indicus*	Toxic, urticaria	Not known
Rengas	*Gluta rengas*	Urticaria, toxic (exudate of bark)	Glutharenghol (phenol derivative)
Sengon	*Albizzia falcataria*	Rhinitis	Saponin ?
Weru	*Albizzia procera*	Rhinitis	Not known
Upas	*Antiaris toxicaria*	Toxic, rhinitis, arrow poison	Cardiac active glycosides
Macassar ebony	*Diospyros celebica*	Allergy, dermatitis	Macassar quinone (naphthoquinone derivative)
Sonokeling	*Dalbergia latifolia*	Allergy, dermatitis, asthma	Dalbergion (benzoquinone derivative)
Akasia	*Acacia melanoxylon*	Allergy, dermatitis, asthma	Not known
Ramin	*Gonystylus bancanus*	Skin irritation, asthma	Not known

Source: Hausen 1981

of string instrument such as a violin. Jewelry made of Ebony, Brazilian and East-Indian rosewood has been observed to induce contact allergy to the wearer.

The problem of contact allergy due to teak is discussed here. The objective is mainly to create awareness of the risk in wood working and to prevent the outbreak of contact dermatitis by applying adequate preventive measures including plantation management techniques which minimize the risk by cultivation of trees, free from such compounds. This issue may become more important if the use of vegetative propagation method like tissue cultures increase. In this method plant materials with the same genetic properties will be cultivated. The probability to produce specimens with or without allergenic compounds will be more predictable, if mother trees with known properties are used. The wood industry and trade should consider to eventually test the logs or veneers for the presence of such compounds. Researchers could develop simple methods that can be applied at the wood yard or veneer plant. In such a case special measurements are required to avoid the outbreak of health hazards.

Allergy to teak

According to generally accepted definitions allergy is understood today as " *a specifically acquired, altered capacity of the body to react to foreign substances based on a pathological antigen-antibody reaction* (type 1 to III, Hausen, 1981). Allergy may be acquired after direct contact or inhalation of the fine dust, a process designated as sensitization. Compounds with such ability are called primary sensitizers. Most compounds causing contact allergy have simple chemical constitution with low molecular weight. The diagnosis of contact allergy to a certain kind of compound, is mostly accomplished by a patch test. Accordingly saw dust or wood extract, allegedly containing such compounds, is dosed on a plaster. This plaster is then applied to the skin, mostly on the back of the person for 24, 48 and 72 hours. Sensitized persons react positively by showing various skin reactions, various degree of erythema or abnormal redness of the skin. Care should be taken to avoid primary sensitization, rather than testing. It is known that primary sensitizer can induce sensitization if the applied amount is too high. In this way the person who is not yet allergic can become sensitized in a wrongly applied patch test. Diagnosis of contact allergy should be done only by experienced dermatologists (Hausen, 1981).

Skin tests with guinea pigs are routinely accomplished in many dermatological department of hospitals to examine the contact allergic properties of various compounds. The method is useful to screen chemicals or isolated fractions from wood extract. It cannot, however, wholly be replaced to test with human beings.

Although teak was already utilized since prehistoric times in India, Myanmar and Thailand and exported to Babylonia, ancient Iran and Egypt, no report was available on its health injurious effects from producing countries. In ancient Egypt, however, where teak was used for shipbuilding, the wood was reported to be toxic (Herrmann, 1969). In Java, where teak is supposed to be imported from India around the first century, an inferior kind of teak, designated jati sempurna , was known to cause skin itching, also dermatitis (Altona, 1923; Simatupang, 2000). The history of teakwood allergy was reviewed by Hausen (1981). The first case of dermatitis due to teak was reported to the editor of the medicinal journal, The Lancet in England in 1896. The first description of teak allergy was given by Evans (1905). Since that time more than 60 papers dealing with teak allergy or its sensitizing constituents have been published. The first attempt to isolate the allergy causing compounds was performed by Matthes and Schreiber in 1914. They suspected fractions containing free resin acids, without giving evidences, as the allergenic compounds. Hoffmann (1926) was the first to declare that teak dermatitis is due to hypersensitivity against this wood. According to Woods and Calnan (1976) teak is one of the most common sensitizers in the wood industry.

The incidence of dermatitis caused by teak exemplarily stated in a publication by Krogh (1962) is cited here. The investigations were accomplished in a furniture factory in Norway in the late 1950s. Patch tests with native teak dust moistened with water were applied on 10 "controls" and 112 workers, who were exposed to teak in various working conditions. Moistened teak dust produced toxic reactions in 20.5%, while native teak dust (air dry) did not have primary irritant effects and was, therefore, considered to be the substance of choice for patch testing; 18.7% of the workers showed an allergic skin reaction to native teak dust. The diagnosis of allergic contact eczema was made in 12.5%, and 6.2% were considered to have latent allergy. Primary irritant (contact) eczema was considered to be present in four individuals who experienced acute, transitory, eczematous eruptions during the hot part of the summer when they perspired freely. In these cases the patch test to native teak dust was negative. Desensitization or "hardening" was observed in four workers. Totally 46 persons, also 41% of the workers at the furniture plant, were affected by teak dust. In most cases the skin lesions were not severe enough to cause sickness absence. In a later publication Krogh (1967) reported that seven out of 13 patients who were allergic to teak, showed cross reactions to Brazilian rosewood, although rosewood has never been used in that factory.

Sandermann and Dietrichs (1959) were the first to isolate a sensitizer, lapachol (Figure 1), from teak. Schulz (1962, 1967) noticed during patch tests that this quinone is a sensitizer, but there ought to be another - stronger - sensitizer in this wood. One person who is allergic against teak dust did not react to pure lapachol. In experimental studies Schulz et al. (1967) showed that it is not possible to sensitize guinea pigs with lapachol. This compound is only a secondary sensitizer. The long sought primary allergenic compound in teak, a quinone, was isolated and its structure eludiciated in 1962 by Sandermann and Simatupang (1962, 1963). The allergenic quinone was isolated after an outbreak of dermatitis in a veneer plant. After slicing some teak logs the still hot and moist veneer were stapled as usual, dried and packed. On handling the respective veneer some workers showed sign of dermatitis. Some veneers were sent to our Institute in Hamburg. On the surface of some veneer specimens, yellow crystals were observed. The yellow crystals were successfully isolated, purified, and characterized. The new compound was designated deoxylapachol, due to its close structural relationship with lapachol. Deoxylapachol is a lapachol minus one hydroxyl group (Figure 1). The chemical structure of the newly isolated compound was also confirmed by synthesis. A patch test with the new compound, accomplished at the Dermatological Department of the University Hospital in Hamburg by Schulz, revealed that deoxylapachol was the main allergenic compound in teak. The allergic property of deoxylapachol is nearly 100-200 times stronger than lapachol (Simatupang, 1964, Schulz, 1967). It is to be mentioned that a quinone with the same chemical structure as deoxylapachol was formerly postulated by Sandermann and Dietrichs in 1959 as a pre-stage compound for tectoquinone in teak.

Allergy to teakwood can be serious, especially for carpenters who can have allergic contact dermatitis for instance the eczematous reactions of the hands, forearms and neck as shown in Figure 2. The person has to avoid further contact not only with teak dust, but also with dust of all wood species containing other kinds of benzo- and naphthoquinones derivatives which are not substituted at one of the positions adjacent to a carbonyl group e.g. deoxylapachol. A cross reaction that can occur between various allergenic quinones and compounds is illustrated in Figure 2. Some Indonesian and Malaysia wood species which can be injurious to human health are depicted in Table 1. The table shows the occurrence of various allergy causing substances in these wood species, of which quinones are important. Some benzo- and naphthoquinones with a free position adjacent to a carbonyl group show such properties and can be specifically detected by the Craven (1931) test. Potential allergy causing woods and components can be easily screened with this reagent.

According to Hausen (2003), no case of teak allergy was reported during the last 15 years. The reason was not clear, although the utilization of the wood, especially for garden furniture is increasing.

Detection and occurrence of deoxylapachol

This compound is easily detected with the Craven-Test. The ethanol extract of wood specimens, which are suspected to induce allergy is analyzed by thin layer chromatography. The plate is sprayed or poured with a solution containing equal amounts (by volume) of 96% ethanol and 25% ammonia to which 3-5 drops of ethyl cyano-acetate are added shortly before use. Deoxylapachol and other benzo- or napthoquinones with a free position adjacent or opposite to a carbonyl group in the quinone ring give a blue to green color after a few seconds. The limit of detection is around 5 g of quinone.

It is also feasible to perform the test with a total ethanol extract. It this case 1 g of wood meal is extracted with 5 ml ethanol at room temperature under occasional shaking. To the filtrate equal volume of a solution according to Craven is added. In presence of deoxylapachol the solution is turning blue to green color after a few seconds. A red color indicates the presence of lapachol or hydroxy-anthraquinone.

Deoxylapachol was detected in only 2 samples out of 13 of ethanol extracts of teak specimens from various countries and regions (Sandermann and Simatupang, 1966). The paper chromatographic examination of 30 drilled increment cores from 28-year-old teak trees cultivated in Java, seeds originated from various countries and regions (Loekito, 1959), showed the occurrence of the allergenic napthoquinone in only 8 specimens. In 7 specimens the compound was detected in the outer sections of the heartwood. In one specimen deoxylapachol could be additionally detected in juvenile wood. The concentration of deoxylapachol in the sections varied from 0.1 to 0.25%. On the contrary tectoquinone, with a concentration from 0.2 to 1.2% was detected in all sections of heartwood, whereas in sapwood the concentration was very low (Simatupang, 1964).

Deoxylapachol can be isolated by preparative thin layer chromatography or column chromatography with silica gel. If rather great amounts of teakwood containing the quinone is available, steam distillation of the wood powder is recommended. The quinone floats on the steam distillate and may be filtered off and purified by crystallization e.g. from methanol or ethanol to which some drops of water is added.

The sporadic occurrence of deoxylapachol in teak wood specimens may explain the rather rare outbreak of teak allergy in the industry. Only in 10 out of 43 (23%) specimens examined, the allergenic compound could be detected (Simatupang, 1964). The absence of teak allergic cases in Europe during the last 15 years may be mainly attributed to the fact that the working conditions for workers in the wood furniture factories are much improved. The maximum permissible amounts of dust particles in the air was reduced substantially. Hand tools as well as wood working machines are provided with good working suction devices. In Germany for instance, teak is classified as a potential allergenic causing wood. It has also to be born in mind that most of the current very popular teak garden furniture are manufactured outside Europe. The risk is shifted to less industrialized countries with lower wages and mostly with lower safety standards for working places. Contact allergy to teak is mostly recorded for carpenters in furniture factories and workers in veneer plants.

DISCUSSION AND CONCLUSION

As was already stated, teak wood especially the dust, is one of the most common sensitizers in the wood industry. Looking at the high a amounts of the wood utilized in industrialized as well as in less industrialized countries, the reported cases of allergic outbreak to this wood are very few. Because of this phenomenon some teak traders even denied that teak can cause allergy. According to them, mentioning teak allergy is detrimental to teak business. However, ignoring the phenomenon may bring more harm. It is better to be realistic and acknowledge these less desirable properties for taking measures to avoid or minimize their detrimental effects.

The comprehensive report of Krogh (1962) has to be evaluated taking into consideration the situation in the 1950. He stated that the furniture factory was continuously expanded and new machines were installed. However, the capacity of the exhaust ventilation facilities were not increased. Suitable protection clothing were not used by the workers. The available shower bath facilities were too few to permit the workers to take a bath within a reasonable time. It was recommended to install sufficient exhaust ventilators and showers. The workers should be compelled to use protection clothes and the showers after working.

It was already stated that according to Hausen (2003), no cases of teak allergy were reported in the last 15 years, although the utilization of teakwood was still high. In veneer plants where teak logs are steamed before slicing, it is recommended to have the facility to test the various logs before steaming. The test can be accomplished with the Craven test on the cross cut of the log. The surface is cleaned and a fresh plane is made with a sharp chisel. The Craven solution is then sprayed or streaked on this fresh cut. Alternatively the wood cutting is ground with a common coffee grinder and extracted with ethanol and tested. Since the compound occurs mostly near the border with sapwood, only 5 to 10 cm of the outer part needs to be examined. A blue violet color shows the occurrence of deoxylapachol. As was already stated specimens with high deoxylapachol content may show yellow crystals on the surface after stapling and drying of the veneer. The quinone is volatile with water vapors. This phenomenon may explain the toxic properties of moistened teakwood dust, whereas air dried ones do not show such properties, as reported by Krogh (1962). Logs and veneers which contain deoxylapachol should be treated very cautiously.

To select mother trees for vegetative propagation, drilled increment core samples of living trees should be collected. There are equipments on the market which enable to make drilled increment cores with a rather high diameter (around 2 cm) and driven with a motor. The cores are cut into pieces of 1-2 cm, ground and extracted. Extracts are then analyzed by chromatographic methods to determine the amount of tectoquinone, deoxylapachol and lapachol. If necessary the amount of total wood extractives can also be determined. Total extractive content may give an indication on the durability and dimension stability.

The occurrence of deoxylapachol and its allergenic properties need not to be dramatized. It is, however, better to be informed on its occurrence, their influences and potential hazards in order to be able to take the required measures to minimize or to avoid its allergic properties.

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Quality Timber Products of Teak from Sustainable Forest Management pp 285-288

Timber Value of Teak Grown in Homesteads : Some Observations from Kerala State, India

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ABSTRACT

Teak (*Tectona grandis* L.f.) is one of the major timber species of home garden forestry in southern India, particularly in Kerala. However, with a general notion that teak from homesteads is inferior to plantation teak in timber quality, the former fetches lower price in the market. This paper critically appraises the timber value of home garden teak and plantation grown teak from Kerala. Home garden teak (35 years) from the 'wet' site with an average of DBH of 39.6 cm has the potential of producing the log diameter similar to that of site quality I (SQ1) prescribed in All India Yield Table. In contrast, teak from 'dry' site had an average DBH of 24 cm which qualifies only for SQ II / III compared to the average DBH of 31 cm from the same aged forest plantation in Nilambur. Regarding wood figure, teak from the homesteads of dry zone with golden brown colour and black streaks was almost similar to that of forest plantations of Nilambur, while the timber of wet zone was slightly paler in colour. This was also reflected in lower extractive content (12%) of wet zone timber as compared to dry zone (16%) and plantation grown timber (13%). Dimensional stability, as evaluated by the shrinkage values was comparable in the dry and wet site samples, while it was slightly higher in plantation grown timber. Pending assessment of durability and strength properties, the present findings indicate that timber quality of home garden teak from dry site is not lower than that from forest plantations although with similar logs, sawn timber output is lower. Though yield is higher from wet site homesteads, timber colour with low extractive content appears to be a price-limiting factor.

Keywords: Wood colour, grain, dimension stability, product yield, quality, home garden forestry, timber price.

INTRODUCTION

Teak (*Tectona grandis* L.f.) is one of the major timber species of home garden forestry in southern India, particularly Kerala. In view of its relatively fast growth in the initial few years and good economic returns, farmers prefer to plant teak in their home gardens in order to support their livelihood and to meet a variety of rural timber requirements. Once the tree is planted there is little proactive management practices like fertilizer application, thinning, pruning or weeding except for other agricultural crops. They fell the tree when it attains a minimum harvestable size at about 30-35 years. There is general notion that teak from homesteads is inferior in qualities such as wood figure (colour, grain, texture), strength, durability and dimensional stability and fetches much lower price in timber market than from forest plantation. The present study critically appraises the timber value of home garden teak at the age of 35 years from both wet and dry localities as compared to the same aged forest plantation teak from Nilambur, Kerala.

MATERIALS AND METHODS

Five defect free home garden teak trees (35 years) were collected from 'Wet' and 'Dry' localities of Kerala. Five dominant teak trees from a typical forest plantation were also collected from Nilambur, Kerala for comparative study. The data on three site conditions and tree characteristics are given in Table 1. Log characterization was also done in the field in the above localities as per the Bureau of Indian Standard IS: 4895(1968). A total of 89 logs were graded covering both wet and dry localities. Teak logs were classified according to the prevalent practice that exists in the Sate of Kerala depending upon the utilisation. Sample trees collected were processed in the sawmill and 5 cm cross sectional discs were drawn from breast height level (1.37 m) to study various physical properties. The properties investigated were log size, visual defects, wood figure, density and shrinkage.

RESULTS

The results of the log grading suggest that visual defects such as bends and knots qualify the timber only to grade II or III as per Indian standard. Grade I timber was not available from either of the two homesteads (Table 2). Pole sized logs were more frequent in dry sight (Table 3). The 35-year old home garden teak from wet site produces timber of average DBH 39.6 cm where as the dry locality produces small dimensional timber of average DBH 24 cm as against the average DBH of 31 cm from the same aged forest plantation (Table 4). Pole sized logs were more frequent in dry site (Table 3).

Wood colour was paler from wet site sample. Golden brown with decorative black streaks of the dry locality sample was almost similar to the plantation grown teak from Nilambur excepting lighter black streaks in the latter (Fig. 1).

Table 1. Environmental conditions of teak trees sampled from 'wet' and 'dry' localities compared to forest plantation at Nilambur, Kerala

Factor	Wet (Muvattupuzha, Ernakulam)	Dry (Nemmara, Palghat)	Forest plantation (Karulai, Nilambur)
Elevation (m.a.s.l)	20	40	60
North latitude	9° 59′	10° 35′	11° 15′
East longitude	76° 34′	76° 35′	76° 13′
Soil type	Loamy sand	Sandy loam	Silt loam
Annual rainfall – range mm	2500 - 3500	1500 – 2300	2500 – 3000
Temperature range °C	17 – 34	26 – 37	17 – 37
Tree age (years)	35	35	35

Table 2. Classification of teak timber from homesteads based on grading

Teak timber class	Girth limits (cm)	Length (m)	Number of logs in each Grade*			Number of logs graded in the homesteads	
			A	B	C	Wet	Dry
1	>150	>3	-	-	-	-	-
II	>100 – 149	>3	3	3	2	5	3
III	>76-99	>3	7	8	4	4	15
IV	60-75	>3	6	10	7	3	20
Total			**16**	**21**	**13**	**12**	**38**

Table 3. Classification of teak poles from homesteads after grading

Pole class	Girth limits (cm)	Length (m)				No. of poles in each Grade				No. of poles graded in the homesteads	
		A	B	C	D	A	B	C	D	Wet	Dry
1	(65-75)	>12	9-12	6-9	3-6	-	-	1	2	-	3
II	(53-64)	>12	9-12	6-9	3-6	1	1	3	2	-	7
III	(41-52)			>6		-	-	5	-	-	5
IV	(28-40)				>6	-	-	-	12	-	12
V	15-27)				<6	-	-	-	11	5	6
	Total	**39**									

**Grade A - Cumulative value of permissible visual defects up to 2.5 units; Grade B - Cumulative value of permissible visual defects up to 5 units Grade C - Cumulative value of permissible visual defects 7.5 units and above*

Table 4. Physical properties of 35-year-old home garden teak in comparison with forest plantation indicating the test of significance for differences among the three sites of tree sampling

Parameters	Wet†			Dry†			Plantation†		
	Mean	*SD*	CV%	Mean	*SD*	*CV%*	Mean	*SD*	*CV%*
Diameter at breast height (DBH) cm	39.6 **	3.84	9.70	24.0 **	2.08	8.60	31.0 **	0.92	2.90
Wood basic density Kg/m^3	600 ns	0.50	8.20	645 ns	0.06	8.50	597 ns	0.06	8.50
Volumetric shrinkage %	9.0 ns	1.23	13.40	8.3 ns	2.20	26.40	11.0 *	2.10	18.00
Heartwood total extractive content % (ethanol-benzene)	12.0 ns	2.23	17.90	16.0 *	1.38	8.60	13.0 ns	2.80	21.00

†*n = 5;** significant at 1% level;* significant at 5% level; ns non-significant*

Tension wood was prevalent in the homestead teak where as it is totally absent in plantation teak. Wood density did not show any significant difference between the homesteads and plantation specimen (Table 2). Volumetric shrinkage also shows a similar pattern, however maximum shrinkage was noticed in the plantation teak.

DISCUSSION

The results indicate that 35-year-old home garden teak in the wet site with an average DBH of 39.6 cm has the potential of producing the log diameter similar to that of Site Quality I (SQ I) prescribed in the All India yield Table (FRI, 1970). In contrast, teak from dry site, where the rainfall is less, produces small dimensional timber of average DBH 24 cm, which qualifies only to SQ II/III with major share of the logs falling to pole classes. Out of the 89 logs graded, only 8 logs came under Grade II timber, the rest falling under Grade III to IV mostly due to visual defects such as bend and sound knots. The timber from dry site had more numerous knots than wet site sample. Grade I timber was not available from either of the two localities. Because farmers manage teak in homesteads without due consideration to specific end-product or market requirements the home garden teak is often of sub-standard in quality. This was reflected in poor log form with bends and numerous knots without standard silvicultural practices. Tension wood was also prevalent in teak from both wet and dry sites which was totally absent in silviculturally managed plantation teak

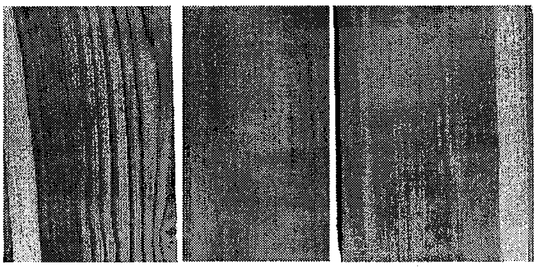

Figure 1. Wood colour variation in home garden teak from Dry (left) and Wet (right) localities in contrast to forest plantation (middle).

Regarding wood figure (colour, grain, texture), the wet zone sample was paler in colour. The golden brown colour with decorative black streaks of the dry site sample was almost similar to plantation teak of Nilambur (Fig. 1). This was reflected in lower total extractive content (12%) of wet site sample compared to 16% in dry site and 13% of plantation grown teak as determined through soxhlet extraction method (ASTM, 1981) using ethanol- benzene (1:2) (Table 4). Dimensional stability as evaluated by shrinkage values was comparable in dry and wet localities. Wood density values were also not significantly different. This suggests that physical properties such as shrinkage and wood density were not of practical value in timber utilisation.

CONCLUSION

Teak grown in wet localities produce timbers of average DBH of 39.6 cm at the age of 35 years which is comparable to the SQ I prescribed in All India Yield

Table. This resulted in higher sawn timber output. The dry site timber produces log size of average DBH of 24.0 cm that qualifies only for SQ II/III and major share of logs falls in pole classes. Lack of appropriate silvicultural practices in home-garden forestry, with the exception of fertilization/irrigation, causes more frequent log bends and knots although the extent of these defects was less in wet site. Heartwood colour was paler in wet site sample, while the golden yellow or brown colour with attractive black streaks make dry zone timber more attractive for making speciality products and decorative veneers in spite of low sawn timber output. The relatively low timber price of home garden teak is possibly due to paler wood colour and more defective log characteristics as compared to good quality plantation teak.

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Effects of Growth Rate on Surface Growth Stress and Residual Stress in Some Tropical Timber Species

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ABSTRACT

In this study, we discuss the effect of growth rate on the magnitude of growth stress generated on the xylem surface and the pattern of the residual stress distribution superimposed in a living trunk of planted tropical timber species. The surface growth stress became constant regardless of the growth rate in the even-aged plantation of each species. The residual stress distributions in two *Acacia mangium* trunks with same diameters but quite different ages were almost identical each other. Magnitudes of the residual stress distributions of *Paraserianthes falcataria* and *Tectona grandis* trunks with same ages but different diameters were essentially identical in each species. These findings suggest that the rate of thickening growth affects neither the magnitudes of the surface growth stress nor the residual stress in the living trunk. Girdling treatment for 1-year-duration was effective for diminishing the residual stress and the moisture content inside a living trunk of a 38-year-old teak

Keywords: Growth stress, residual stress, tropical timber, girdling treatment, *Acacia* spp. *Paraserianthes falcataria*.

INTRODUCTION

Extensive afforestation aims at both maintenance of the global environment and sustainable supply of forest products to the world market. Recently, plantation programmes of various timber species became popular in many tropical countries. To step up these efforts, it is necessary to increase the economical value of the forest products as buildings materials or furniture by adopting best silvicultural techniques for the planted species. As part of the program, we have investigated various xylem qualities from the plantations of *Acacia* species in West Java and North Borneo, and *Paraserianthes falcataria* and *Tectona grandis* in West Java. Those contain surface and residual growth stresses in living trunks, which often cause processing defects, e.g. heart checking, end splitting, lumber crooking, etc. during harvesting and lumbering the logs. Some researchers have conceived that the tree growth rate has something effects on those xylem qualities, however, very few have measured those xylem qualities in relation to the tree growth rate (Bhat *et al.*, 2000, Wahyudi *et al.*, 1999; 2000), although a number of papers have been dealing with the plantations from the viewpoint of forest management aspects. In this study, we focused attention on the effect of the rate of thickening growth upon the magnitudes of the growth stress on the xylem surface and the residual stress superimposed in the living trunks or logs. Especially for the problem of the residual stress, we discuss the possibility of visco-elastic relaxation in a living trunk. Moreover, we consider the feasibility of the reduction of the residual stress inside a standing trunk of teak (*Tectona grandis)* by giving the girdling treatment for 1-year duration.

MATERIALS AND METHODS

Sampled trees

Trees from 11-year-old man-made forest of three

Acacia species (*A. mangium, A. auriculiformis, Hybrid A.*), planted in Sabah, Borneo, Malaysia, and from 3-, 4-, 5- and 6-year-old plantations of *Paraserianthes falcataria*, planted in West Java, Indonesia as well as from 38- and 39-year-old plantations of *Tectona grandis*, planted in West Java, Indonesia, were used for the present investigation. A total of 40 trees for each of *Acacia* species, 21 trees for *P. falcataria*, and 10 trees for *T. grandis* with various diameters were selected, and the surface growth stresses were obtained as the longitudinal released strains of the growth stresses on the xylem surface in standing trees. Thereafter, they were harvested, and some trees were used for determining the radial distributions of the longitudinal released strains of the residual stresses across the diameters in living logs.

One tree among two 39-year-old *T. grandis* had been given the girdling treatment at the knee height for 1-year duration. Furthermore, from two even-aged man-made forests of *A. mangium* in West Java, Indonesia, two trees with the same diameters but different ages, 4- and 10-year-old, were cut and used for determining the radial distributions of the released strains across the diameters in living tree trunks.

MEASUREMENT OF THE RELEASED STRAINS

Surface stress

Around the periphery at breast height in each living trunk, several measuring points were prepared on the outermost surface of the secondary xylem, and foil-typed strain-gauges of 8 mm length were pasted on each point by using a quick-dry glue. The surface stress distribution was released by slashing xylem surface around strain-gauges with a small saw and a kerf. Then, longitudinal released strain was detected by a commercial strain meter (Okuyama *et al.*, 1981). Thereafter, detected values were averaged in each tree.

Residual stress

Radial surface across the diameter was manually visualized in the middle of a 2 m living stem. The strain-gauges were pasted on the exposed xylem along the radial direction at 1.5 mm intervals. Thereafter, longitudinal released strains were detected by the commercial strain meter (Wahyudi *et al.*, 1999).

RESULTS AND DISCUSSION

Surface growth stress

Figure 1 shows the relationship between the longitudinal released strain of the surface growth stress (averaged value along periphery) and the breast height diameter in each tree for each species. Negative value asserts that tensile growth stress was generated at that point. In either species, the surface growth stresses became almost constant regardless of the diameters and tree ages. This coincides with our previous studies using various species (Wahudi *et al.*, 1999, 2000, 2001). ANOVA reveals that there are significant differences in the averages of the released strains among three *Acacia* species. Especially in *A. auriculiformis*, some trees have large tensile growth stresses of which released strains exceed over -0.10 %. These are attributable to the formation of the tension wood fiber in crooked stems. In species generating a high tensile growth stress, processing defects, such as heart splits and lumber crooking at sawing are anaticipated (Okuyama and Sasaki, 1979). It is essential to adopt the best

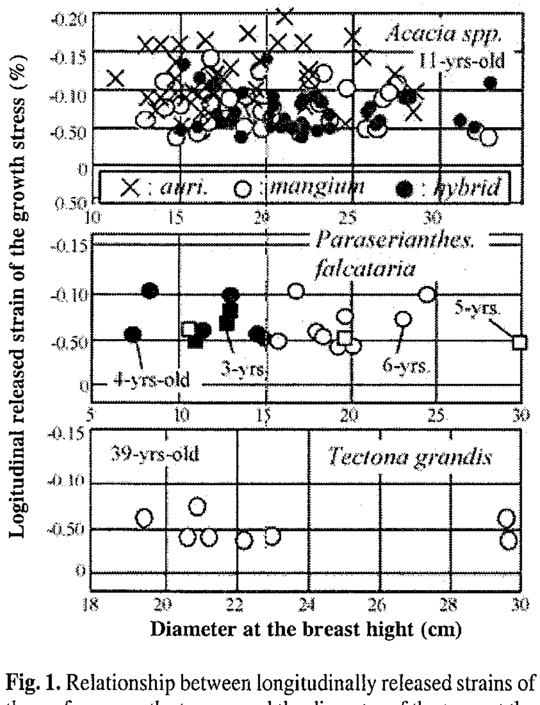

Fig. 1. Relationship between longitudinally released strains of the surface growth stresses and the diameter of the trees at the breast height.

silvicultural technique so as to control the tension wood formation in tropical man-made forests in order to provide raw materials for buildings structures and furniture.

Residual growth stress

Figure 2 shows the radial distributions of the longitudinal released strains of the residual stresses across the diameters inside the trunks. Magnitudes and patterns of the residual stress distributions of *P. falcataria* and *T. grandis* logs with the same ages but different diameters were essentially identical in each species. These suggest that the rate of thickening growth affects neither the magnitudes of the surface growth stress nor the residual stress in the living trunk. However, stress gradient from the pith to the bark becomes steeper in a slow-growing tree than in a fast-growing one. Thus, it is expected that processing defects due to residual stress gradient would be less severe in a fast-growing tree than in a slower-growing one.

The residual stress distributions in two *Acacia mangium* trunks with same diameters but different ages were measured for detecting the effect of the growth rate. The results (Fig.2 c) showed that they were almost identical each other, which means that the growth rate does not affect the magnitudes of the residual stress inside a living trunk. As well known, the wood is a visco-elastic material that shows stress relaxation under the induction of the load. Then, it is expected that the residual stress is easily diminished in a slow-growing tree than the fast-growing one with same diameter. However, obvious difference could not be seen in the present experiment. By the way, we simulated the superimposing process of the residual stress in a log on the basis of the visco-elastic analysis. We assumed a mechanism of the simple visco-elastic recovery, and calculated the effect of the growth rate on the

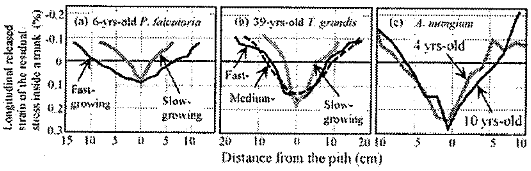

Fig. 2. Longitudinally released strains of the residual stress across the diameter.

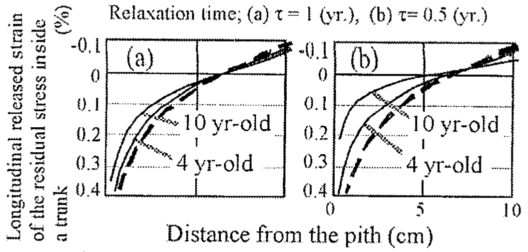

Fig. 3. Simulation of the visco-elastic relaxation of the residual stresses in logs for effect of the thickening growth rate. Broken line stands for the solution from the complete elastic model.

relaxation of the superimposed residual stress in a log. The simulation concludes that the visco-elastic relaxation of the residual stress must be prominent in a slow-growing tree (see Figure 3). However, experiment denied it. This implies that the relaxation time of the living xylem becomes considerably longer than in an isolated sample. Similar phenomenon was reported by Chardin *et al.* (1986). However, its reason is still unexplained. In either case, the growth rate affects neither the surface growth stress nor the residual stress so far as we investigated. This encourages us to shorten the cutting cycle of the plantation without increasing the processing defects due to growth stress provided that the tension wood formation can be possibly avoided.

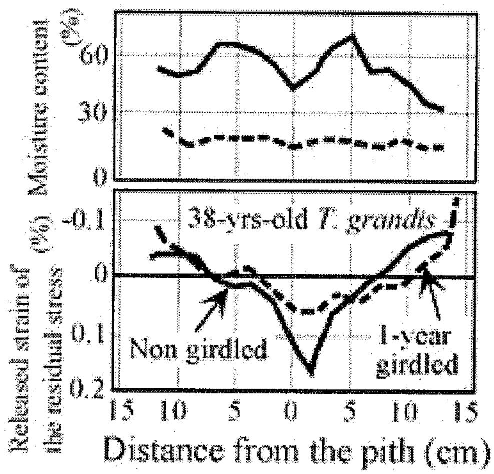

Fig. 4. Effect of the girdling treatment on the reductions of the moisture content and the residual stress inside a living tree of 39-year-old plantation teak.

Effect of girdling treatment

In teak plantation in Java, Indonesia, the trees are killed by slashing the sapwood circumferentially for 1 or 2 years before harvesting. The girdling treatment is one of the traditional operations in Indonesian teak forestry which aims to reduce the cost of transportation and drying of harvested logs. Our preliminary investigation showed that the residual stress distribution inside the girdled tree was more or less relaxed especially near the pith, and that the moisture content distribution in the girdled trunk became clearly smaller than in the untreated trunk (see Fig. 4). It is tentatively concluded that the girdling treatment is effective for diminishing the residual stress and the moisture content of living teak trees.

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Impact of Biodeterioration on Timber Quality of Teak in Karnataka

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ABSTRACT

Teak, *Tectona grandis* (Linn.) is the most valuable tree grown in natural forests and plantations of Karnataka. Value of the timber of teak is highly reduced due to biodeterioration by the combined activity of the teak heartwood borer, *Alcterogystia cadambae* (Lepidoptera; Cossidae), wood decaying microbes and termites. A survey was conducted in the teak growing forests and plantations of 5 Divisions of North Canara Circle during 2000- 2002 to assess the infestation level of wood boring insects and the nature of damage. The surveys revealed that in the infested areas (Haliyal and Yellapur Divisions) 15.85 % of trees above 20 years of age showed symptoms of attack by *A.cadambae* in varying degrees. Studies were conducted in 9 timber depots located in 4 Divisions of North Canara Circle to estimate the loss of timber biomass due to the biodeterioration. Damage assessment of the logs in the depots showed that an average of 11.7% of logs were damaged in varying degrees, either with hollowness of heartwood or with borer holes or both. On an average, 2.17% of the volume/ weight of the timber is lost due to the hollowness of teak timber. In the depots in Haliyal and Yellapur Divisions, 36.13% of the damaged logs were with bore hole complexes. Due to the damaging effects of biodeterioration, the value of teak timber is often reduced to bare minimum.

Keywords: Teak, biodeterioration, timber, plantation, natural forests, wood biomass, microbes, termites, *Alcterogystia cadambae*, cossids.

INTRODUCTION

Teak, *Tectona grandis* Linn. F., the highly valuable timber species is being successfully planted on a large scale in India. Though more than 250 insects are known to be associated with this tree, only two species of defoliators, *Paliga machoeralis* and *Hyblaea puera* cause major damage to the trees. But recently the heartwood borer, *Alcterogystia (Cossus) cadambae* has attained the status of a major pest in teak plantations in heavy rainfall tracts of Karnataka, Kerala and also Tamil Nadu. *A. cadambae* is a cossid (Order: Lepidoptera) popularly known as carpenter worm, whose larvae live for 8-9 months, tunnels from periphery and bore into the heartwood of the tree rendering the wood unfit for any purpose. Mathew (1990) conducted studies on the occurrence and distribution of this insect in Kerala. The incidence of the pest during 1988-89 was 15-20% in Barchi sub Division in Karnataka. The pest problem was cited as a " threat to Forest Gold" (Lingappa *et al.*, 1991). Ever since the report, the population is observed in growing intensities and a recent survey in the affected areas showed that the attack has spread to areas like Dandeli, Haliyal and Yellapur in Karnataka. Santhosh and Prasad Kumar (2002) studied the infestation status of the borer in clonal seed orchards of Karnataka.

The attack of decay fungi and termites leaves very big holes in the heartwood of the tree. Combined activity of *A. cadambae*, termites and fungi reduce the biomass, quality, strength and aesthetic appeal of the timber, rendering the timber unfit for any purpose except as fire wood. The value of much of the teak timber reaching the depots is reduced due to the irregular holes, tunnels and hollowness in the heartwood. An account of the survey details on the prevalence of teak borer in Karnataka and an estimate of heartwood loss and damage of timber due to borer holes are presented in this paper.

MATERIALS AND METHODS

Surveys were conducted as per Proportionate Population Method (PPM) in the teak plantations and teak forests distributed in the five Divisions, Haliyal, Yellapur, Honnawar, Karwar and Sirsi of the North Canara Circle to study the incidence and distribution of borer affected teak trees. Observations were taken on the presence of bore holes and complexes on the trees. The plantations of varying ages and silvicultural practices were observed.

Nine timber depots located in Haliyal (Bhagavathi, Kulgi, Jabalpet and Dandeli), Yellapur (Kirwathi), Honnawar (Idagungi, Kabbinahakkalu) and Karwar (Hattigeri and Kadra) Divisions of North Canara Circle were surveyed to assess the loss of teak timber due to the biodeterioration by various agencies. The timber logs were inspected and observations were taken on the length and diameter of each log. The depth and diameter of the hollowness in the timber are also measured. The surface of the logs was scanned to note the number of bore hole complexes, number of bore holes/complex, diameter and depth of the bore holes etc. Using the formula, 'Àr^{2}h' volume of the log, volume of the hollowness and the percentage of volume loss were calculated. The frequency distribution of the logs with varying volume loss and number of bore hole/complex/log was calculated.

RESULTS AND DISCUSSION

The survey conducted in the 5 Divisions of the North Canara Circle revealed that only 2 Divisions, Yellapur and Haliyal had the prevalence of heart wood borer, *A. cadambae* (Table-1). The borer incidence was very much apparent with the trees showing holes and hole complexes on the trunk of the tree. The damage syndrome of hole complexes is termed as "Gandumale" in local Kannada language. A total of 102 plantations were surveyed and 625 among 3943 trees in the 2 infested areas showed the symptoms of borer attack. The infested trees were all above 20 years old. The incidence was 16.31%and 15.67% (average-15.85) respectively in Yellapur and Haliyal Divisions.

The details of the timber depot survey data are presented in Table 2. Damage assessment of the logs in the depots showed that an average of 11.7% of logs were damaged in varying degrees, either with hollowness of heartwood or with borer holes or with both. The percentage of damaged logs varied from one depot to another. The number of logs in each depot depended on different factors like log arrival, log disposal and the sale transactions. During our survey, the highest % of damaged logs was in Dandeli depot (22.09%) and lowest in Bagavathi (4.57%).

The volume loss was calculated based on the hollowness in the logs. Though some of the logs were very badly riddled by the bore holes of the teak heartwood borer, *A. cadambae*, the exact volume loss due to the borer alone could not be properly estimated. Many of the logs with hollowness in the heartwood were actually free from the teak borer damage. Some of them exhibited both teak borer damage holes as well as hollowness. This indicates that the hollowness caused due to fungal and termite inhabitation in the teak log is irrespective of the damage by *A.cadambae*. The average volume loss in different depots varied from 0.55 – 11.48 %. On an

Table 1. Survey details on the incidence of teak heartwood borer, *A. cadambae* in North Canara Circle

Name of Division	Total number of teak plantations	Number of plantations surveyed	Total number of trees observed	Number of trees with borer damage	% of borer infested teak trees
Yellapur	212	12	1079	176	16.31
Haliyal	571	30	2864	449	15.67
Sirsi	182	7	1092	-	-
Honnawar	603	42	1110	-	-
Karwar	275	11	684	-	-

Table 2. Details of survey in the teak timber depots in North Canara Circle

Name of the Division	Name of the depot	Total No. of logs	No. of hollowed logs	% of hollowed logs	Average volume loss(%)	Volume loss Range (%)	No. of logs with borer damage	% of damaged logs with borer holes
Haliyal								
1	Bhagavathi	721	33	4.57	0.98	0.0004 – 27.21	29	69.04
2	Kulgi	1029	74	7.19	0.637	0.001 – 2.31	17	22.66
3	Jagalpet	161	19	11.80	11.48	0.11 – 40.81	4	19.04
4	Dandeli	715	158	22.09	0.94	0.11 – 7.12	34	19.88
Yellapur								
1	Kirwathi	308	62	20.12	0.84	0.0002 – 7.56	39	50.00
Honnavar								
12	Idaganji	851	85	9.98	2.38	0.02 – 47.13	Nil	Nil
	Kabbinahakkalu	50	6	12.0	0.55	0.01 – 4.26	-	-
Karwar								
12	Kadra	1758	108	6.14	0.72	0.002 – 5.74	-	-
	Hathygeri	880	105	11.93	1.008	0.02 – 27.51	-	-

Table 3. Frequency distribution of teak timber showing percentage of volume loss due to biodeterioration

Sl. No	% of Volume loss	No. of logs
1	0 – 5	665
2	5.1 - 10	25
3	10.1 – 15	8
4	15.1 – 20	5
5	20.1 – 25	2
6	25.1 - 30	5
7	> 30. 1	3

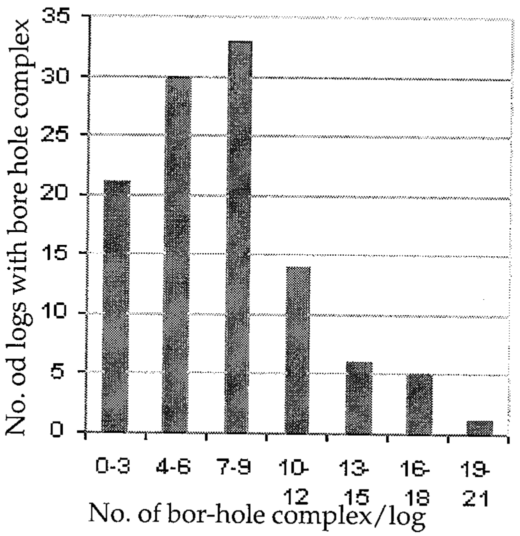

Figure 1. Frequency distribution of teak logs with varying number of bore hole Complex

average, 2.17% of the volume/ weight of the timber is lost due to the hollowness of teak timber. The variation of volume loss in individual logs and depots varied widely. The maximum loss on a log was 47.13, 40.81, 27.51, 27.21, 7.56, 7.12, 5.74, 4.26 and 2.31 percentage in the depots, Idugungi, Jagalpet, Hattygeri, Bagavathi, Kirwathi, Dandeli, Kadra, Kabbinahakkalu and Kulgi respectively. The frequency distribution of logs depending on the percentage of volume loss is given in Table 3. The highest number of logs (665) were with volume loss below 5 percentage.

The number of logs with borer damage alone (holes and hole complexes on timber surface) varied from depot to depot. In the depots of Honnawar and Karwar Divisions, the *A.cadambae* damaged logs were not available. This indicates that these two Divisions are free of the borer incidence. This observation is in corroboration with the plantation survey data, which shows that these Divisions are free of borer attack. The highest number of logs with *A.cadambae* damage was in Kirwathi depot. Frequency distribution of teak logs with varying number of bore hole complex is given in Fig. 1. The highest numbers of logs were with 7 – 9 complexes. The number of holes per complex varied widely. In some cases number exceeded 20. The mean percentage of damaged logs with bore holes was 36.13.

Information was collected on the value of the good and damaged teak timber. The ones, which were damaged, were auctioned by the forest department and the prices fetched were very low. In some cases they were sold for firewood prices. The study revealed that biodeterioration of wood in the plantations is a serious menace in Karnataka, leading to the reduction of quantity and quality of teak timber produced.

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Heartwood and Natural Decay Resistance in Plantation Grown Teak (*Tectona grandis* L.f) from Togo, West Africa

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ABSTRACT

Natural durability, which represents the most determining property of teakwood quality, was evaluated using four fungi, of which two were from tropical zones and two from temperate zones. The tests carried out on 1200 samples showed that Togolese teak was very resistant to fungal attack. More than 90% of the samples were classified as highly durable or durable. Assessment of natural durability with regard to termite attack showed that plantation teak has greater variability, as compared to that from natural forests.

Keywords: Natural durability, pathogen, termite.

INTRODUCTION

Teak (*Tectona grandis* L.f) is a tropical hardwood highly prized for its superior mechanical and physical properties, as well as aesthetic appearance (Kjaer *et al.*, 1999; Sanwo, 1987;1990). Teak can be used for both interior and exterior purposes, as the heartwood is naturally durable and resistant to pathogens. The necessity over the last few years to reduce toxic preservatives, calls for using those woods which are naturally durable. Therefore, selection programmes or management methods which can improve heartwood quantity or quality will be of utmost importance to developing countries.

Over 10,000 hectares of teak plantations exist in Togo (Behaghel, 1999), and were first established in the 1920s (Lamouroux, 1957). As these plantations were abandoned for a long time (Souvannavong, 1986), tree density is extremely high (1000-2000 trees ha^{-1}) and soil is not treated or fertilised. A severe silvicultural program of thinning and felling has now begun, but which is not sufficient to promote good tree growth. Teak wood originating from Togo is extensively used in the construction and carpentry industries and most of the timber from these plantations is exported to India, China and Japan. However, no studies exist to date, concerning the quality of Togolese teak wood, with regard either to its mechanical and physical properties, or to its durability. No information exists on variation in the proportion of heartwood and its quality in relation to geographic location of the stand or type of management. The aim of this study was therefore to determine the proportion of heartwood and the natural durability of teak wood of samples from plantations situated in different ecological zones in Togo.

MATERIALS AND METHODS

Site description

Trees (6-70-year-old) were selected for analysis from five ecological zones in Togo. Trees of different ages were chosen from different ecological zones of different types of climate, vegetation and soil to determine the age effects on certain characteristics. (Lamouroux, 1957) (Fig. 1). This zones are classified in to I -V depending on the flora present (Ern, 1979; Kokou 1998). The zones and sampling techniques were described by Kokutse *et al.* (2003).

Measurement of heartwood distribution

In order to measure heartwood distribution both within a tree and between trees growing in different environmental conditions, 80 trees were chosen at random from stands in the five ecological zones described above. In zones I, II and IV, material was limited, and only 10 trees per zone could be harvested. In zones III and V, where plantations were more frequent, 27 and 23 trees were felled in zone III and V respectively. After the trees were felled, height from the tree base to the base of the crown and total height were measured, along with the diameter at breast height (BH). Discs, 5 cm thick, were then sawn and removed at BH, and every 5 m hight level up to the base of the crown.

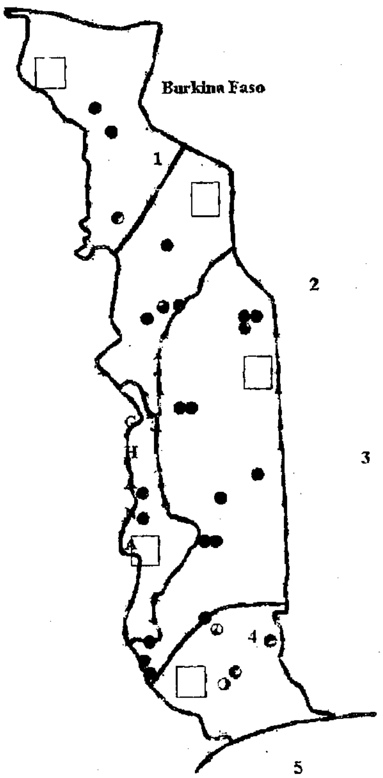

Fig. 1. The ecological zones of Togo representing the sample origin in Solid black circles.

Wood discs were sanded, and the distance between the pith and the heartwood boundary and the cambium along at least four radii were measured (Fig 2). Heartwood was easily identified on the freshly cut discs, due to its deep colour. If the discs were highly irregular, as was often the case in discs taken from BH, up to eight measurements were made. The cross-sectional area of heartwood was then calculated [Equations1, 2] (Pardé et Bouchon, 1988; Berthier *et al.*, 2001). Heartwood as a percentage of the total cross-sectional area of the discs was then determined (n = 400 discs).

An analysis of variance was carried out to determine the difference between percentage of heartwood as a function of tree age (using age classes presented in Table 1) and ecological zone.

$$S_t = \frac{\pi\left(\sum_{i=1}^{4} R_i^2\right)}{4} \qquad [1]$$

$$S_{HW} = \frac{\pi\left(\sum_{i=1}^{4} r_i^2\right)}{4} \qquad [2]$$

where: S_t = total cross-sectional area of the discs
S_{HW} = cross-sectional area of heartwood

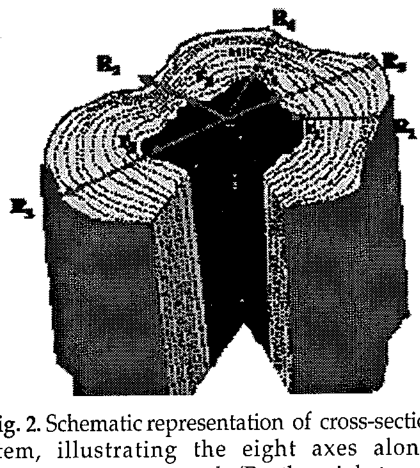

Fig. 2. Schematic representation of cross-section of teak stem, illustrating the eight axes along which measurements were made (R = the axis between the pith and the bark, r = the axis between the pith and the heartwood boundary).

Wood samples for decay resistance

Wood samples were taken from 31 trees originating from 23 plantations situated throughout Togo. Wood samples 50 x 15 x 20 mm (longitudinal, tangential and radial directions respectively), were cut from slices of heartwood removed at a height of 1.3 m in the tree stem. The exact location of each wood sample, according to its position in the stem, was recorded by measuring its cambial age and the distance from the pith. The cambial age corresponded to the number of annual growth rings between the central ring of the sample and the pith (Thibaut, 1997). A total of 1200 wood samples were used to evaluate natural durability.

Measurement of decay resistance

Natural durability tests were carried out using the European standard NF-EN 350-1 guidelines (1994). Before testing, 1200 fresh samples were dried at 20°C and 65% humidity for three months, until a moisture content of 12% for each sample was reached, and wood biomass was constant. Samples were then weighed (mass M_i) and sterilised with ionised radiation (European standard NF-EN 113, 1997) before testing. Four species of pathogenic fungi were used to test natural durability, two originating from tropical zones; *Pycnoporus sanguineus*, a white rot, and *Antrodia* sp., a brown rot, and two from temperate zones; *Gloephyllum trabeum*, a brown rot, and *Coriolus versicolor*, a white rot. Fungi were inoculated in malt agar medium in sterilised glass jars, until the fungal mycelia had completely covered the surface of the medium, a procedure which took approximately 15 days. Two blocks of wood, which had been removed side by side from the stem, were then placed in each jar. Samples were left in a growth chamber for 16 weeks, at a temperature of 22°C and 65% humidity. Also, 389 control wood samples were prepared and weighed in the same way as the treated samples, but were not subjected to fungal attack.

In order to compare the natural durability of teak with a reference, eight samples of Scots pine (*Pinus sylvestris*) and eight samples of beech (*Fagus sylvatica* L.) were cut to the same dimensions as the teak wood samples and subjected to exactly the same treatment. In order to verify that the fungi used are in the treatments are healthy, reference sample mass must be reduced by 20% at the end of the experiment (European standard NF-EN 350-1 guidelines, 1994).

After 16 weeks, teak and reference samples were removed from the glass jars and the mycelia present on the samples scraped off the wood surface. The treated and control samples were then dried at 103°C for 48 hours and weighed (mass M_f). The difference in mass, M_m, between M_i and M_f was then calculated using:

$$M_M = \frac{(M_S - M_f)}{M_S} \qquad [3]$$

Where:
M_S is the supposed dry mass of the sample before fungal attack, and is calculated using:

$$M_S = M \times M_i \qquad [4]$$

Where:
K = a coefficient allowing the estimation of theoretical dry mass of samples before fungal attack. K was calculated for the series of control wood samples identical to those used for testing, but which were not subjected to fungal attack.

$$K = \frac{M_a}{M_{12}} \qquad [5]$$

Where:
M_a = dry mass (g) of the control samples.
M_{12} = mass (g) of control samples dried to 12% moisture content.

In order to clasify the natural durability of wood, the percentage reduction in mass of a sample must be calculated. Depending on this mass loss, a durability score is given to the wood (Table 2).

Analysis of variance was used to determine the differences in fungal attack occurred between teak wood and the reference samples.

RESULTS

Heartwood distribution

The percentage of heartwood differed significantly in

Table 1. The proportion of heartwood in teak trees of different ages born in different cological zones.

	Zone I		Zone II		Zone III					Zone IV		Zone V		
Age (years)	13	70	44-48	67	12	24-25	39	41-46	57-59	16-18	43-45	11	29-32	45-50
Stand Density	1700	1300	2000	1000	2500	2300	2000	2100	2200	NA[2]	NA[2]	2000	1700	2000
Mean stand DBH (cm)	12.9±2.1	32.3±5.3	35.7±8.5	27.1±8.9	11.3±4.2	26.8±3.8	21.4±4.1	22.6±3.4	26.6±2.6	21.6±3.4	29.2±3.7	19.1±4.4	31.3±3.5	24.4±8.5
Height (m)	7.4±2.7	21.1±1.9	37±6.7	19.3±3.2	8.4±1.8	22.1±1.4	16.7±2.3	21.6±2.1	23.8±3.3	16±1.4	20.3±6.4	17.9±2.0	27.5±2.2	15.3±3.8
% Hw[1] at0.0 m	35.1±12.8	74.0±9.4	65.9±11.6	69.5±5.6	35.0±14.5	60.9±5.3	65.5±4.5	69.8±2.4	65.0±7.7	35.5±8.1	67.4±3.5	44.3±11.0	69.1±6.5	69.9±9.3
% Hw at1.3 m	26.1±12.6	72.3±8.5	67.3±1.1	69.6±2.2	36.7±14.0	63.7±1.7	62.0±3.0	69.3±2.3	63.5±6.7	31.1±9.8	66.1±4.4	42.1±13.4	65.7±6.6	65.6±17.0
% Hw at 5.0m	NA[2]	61.0±5.4	62.8±0.2	59.5±7.4	34.5±15.8	59.5±4.9	51.9±6.1	63.4±3.4	60.7±7.8	35.4±0.5	63.5±3.9	31.5±9.9	66.5±8.4	59.5±8.3
% Hwat base of crown	NA	64.3±7.0	43.8±3.0	54.8±4.6	26.4±17.3	60.3±5.1	45.5±6.5	59.4±2.5	50.9±9.1	28.9±8.4	54.6±6.1	20.6±10.6	51.3±8.8	52.3±14.0

[1]Hw = heartwood
[2]NA= data not available

Table 2. Clasification of natural durability of wood according to the percentage reduction in mass after fungal attack (European Standard NF-EN 350-1 guidelines , 1994).

Durability class	Description of durability	Reduction in mass x (%)
1	Very durable	x = 5
2	Durable	5 < x d•10
3	Moderately durable	10 < x d•20
4	Slightly durable	20 < x d•30
5	Not durable	x > 30

trees depending on the ecological zone in which they grew (Table 1). Heartwood proportion in old trees from zones III, IV and V was significantly different from that in zone I ($F_{4,66}$ = 5.05, P < 0.001). In zone I, 13-year-old trees possessed 26% heartwood at BH compared to 12-year-old trees from zone III, in which 37% heartwood was present. Eleven-year-old trees from zone V possessed 61% more heartwood than teaks from the same age from zone I (Table 1). Thirty-year-old trees from zone V possessed only 9% less heartwood than in 70-year-old trees from zone I. 64% heartwood was present in 25-year-old teaks from zone 3 compared to 72% in 70-year-old trees from zone I. The percentage of heartwood in trees from zone II did not differ significantly from trees in any other zone. At the age of 45 years in trees from zone II, almost three-quarters of the stem at BH is already transformed into heartwood.

Percentage of heartwood was significantly correlated to tree age in trees of ecological zones I, III, IV and V. However, only in young trees (DBH 10-20 cm), when all the trees were considered together regardless of zone, the percentage of heartwood and DBH were significantly correlated (y = 1.95x + 4.66, R^2 = 0.54, P <0.001) (Fig. 3) . Above a DBH of 21 cm, heartwood percentage increses slowly (y = 0.31x + 60, R^2 = 0.09, P = 0.04) . This correlation could not be carried out for trees in zone II, where all trees were over 40 years old.

Decay resistance

In the reference species, *Antrodia* sp. resulted in a 26.6 ± 2.7% loss of mass in Scots pine samples, which was significantly greater than the 22.0 ± 1.9% caused by *G. trabeum* ($F_{15,1}$=16,64, P < 0.001). In beech samples, there was no significant difference in loss of mass from attack between *P. sanguineus* (23.6%) and *C. versicolor* (23.8%). In all tests, the loss of mass was greater than that necessary in order to conform to the European standard guidelines used (NF-EN 350-1, 1994).

Significant differences were observed in the degree of pathogen attack on teak wood, depending on fungal species. *Antrodia sp.* and *C. versicolor* resulted in a greater loss of mass than *P. sanguineus* and *G. trabeum*. Up to 20% loss of mass was caused by *Antrodia sp.* and *C. versicolor*, and out of 357 teak wood samples subjected to the former pathogen, 73% were considered as very durable, 16% durable, 9% moderately durable and 2% slightly durable. Further, 93% of the 238 samples exposed to *C. versicolor* were highly durable, 6% were durable and 1% was slightly durable. Resistance to attack by *P. sanguineus* and *G. trabeum* was greater, with a mass of loss of 0-7% for the former and 0-3.5% for the latter. Out of 361 samples subjected to *P. sanguineus*, 359 were classed as highly durable and 0.5% i.e. two samples only, as durable. All 239 wood samples exposed to *G. trabeum* were classed as highly durable.

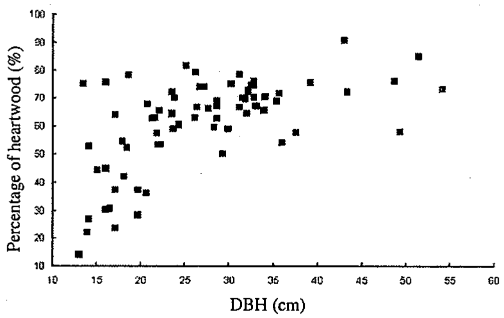

Fig. 3. Relationship between heartwood ratio and DBH of trees of various ages ($y = 40.12\ Ln(x)-71.44$, $R^2= 0.61$).

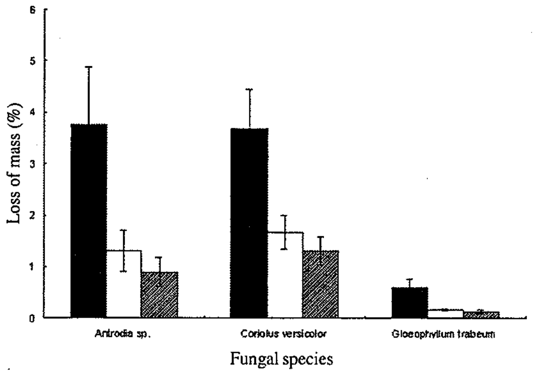

Fig. 4. The loss of mass due to fungal attack in teak heartwood in relation to the radial position of the sample within the tree (Solid black-inner, Empty- middle and Shaded bar-Outer heartwood).

The radial position of the sample in the tree was found to have an influence on the degree of attack with regards to *Antrodia* sp., *G. trabeum* and *C. versicolor*. Inner heartwood samples taken from near the pith were significantly less resistant to pathogen attack than intermediate and outer heartwood samples (Fig. 4). No significant differences were observed between trees of different ages, or from different ecological zones.

CONCLUSION

Results show that the percentage of heartwood in stems did not differ in trees aged 45-60 years. In a similar study, Bhat (2000) showed that no increse in heartwood volume occurred in trees aged 55-65 years. Results also support those of Okuyama *et al.* (2000) who found that the percentage of heartwood increased more rapidly with trunk diameter in young trees compared to trees over 30 -year-old. Therefore, heartwood volume seems to be more dependent on diameter than plantation age and it can be supposed that the proportion of heartwood in plantation teak does not increase significantly once the age of 45 years has been reached (Kokutse, 2002). This age may therefore be a suitable age to carry out a clear felling of the stand, if shorter rotation times were desired. However, further data on tree growth rate and heartwood volume depending on age, are needed in order to determine optimum rotation periods in Togo.

Out of the 1200 samples tested, only 32 samples were moderately durable (class 3) and 10 were slightly durable (class 4). Therefore resistance to pathogens of plantation teak can be regarded as comparable to that of teak originating from natural forest conditions (Kokutse, 2002). Results showed that the inner heartwood of teak was less resistant to pathogen attack than the intermediate or outer heartwood. Similar results have been found in teak (Simatupang and Yamamoto, 1999, Bhat and Florence, 2003), as well as other tropical species e.g. Dabéma (*Piptadeniastrum africanum*) (Deon *et al.*,1980) and temperate species e.g. Sweet chestnut (*Castanea sativa*) (Dumonceaud, 2001).

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Wood Anatomical Basis for the Production of Good Quality Teak Stumps

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ABSTRACT

Traditionally, teak plantations of Kerala are raised from stumps produced from one-year-old seedlings. Optimum nutrition and sowing practices in the nursery are found to yield better seedlings suited for making stumps. Hence, in this study, nutrient and spacing treatments were imposed in a factorial combination to study the differences in growth, biomass and anatomy of nursery seedlings. The experiment was laid in factorial CRD with three levels of nutrients, viz., i. Farmyard manure ($0.4 kg/m^2$; basal application) and neem cake ii. Farmyard manure ($0.4 kg/m^2$; basal application) and neem cake ($0.2 kg/m^2$; basal application) iii. No nutrient supplements. Four levels of sowing methods, namely i. roadcasting ii. Dibbling in lines (4 cm x 4 cm) iii. Dibbling in lines (8 cm x 8 cm) and iv. Dibbling in lines (12 cm x 12 cm). Root trainer seedlings were also compared with the above treatments. Biometrical observations were taken at fortnightly intervals for a period of 8 months. Wood anatomical properties of the seedlings were studied at monthly intervals.Treatments were devised in such a way that they do not deviate much from the currently used practices in Kerala. The nutrient and sowing treatments which yielded larger seedlings were selected. An attempt was made to explain growth differences of the seedlings from the wood anatomical perspective. It was found that, in general, seedlings raised in a combination of farmyard manure ($0.4 kg/m^2$; basal application) and broadcasting (@ 6 kg/bed) of seeds gave higher collar girth and height. These seedlings were found to have vessels, wider rings and higher fibre to vessel ratio. Overall performance of root trainer seedlings was not satisfactory in terms of growth and survival.

Keywords: Nutrients, spacing, farmyard manure, neem cake, dibbling, wood anatomy

INTRODUCTION

For raising quality plantations of teak (*Tectona grandis* L.f.), good planting materials are essential. Traditionally, the teak plantations of Kerala are raised from stumps, which are one year old seedlings that are cut to retain only a part of the stem and root in an ideal proportion. Optimum nutrition and sowing practices in the nursery are found to result in an early and better sized stock of seedlings suited for making stumps. Growth characteristics and anatomical properties of seedlings contribute greatly to the quality of the seedlings and stumps and thereby it will reduce the nursery time. Hence the present study was undertaken to evaluate the growth characteristics and wood formation of teak seedlings as affected by nutrient status of the nursery beds. The study also aims at finding out the best nutrient levels and sowing treatments required for the production of good quality stumps based on growth and anatomical properties of the seedlings with particular reference to wood formation.

MATERIALS AND METHODS

The study was conducted at College of Forestry, Vellanikkara, Thrissur (10°32′ N latitude, 76°16′E longitude; 22.25 m above sea level) in Kerala State, India. The experiment was laid out in factorial CRD with three levels of nutrients, viz. i. farm yard manure

(0.4 kg/m^2; basal application) and neem cake, ii. farm yard manure (0.4 kg/m^2; basal application) and neem cake (0.2 kg/m^2; basal application), iii. no nutrient supplements and four levels of sowing methods, namely broadcasting (@ 6 kg/bed), dibbling in lines (4 cm x 4 cm), dibbling in lines (8 cm x 8 cm) and dibbling in lines (12 cm x 12 cm). For this, uniform sized seeds of teak were sown after applying the nutrients mentioned before, as per the above mentioned sowing methods in nursery beds of size 1.2 m x 10 m and 15 cm height. The seeds were given the pre-treatment of alternate wetting and drying for a cycle of 5 days before sowing. Biometrical observations such as shoot length, collar girth and number of leaves were taken at fortnightly intervals for a period of 8 months. Seedlings were hand sectioned and stained using the procedure outlined by Johansen (1940). Anatomical properties of the seedlings such as ring width, vessel size, vessel frequency and tissue proportions were analysed using stage and ocular micrometer at monthly intervals. The results of the study are as follows.

RESULTS AND DISCUSSION

Biometrical observations

Treatments differed significantly at the end of 16th fortnight of growth in the nursery with respect to height, girth and collar girth. The treatment consisting of Cow dung @ 0.4 Kgm^{-2} and neem cake @ 0.2 Kgm^{-2} and seeds sown at a spacing of 12 cm x 12 cm (T12) produced best results in terms of shoot height and collar girth. Interestingly, broadcasting

Table 1. Details of nutrient and sowing treatments studied

Treatment	Code	Treatment details
1	N0S0	No nutrients applied ; seeds are broadcasted
2	N0S1	No nutrients ; seeds sown at a spacing of 4 x 4 cm
3	N0S2	No nutrients ; seeds sown at a spacing of 8 x 8 cm
4	N0S3	No nutrients ; seeds sown at a spacing of 12 x 12 cm
5	N1S0	Cow dung @ 0.4 Kgm^{-2} ; seeds are broadcasted
6	N1S1	Cow dung @ 0.4 Kgm^{-2} ; seeds sown at a spacing of 4 x 4 cm
7	N1S2	Cow dung @ 0.4 Kgm^{-2} ; seeds sown at a spacing of 8 x 8 cm
8	N1S3	Cow dung @ 0.4 Kgm^{-2} ; seeds sown at a spacing of 12 x 12 cm
9	N2S0	Cow dung @ 0.4 Kgm^{-2} and neem cake @ 0.2 Kgm^{-2}; seeds are broadcasted
10	N2S1	Cow dung @ 0.4 Kgm^{-2} and neem cake @ 0.2 Kgm^{-2}; seeds sown at a spacing of 4 x 4 cm
11	N2S2	Cow dung @ 0.4 Kgm^{-2} and neem cake @ 0.2 Kgm^{-2}; seeds sown at a spacing of 8 x 8 cm
12	N2S3	Cow dung @ 0.4 Kgm^{-2} and neem cake @ 0.2 Kgm^{-2}; seeds sown at a spacing of 12 x 12 cm

Table 2. Effect of nutrients and sowing treatments on ring width (μm) of teak seedlings

	Months							
Treatment	1	2	3	4	5	6	7	8
1	43.99	102.99	158.12	341.96	485.55	538.67	649.46	774.39
2	91.30	177.62	308.35	493.85	634.12	742.02	883.02	1129.10
3	127.82	282.20	444.05	539.50	674.79	824.19	1086.35	1453.10
4	124.50	325.60	411.68	576.85	768.58	882.08	1075.32	1325.90
5	81.34	169.09	324.53	445.77	531.20	654.04	851.51	948.69
6	66.40	169.09	346.55	462.31	550.29	664.83	951.12	1251.62
7	159.36	355.24	493.22	618.35	786.01	993.50	1324.97	1498.60
8	175.96	350.26	443.22	540.41	678.94	897.23	1082.63	1368.50
9	134.46	297.13	478.91	648.23	775.22	866.52	1004.64	1119.78
10	83.00	301.29	460.65	535.33	674.39	761.11	856.56	969.36
11	159.36	309.59	525.40	622.26	746.07	848.48	1138.34	1366.75
12	292.99	523.89	681.43	844.11	971.52	1207.05	1390.90	1537.60
F	13.63**	12.57**	16.43**	40.03**	30.3**	41.24**	22.98**	32.25**
SEM	4.513	6.197	6.08	5.305	6.439	8.53	10.956	9.861

** Significant at 1 % level

Table 3. Effect of nutrients and sowing treatments on vessel size (μm) of teak seedlings

Treatment	Months 1	2	3	4	5	6	7	8
1	44.57	45.31	46.20	41.62	44.34	42.40	48.71	50.30
2	38.70	42.07	43.91	40.01	43.62	45.87	43.03	48.46
3	39.18	36.19	46.69	41.59	41.08	39.84	41.83	42.08
4	31.71	40.50	41.17	38.51	36.74	38.40	39.84	40.84
5	30.38	33.50	38.51	39.94	42.54	47.89	36.27	43.74
6	26.56	32.54	39.01	41.09	48.22	42.51	40.77	41.50
7	30.96	37.68	48.64	47.39	48.80	48.80	32.95	36.01
8	32.81	40.95	40.34	46.37	45.59	47.48	44.82	47.70
9	29.18	32.87	34.90	38.18	46.15	30.40	42.33	48.14
10	33.31	36.35	46.65	43.27	55.28	52.95	45.65	48.56
11	29.62	29.75	41.50	47.31	39.34	38.18	41.02	45.24
12	27.19	35.61	28.97	46.65	45.40	48.97	53.78	52.79
F	6.488**	4.197**	5.088**	1.303NS	4.111**	8.105**	6.953**	5.250**
SEM	0.681	0.750	0.849	0.994	0.867	0.999	0.737	0.752

** Significant at 1 % level NS – Non-Significant

Table 4. Effect of nutrients and sowing treatments on vessel frequency (no. / mm^2) of teak seedlings

Treatment	Months 1	2	3	4	5	6	7	8
1	123.41	140.20	133.46	135.75	144.71	157.50	175.57	160.05
2	79.13	103.81	95.93	86.00	88.17	93.99	108.65	119.34
3	149.48	137.15	143.64	147.32	120.22	79.13	84.48	87.15
4	147.58	142.49	136.13	122.14	101.78	72.52	54.71	54.71
5	162.85	153.94	151.08	139.95	133.59	132.32	65.40	97.71
6	80.66	115.80	123.41	147.83	152.67	147.58	143.77	145.04
7	171.76	226.46	230.02	145.04	120.87	94.15	97.96	91.09
8	106.36	193.85	199.49	99.24	101.53	101.52	110.94	97.07
9	101.02	143.64	163.36	122.39	81.17	111.45	144.40	99.75
10	68.07	134.86	142.49	125.70	149.87	111.32	126.25	130.28
11	89.06	127.23	142.49	105.54	101.78	110.73	106.87	91.35
12	100.76	119.59	108.14	108.65	146.31	90.33	97.25	89.53
F	5.212**	13.825**	11.579**	10.752**	12.537**	5.32**	39.66**	13.899**
SEM	4.083	3.134	3.732	2.785	3.695	3.817	2.447	2.769

** Significant at 1 % level

with no application of nutrients gave the best results as far as collar girth is concerned. In this study, application of cow dung @ 0.4 Kgm^{-2} and neem cake @ 0.2 Kgm^{-2} and seeds sown at a spacing of 4 cm x 4 cm (T10) had poor growth as compared to the rest of the treatments.

Anatomical observations

Anatomical properties of seedlings such as ring width, vessel size, vessel frequency and tissue proportions varied significantly between themselves at most of the periods of observation. Details of the observations on the ring width, vessel size and vessel frequency are given in tables 2 to 4. Ring width was found to be the highest (1537.6 μ) in the treatment T7 (cow dung @ 0.4 Kgm^{-2} and seeds sown at a spacing of 8 cm x 8 cm and cow dung @ 0.4 Kgm^{-2} followed by the treatment T12 (neem cake @ 0.2 Kgm^{-2} and seeds sown at a spacing of 12 cm x 12 cm). Incidentally, the treatment T12 produced best results in terms of shoot height and collar girth. It is note worthy that in the above treatments, the seedlings were growing at a wider spacing and hence having more growing space. Wider rings indicate faster rate of growth and the seedlings are expected to have higher sizes of vessels. In the present study also, the treatment T12 produced the maximum vessel size of 52.79 μ. These results are in agreement with the study made by Rao and Dave (1981). Interestingly, the treatment T1 (No nutrients applied ; seeds were broadcasted) had the highest vessel frequency (160.05 / mm^2). The treatments T1 and T12 had higher fibre proportion compared to the rest of the treatments and comparatively lower parenchyma and ray percentages, indicating that bulk of the plant tissue of the seedlings grown in the better treatments are made up of xylem fibers which are more strength giving than having the function of conduction.

CONCLUSION

Wider spacing of seeds at the time of sowing resulted in larger sized seedlings suitable for the production of stumps. Nutrients were not having a profound influence on the growth of the seedlings compared to spacing. Ring width, vessel size and fibre proportion were found to be higher in the treatment that gave the best result viz. Cow dung @ 0.4 Kgm^{-2} and neem cake @ 0.2 Kgm^{-2} and seeds sown at a spacing of 12 cm x 12 cm and hence can be taken as the anatomical parameters for predicting the suitability of teak seedlings for superior quality stumps.

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Variation in Volume and Dimensions of Ray of Teak Grown in Bangladesh

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ABSTRACT

Six teak (*Tectona grandis L.*) trees were sampled from two districts in Bangladesh. Ray proportion and dimensions of ray on tangential section were measured. Ray proportion remained more or less constant from pith to bark. Number of ray/mm^2 was highest in the first ring and showed rapid decrease in the first few rings and then it reached constant. Dimensions of ray (ray area, ray height, ray width) were minimum in the earliest rings and then increased rapidly until a relatively constant value was reached at about ring 10. Ray proportion and dimensions of ray showed characteristic values from tree to tree and were not affected by growth rate. Hence it may be feasible to breed teak with a high ray proportion.

Keywords: *Tectona grandis* L., ray proportion, ray dimensions, ring width, distribution pattern of ray.

INTRODUCTION

The relationship between anatomical structure and wood properties has been a major subject of research for better sustainable management to produce high quality wood. Teak has a unique position for its straight bole, high quality timber and decorative design. Teak woods are composed of four major kinds of cells; fiber, vessel element, longitudinal parenchyma and ray parenchyma. All ray cells of ray of hard woods are of parenchyma type, but there are different types of ray cells. The difference is in cell shape or configuration. Rays have been ignored by wood technologists or forest geneticists. Taylor (1969a,b) indicated that specific gravity increased with proportion of ray tissue in hardwoods. In teak, Bhat *et al.* (2001) reported that ray percentages were 20.3% in fast grown trees and 18.7% in slow grown tress. About one-fifth of the total xylem of teak is composed of ray. It is obvious that variation in the volume of ray is quite important. In this research we measured the variation of ray volume and the dimensions of ray as a part of the research to investigate the influence of tissue proportion on wood density of teak. The distribution pattern of the ray area, ray height and ray width was also studied.

MATERIALS AND METHODS

Teak (*Tectona grandis L.*) wood samples were taken from two districts in Bangladesh- Sylhet district (ST teak), situated on the north-east of Bangladesh under Sylhet division and Rangamati district (RT Teak), situated on the south-east of Bangladesh under Chitagong division. Ring numbers were 32-38 for ST teak and 37-45 for RT teak. Three sample trees were taken from each location. From each sample tree a disc was taken at breast height and continuous cross sections were cut from pith to bark. The sections were stained with safranin, mounted on microscopic slides and photographs were taken. Rays were observed on tangential section with electron microscope and then five photographs were taken from each ring. Ray proportion and ray dimensions (ray height, ray width and ray area) were measured from the photographs by an image analysis system.

RESULTS AND DISCUSSION

Ray proportion remained more or less constant within individual tree (Fig.1.). Number of rays per mm^2 decreased at first rapidly with ring number from pith and become constant above ring 10 (Fig.2). Average ray area (Fig.3) and ray height (Fig.4) increased from the pith to about 10 ring and thereafter remained more or less constant. But ray width was minimum in the rings near pith. (Fig.5). Kedharnath *et al.* (1963) reported the juvenile wood zone to include the first nine rings in 60-year-old teak in India, based upon fiber length. This is in agreement with our results based on ray tissue. Bhat *et al.* (2001) found that the age of demarcation between juvenile wood and mature wood varied from 15 to 20 or 25 years depending on the maturation age of the properties (microfibrillar angle, fibre length, vessel diameter and ring width) and plantation locality.

Average of ray proportion, number of rays per mm^2, ray area, ray height and ray width in mature wood are shown in the Table 1.

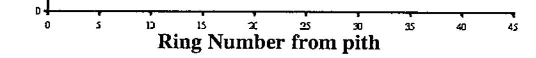

Fig.1. Variation of ray proportion

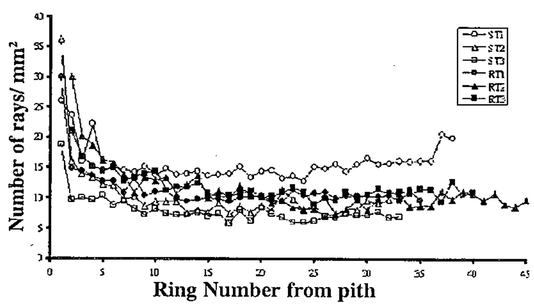

Fig.2. Variation of number of rays/mm^2

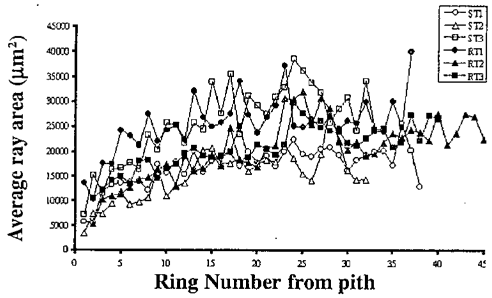

Fig.3. Variation of average ray area

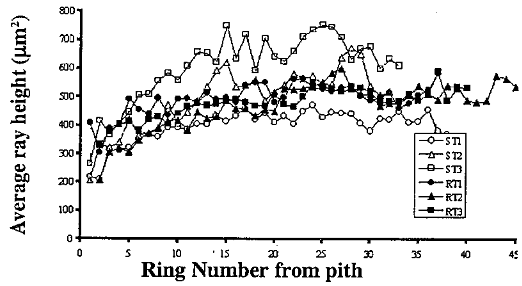

Fig.4. Variation of average ray height

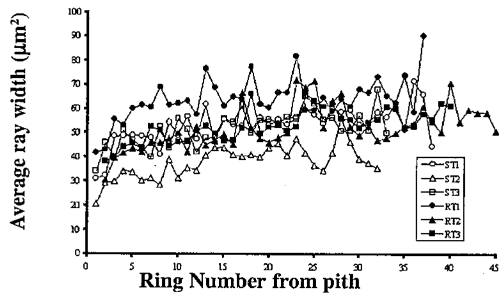

Fig.5. Variation of average ray width

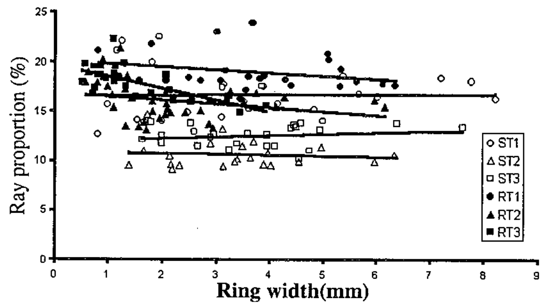

Fig.6. Relationship between ring width and ray propotion

Fig.6 shows the relationship between ring width and ray proportion in mature wood. The ray proportion was not influenced by growth rate except RT3. There was also no effect of ring width on number of rays/mm^2 (Fig. 7). Fig.8 shows the relationship between ring width and average ray area. A negative relationship was obtained in RT2 and RT3. But no relationship was observed in other trees. There is no relationship between ring width and average ray height (Fig.9) and average ray width (Fig. 10). There are three types of distribution pattern of ray area in mature wood (Fig.11). ST1 and ST2 had peak frequency on ray area 10000-14999 mm^2 and 5000-9999 mm^2 respectively. Whereas the rest showed more of less same pattern having peaks by area 10000-29999 mm^2.

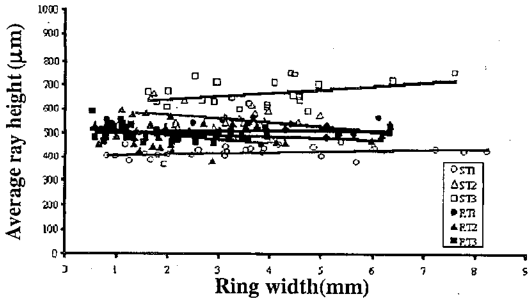

Fig.9. Relationsship between ring width and average ray height

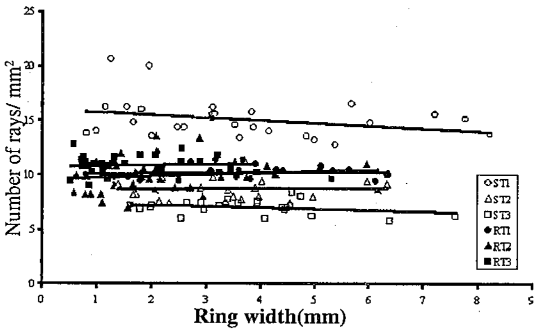

Fig.7. Relationship between ring width and number of rays

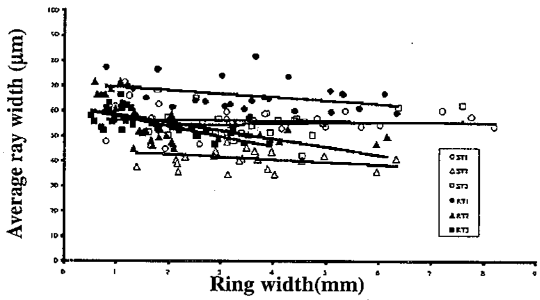

Fig.10. Relationship between ring width and average ray width

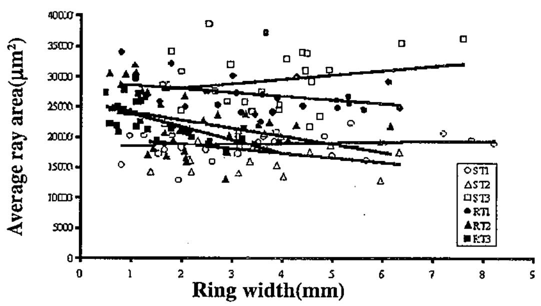

Fig.8. Relationship between ring width and average rays area

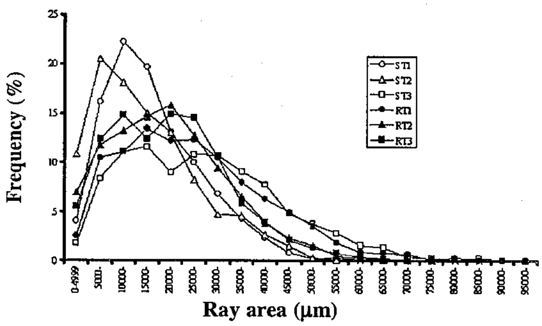

Fig.11. Distribution of average ray area

Table 1. Ray proportion and dimensions of ray in tangential section.

Sample tree	Ray proportion(%)	Number of rays per mm^2	Ray area (mm^2)	Ray height (mm)	Ray width (mm)
ST1	16.7	15.2	18885.7	421.7	55.9
ST2	10.6	8.7	17814.2	552.9	41.2
ST3	12.5	7.0	29442.2	665.5	54.6
RT1	19.0	10.2	27408.5	514.2	66.5
RT2	16.0	9.9	22557.5	498.5	54.5
RT3	17.8	10.9	22634.4	500.1	55.2
AVERAGE	**15.4**	**10.3**	**23123.8**	**525.5**	54.7

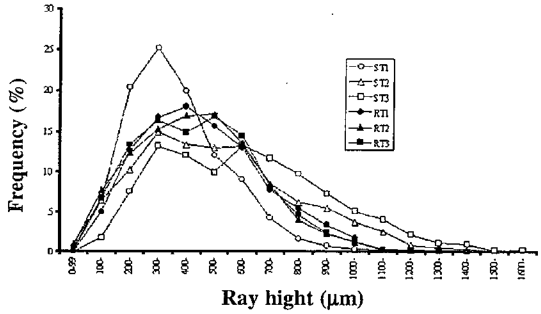

Fig.12. Distribution of average ray hight

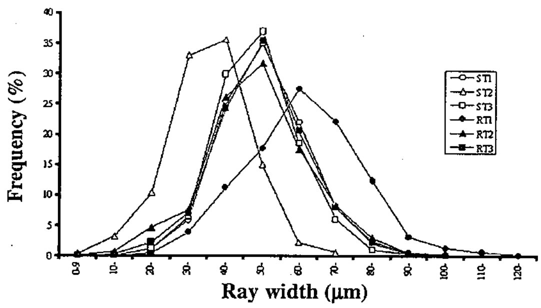

Fig.13. Distribution of average ray width

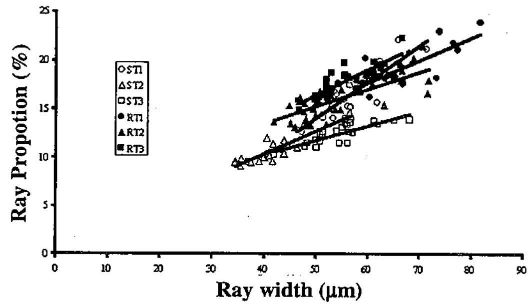

Fig.14. Relationship between ray width and ray propotion

Fig.12 shows distribution pattern of ray height, where ST1 had a peak on ray height 300-399 ?m. But the rest showed more or less same pattern of distribution with a peak on ray height 300-699 ?m Fig.13 shows three distribution patterns of average ray width. ST2 had many narrower rays and RT1 had many wider rays. The rest of the trees showed similar distribution pattern of ray width with medium value at the peak.

From the results ray proportion and dimensions of ray appear to be under fairly strong genetic control. Growth rate has no important effect on ray proportions and ray dimensions. The ray proportion that is considered to be the important influencing factor on wood density had strong relation with ray width, one of three-dimensional parameters of ray (Fig. 14). But the ray proportion was different for different trees in spite of same ray width. Distribution of ray dimensions on tangential section had characteristic patterns. There were three distribution patterns of ray width. RT1 had many wider ray and showed higher ray proportion (Table1). Selection for high ray proportion may result in selection for high wood density if the density of ray is higher than the surrounding tissues.

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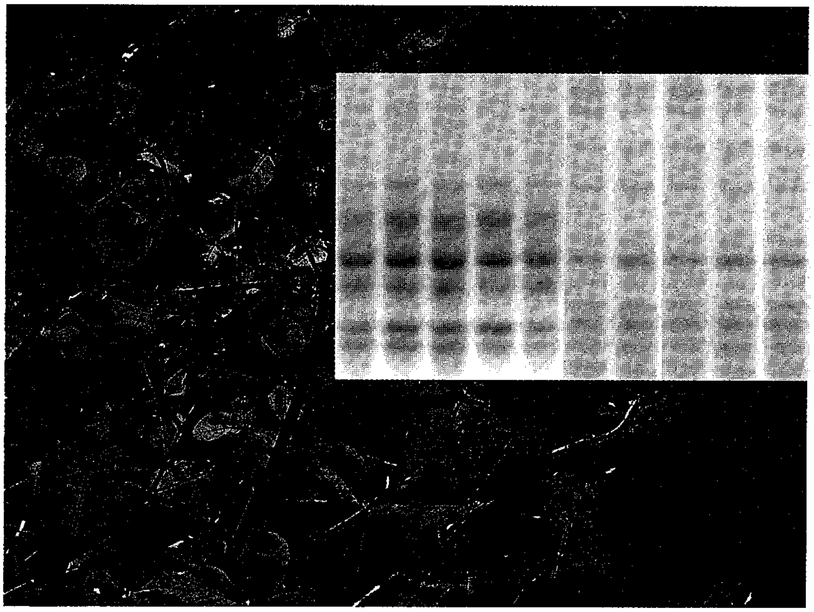
Genetic Aspects of Teak Wood Production



Quality Timber Products of Teak from Sustainable Forest Management pp 311-320

Genetic Aspects of Quality Teakwood Plantations

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ABSTRACT

Teak trade has known for centuries that the quality of teak wood varies between geographic origins. Provenance studies have since shown that this variation is partly due to genetic differences and that selection of the best origins can improve the value of the teak plantations. Experience from decades of teak breeding has further shown that external quality characteristics (stem form, clear bole, etc.) can be improved through selection and breeding. Less focus has been on breeding for the important heartwood qualities such as durability, colour and chemical content, but the available studies suggest that improvement of these factors is also feasible. An important 'new' breeding target seems to be heartwood percent. This trait exhibits high level of variation and increased heartwood percent is important in order to mitigate the otherwise low heartwood yield from short rotations. Much more research into the heritability of heartwood quality traits is required.

Keywords: Teak, *Tectona grandis*, heartwood, variation, provenances.

INTRODUCTION

Teak is widely planted in South East Asia, and as exotic species in Africa, South and Central America (Ball *et al.*, 1999). The species has gained its high reputation from trees grown in natural forest or plantations with long rotation age. However, a large number of the present plantation programmes aim at growing the trees in a substantially shorter rotation, and obtaining good quality wood in the plantations must therefore be considered to be a major challenge for future tree improvement programmes.

DOES QUALITY DEPEND ON THE GENETIC ORIGIN OF THE PLANTING MATERIAL?

Teak covers a large distribution area with clear morphological races. Knowledge of variation in characteristics of wood has been used for many years in the trade of teak logs. These differences between locations concern proportion of sapwood to heartwood, wood structure, fibre length, strength, specific gravity, shrinkage, durability, termite resistance, extractives from the wood, colour of the heartwood, content of minerals in the heartwood, resistance to various pests and diseases, leaf morphological characters, leaf morphology in relation to resistance to drought and disease, and general stem and branch characteristics (see *e.g.* review in Lauridsen *et al.*, 2003).

Geographic variation can be due to a combination of genetic differences (provenance variation) and differences in growing environments (soils, climate, silvicultural practices). Provenance research in teak permits the separation of genetic and environmental effects and has therefore attracted interest for decades in many countries. There are at least five major series of old provenance trials that have assessed the variation on trees beyond the early establishment phase, and these have shown that much can be gained by selecting the best seed sources, both in terms of growth rate and bole quality. Some general results are presented in Table

1 (here mainly after Lauridsen *et al.*, 2003), but consultation of the organisations responsible for the trials will be important in order to get access to the detailed findings.

The provenance studies (Table 1) have shown that important differences exist between seed sources in terms of growth rate and bole quality. Far fewer studies have investigated variation in the heartwood quality including important parameters such as heartwood colour, wood stability and durability. Still, Bailleres and Durand (2000) have discussed use of non destructive methods for investigating wood quality, and based on Indian results, Bhat (2001) has elaborated on the potential of including wood quality in the breeding effort.

Simatupang *et al.* (1995) have investigated a number of chemical contents considered important for the teakwood properties. They found a large variation between origins in total extractive contents as well as concentrations of single compounds, and suggested that content of wood extractives should be considered as an important selection parameter in tree breeding.

Kjaer *et al.* (1999) investigated the heartwood percent in a 17 years old trial, and found a surprisingly high degree of variation between trees, where heartwood percent varied between 30% and 90% for trees of the same size (Figure 1). The variation included significant differences between the provenances. A recent study by Mandal and Chawhan (2003) based on a 20 years old progeny trial has verified that substantial genetic variation can be found in the heartwood percent in young plantations, and the authors estimated a high single tree heritability suggesting that heartwood percentage can be improved substantially through selection and breeding. Heartwood percent is not a wood quality parameter *per se*, but selection of fast growing plants with high heartwood percent will substantially increase the production of heartwood from short rotation plantations. Heartwood percentage is not easily assessed on standing trees, but can be assessed from a bore core. Given the apparently high heritability, heartwood seems to be a feature than can fairly easy be included in on going breeding programmes and therefore should be considered whenever short rotations are targeted.

Colour of the wood is a trait of major importance (known to vary between origins) that also has attracted fairly low interest from genetic studies. Kasosa-ard (unpublished data) looked at the heartwood colour in a number of provenances grown in a trials in NE Thailand, but concluded that most of the variation here was due to environmental effects rather than the origin of the trees. Studies of colour from teak grown in home gardens in Kerala showed darker wood from teak trees grown under drier conditions compared to wet sites, also indicating large environmental influence (Bhat, 2003). Given the major importance of colour, more research into the matter will be appropriate.

Along with colour and structural stability, wood durability is an important feature of the teak wood for exterior use such as garden furniture or fittings on ships. Plantation grown wood may show fairly large tree-to-tree variation in wood durability, and even large differences between wood samples from the same trees (Reichter *et al.*, 2003), indicating that genetic improvement of this trait is not as easy as one could expect. Still, the genetics of durability also deserves further research.

TREE IMPROVEMENT: OPTIONS AND POTENTIAL GAINS

Tree improvement activities may include progeny trials at multiple test sites and propagation in intensely managed seed orchards, by cuttings or tissue culture. In less advanced programmes, tree improvement activities concentrate on establishment of a few well adapted seed sources based on progenies from a number of phenotypically selected mother trees. Generally speaking, first generation tree improvement consist of one or more of the following activities in combination:

1. Seed source identification and selection of seed sources (provenances) based on a system of 'tree planting zones' with uniform ecological conditions
2. Seed source (provenance) testing and use of best seed sources

Table 1. An attempt to identify some general finding from old provenance trials. Based on Lauridsen *et al.*, 2003 and discussions and references herein

Series	General findings
'The All-India Provenance trials' initiated in 1930, including 11 provenances in trials in 13 locations spread in India, and later a new series was established in 1980-81.	The early results indicated that in the natural range of teak, the local provenances will likely perform well, but introductions from moist areas may give better yields. Provenances from moist South West India (Nilambur, Kerala) seem to prove as a stable, vigorous provenance, whereas the Burmese provenances differ in performance with planting locality. Later trials established in the 80'ties have supported these results, suggesting that selection of the right seed source may be of major importance within the Indian distribution area. Practical experience further supports that the Nilambur provenance – when planted in dry areas - will often suffer a lower survival, but that the subsequent growth of surviving trees are good.
'Indonesian series of provenance trials' established in Indonesia in the 30'ies, and later in 1959.	The trials still exist and apparently reveal important differences between provenances, but reports were not available in English when preparing the present paper. For planting programmes in Indonesia, it must be considered as an important source of information to be consulted.
'Chinese series of provenance trials' initiated in 1973. Provenances tested included old introductions to China from Burma, Malaysia, Indonesia, and India, together with new introductions from Burma, Thailand and India.	A South West Indian Provenance (Sungam, Kerala) produced 50% more volume than the best Burmese provenance and showed better drought resistance than provenances from Burma and Thailand when exposed to dry conditions in nursery trials. Additional reports are available in Chinese, but due to the language barrier not accessible to the author when preparing the present paper. For planting programmes in tropical China or similar conditions, it must however be considered as an important source of information to be further consulted.
'Provenance trails in Thailand' included four trials with a large number of local provinces established in 1969 assessed at age 5, of which one was subsequent assessed at age 12. Two international provenance trials were established in 1974 including several Thai provenances.	Differences between provenances could be observed, but the variation between Thai provenances was not large compared to what has been observed in other countries.
'International DFSC coordinated series of provenance trials' including a large number of provenances tested initially at more that 50 sites mainly *outside* its natural distribution range. Trial were assessed at age 9 (18 sites) and again at age 17 (7 sites).	General trends include observations that (i) provenances from *Indonesia* (although important exceptions were observed) were in generally of good survival, health, fast growth, but rough in respect of branch size, epicormic branching and buttressing, and a tendency to wavering stem form, (ii) provenances from the *Kerala State of India* in general appear to be of good production, good stem quality, and with fine branch size, but may be slightly inferior in health in initial stages, and that (iii) provenances from *Thailand* reveal a tendency to grow a bit slower than other provenances, and may be more unpredictable for both survival, health and volume production, but seem to produce trees with good persistence (clear bole), with good form, and branching characteristics, and have relative light epicormic branching. These general observations can be of value when planting teak as an exotic. More detailed information on the performance of all the assessed traits of each provenance in each trial can be found in the annexes of Lauridsen *et al.* (2003).

3. Development of seed production areas through progressive selective thinnings
4. Selection of superior trees (plus trees) for breeding
5. Establishment of progeny trials at multiple sites and selection of superior families and individuals (forward and backward selection), with or without marker aided techniques.
6. Establishment of clonal trials at multiple sites and selection of superior clones
7. Genetic modification by inserting a characterised gene
8. Mass propagation of improved material for commercial plantations.

The activities (1) and (8) do not alter the genetic properties of the germplasm, and one can therefore argue that they do not represent true tree improvement in a narrow sense. However, they are important in the crucial 'deployment' strategies, and therefore also deserve some comments in the present context.

Delineation of ecological zones and matching of provenances to planting sites

Identification and selection of seed sources based on an untested planting zone system is often the starting point in domestication programmes of native species. This is because application of local seed sources of a native spices seems the most safe choice in the absence of reliable results from formal provenance trials, and because delineation of ecological based 'tree planting zones' in such situations is a systematic way to define 'what is local enough to be safe' (Lillesøe *et al.*, 2001). This is of course also true in principle for teak, but the worldwide provenance tests of teak has shown that (at least) outside the natural distribution area, it is very difficult to predict the most suitable seed sources simply by matching seed sources to planting sites based on basic climatic conditions (see e.g. Table 2). This finding combined with the generally large differences observed between provenances, speaks in favour of establishment of some kind of local seed source testing. Also, systematic collection and analysis of practical experiences will be an important activity in major local or regional teak plantation programmes.

Delineation of ecological similar 'planting zones' is still important in large scale domestication activities, even if matching 'teak seed to site' based on basic climatic data has limitations. Trees are often planted under variable conditions with only limited possibility to manipulate the environment (soil preparation, weeding, fertilisers, water etc.). Improved teak sources developed and tested in one region (breeding programme) may not be as suited under different growth conditions. This problem is termed "genotype by environment interaction" and the Multiple Population Breeding Strategy has been developed (Namkoong *et al.*, 1980, *cf.* also Barnes, 1995), in order

Table 2. Relative growth rates (basal area at age 17 years) of 12 teak provenances grown in field trial at Aracruz, Brazil

Origin	Provenance (location of collection site)	Estimated annual rainfall	Average growthrelative to the fastest growing (%)
Southern India	Mount Start, Tamil Nadu.	2032 mm	100 %
Southern India	Nilambur, Kerala	2565 mm	96 %
Southern India	Konni, Kerala	2540 mm	91 %
Indonesia	Ngliron, Java	1200 mm	86 %
Ghana (African landrace)	Jema	Not available	69 %
Laos	Khong Island	1925 mm	58 %
Northern India	Purunakote, Orissa	1350 mm	58 %
Laos	Vientienne Town	1570 mm	55 %
Thailand	Ban Pha Lai	1100 mm	54 %
Thailand	Ban Mae Pam	1200 mm	47 %
Northern India	Munda Reserve Forest	1350 mm	47 %
Laos	Savannakhet	1300 mm	44 %

to cope with this problem. In the multiple population approach, the breeding population (selected mother trees) is divided into sub-groups - often one sub-group per tree planting zone – and separate breeding programmes established in ecologically different regions. Thereby, loss from using only partly adapted material is reduced. The sub-groups may also reflect different selection criteria (see e.g. White *et al.*, 1993), if these vary between regions or types of application. Thereby the gain

Selection of superior trees and establishment of trials leading to family and clonal selection

Different approaches to tree improvement can be pursued depending on the context (Kjaer *et al.*, 2000). Conventional breeding programmes will typically be based on a combination of selection of superior trees (plus trees) followed by establishment of seed orchards grafting, progeny trials at multiple sites and final selection between the clones in the seed orchard based on the results from the progeny testing. Smaller scale, farmer or enterprise based approaches will often be based on a lower input approach (Puri, 2003) based on seed production from seed production areas or seedling seed orchards developed at one or multiple sites (multiple population breeding). Large scale tree improvement programmes in India (Kumaravelu, 1993; Emmanuel, 2001), Thailand (Kaosa-ard, 1993; Kaosa-ard *et al.*, 1998), and Indonesia (Indonesia Forest State Enterprise, 1993) have been in action for decades, and trials have therefore reached an age where it is possible to evaluate the potential gains from the breeding activities. Kaosa-ard *et al.* (1998) tried, based on Thai experience, to estimate the expected gain from different types of teak improvement activities in Thailand:

- Seedlings from classified seed stands were expected to have at least 8% higher value production than seedlings from unclassified (random) seed
- Untested Clonal Seed Orchards were expected to be at least 4 % better than classified seed sources, because they consist of selected clones from the best seed sources (effect from plus-tree selection).

This means a total of at least 12 % (8 % + 4 %) higher

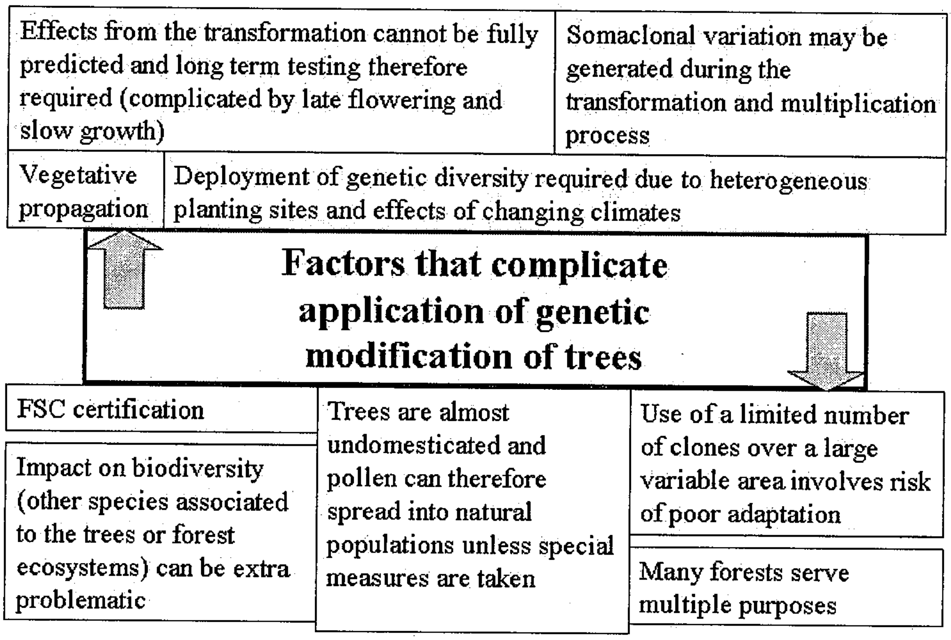

Figure 1. Technical and ecological factors that complicate use of transgenic techniques in breeding of long lived trees compared to agricultural crops.

value production from un-thinned Clonal Seed Orchard progeny compared to seedlings from unclassified seed sources.

- An additional 5% were expected to be gained from collecting seed exclusively from the best clones in the CSOs, (e.g. if multiplying these seedlings by vegetative propagation) – or seed collection after genetic thinning of the CSOs

Kjaer and Foster (1996) evaluated the potential economics of tree improvement of teak, and found that a gain on 10% would justify genetic breeding programmes for planting programmes of only a few 100 ha per year. Puri (2003) evaluated the economics in breeding for small holders and reach to a similar conclusion: even small scale planting programmes could justify investment in specific tree improvement activities.

When dealing with genetics of quality wood production, it is important to consider if selection for wood quality is expected to be as efficient as growth rate. The general good stem form of the graftings from selected, mature trees in the old clonal seed orchards indicates that plus tree selection may (if performed carefully) be fairly effective in terms of more clear bole, and therefore produce substantially more gain than the modest 4% suggested above. However, the effectiveness of recurrent selection programmes will in the long run depend on the possibility to select for good wood quality at a young stage in order to allow fairly short breeding cycles. Kjaer and Lauridsen (1996) therefore compared the finding from the international provenance trial at age 9 and 17 respectively, in order to study if significant new information had occurred during the 8 years between the two assessments. The general finding was that differences between provenances in growth rate were very well established after the first 9 years. The differences in stem form were more labile, indicating that stem form is more difficult to predict at a young stage. Still, selection for trees with few flowers, and good persistence of axis at age 9, would lead to high percentage of trees with high clear bole at age 17 (Kjaer and Lauridsen, 1996). Care must be taken when generalising the findings from provenance trials to progeny trials, but it seems reasonable to assume that selection for good stem form is a bit less effective than selection for growth rate at a young age.

Genetic juvenile-mature correlations for the 'true' wood quality traits are more difficult to estimate at the present stage. The transition from juvenile to mature wood includes a number of changes in wood characteristics (Bhat *et al.*, 2001), and assessment of the quality of the mature wood from juvenile trees may therefore be difficult. However, the core of juvenile wood will contribute substantially to the total amount of heartwood produced in trees grown at short rotations. Therefore, the quality of the juvenile wood itself will be an important target for improvement, and this can be assessed at an earlier stage. Breeding for higher heartwood percentage is also an important option to be pursued, as discussed above.

Selection at a juvenile stage can be facilitated by marker aided selection, given that large pedigreed progeny trials exist, and that suitable genetic markers are available. Several research projects such as the Europe-Asia based 'TEAKDIV' and Europe-West Africa based 'WAFT' (www.cordis.lu) are developing and testing SSR and AFLP markers suitable for genetic mapping, which will facilitate future use of marker aided selection. Marker aided selection may thus in the future become a valuable tool in early selection for quality traits in intensive breeding programmes.

GENETIC TRANSFORMATION

Genetic transformation (insertion and expression of a single gene with known effect) has become an important technique in breeding of agricultural crop in the recent decades, and the first trees were genetically modified more than 15 years ago. One application that has draw substantial interest is insertion of the so-called *Bt*-gene in order to obtain resistance against certain insects. Reduced lignin and improved pulping quality through modification of biochemical pathways is another pioneer research area (Hu *et al.*, 1999).

Genetic transformation is different from other breeding techniques by involving insertion of one (or multiple) copy of a specific gene from another species. Insect resistant teak trees that avoids defoliation may be grown in shorter rotation, and with reduced damage to the timber from insects such as the bee hole borer. However, teak trees must grow for a number of years in order to produce timber, and this fact complicates the use of genetic transformation in several ways compared to agriculture crops. The expression of inserted genes may stop after some years due to unexpected gene regulation, or the insects may develop resistance against the inserted *Bt*-gene after some years. Also, proper testing in trees requires a substantial number of years in order to test for effects over the full rotation. Finally, *Bt*-genes may spread to other teak trees and thereby have a negative impact on the many harmless insects that are naturally associated with teak trees.

In teak, wood quality especially relates to the amount, colour and durability of the heartwood. Genetic modification for improved wood quality could therefore focus on the processes related to heartwood production. From a biological risk assessment point of view, modification of heartwood formation seems less problematic than insertion of insect resistance, but the limited understanding of the exact biochemistry behind these processes in teak is an important obstacle against such application at present. Another (at present purely speculative) application would be modification of the transition from juvenile to mature phase, which could lead to teak trees that kept up the fast juvenile growth speed for more years reducing the rotation age and yielding higher percentage of heartwood.

Although of relative minor importance today, genetic modification may become more an important technique in the future if general research into genomics of trees leads to identification of important functional genes related to wood formation. There remains a number of aspects has to be considered including the fact that transgenic teak trees may be perceived negative by the market and *e.g.* not obtain FSC certification (Owusu, 1999).

'SCALING UP' – ADEQUATE MULTIPLICATION TECHNIQUES

Although not tree improvement in a narrow sense, mass propagation into commercial quantities holds the key to scaling up of the improved plant material. In the case of teak, lack of adequate mass propagation techniques has probably been be the most severe obstacle against harvesting the potential gains from genetic improvement in the past (Kaosa-ard *et al.*, 1996).

Production of teak seedlings requires procurement of a large amount of seeds due to low germination percent and sporadic germination behaviour of the seed, which combined with low productivity of seed in clonal seed orchards (CSOs) has lead to a sever bottleneck in the propagation phase in the large teak breeding programmes in both Thailand, Indonesia and India. Much effort has been put into investigation of the reasons for the low seed yield in order to improve the seed set (see e.g. Nagarajan *et al.*, 1996, Palupi and Owens, 1996, Tangmitcharoen and Owens, 1996; Varghase *et al.*, 2003; Gunaga and Vasudeva, 2003; Vasudeva *et al.*, 2003). These finding has provided a better understanding of the reproductive biology and must be expected to lead to better seed orchard management practices and application of more fertile and synchronously flowering clones in the future. Mass propagation from more juvenile trees in breeding seedling seed orchards is e.g. an interesting option to be pursued as it may be suitable for low input, multiple population breeding, farmer based improvement programmes.

Development of vegetative propagation has been given high priority in last two decades due to the sever problems with propagation in clonal seed orchards in Asia. As a result, protocols for propagation by rooted stem cuttings and tissue culture are available and commercialised in medium scale application (Gupta *et al.*, 1980; Kaosa-ard *et al.*, 1987, Goh and Monteuuis, 1997). Vegetative propagated plants are more expensive than seedlings, and vegetative propagation therefore in general concentrate on propagation of trees (or seed from trees) with improved genetic quality. Also, plants from tissue culture are in general more expensive (and required more centralisation, investments and skills) compared to rooted stem cuttings. Combination of different options can be considered including bulk propagation by rooted cuttings of seed from improved clonal seed orchards, or clonal deployment based on initial tissue culture of mature, re-juveniled trees combined with propagation by stem cuttings (see e.g. Kaosa-ard *et al.*, 1998, Goh *et al.*, 2003, Nadgauda *et al.*, 2003, Yashoda *et al.*, 2003, Palanisamy *et al.*, 2003).

Scaling up has been a server bottleneck for application of improved planting stock in the past. However, at present the techniques for 'scaling up' to commercial size seem to be available either by seed or vegetative propagation. This does not mean that research into propagation is no longer required. Technologies and their application still need refined and adaptation, in order to reduce cost, increase seed yield in clonal or seedling seed orchards, and/or allow easy propagation of more clones. It should further be noted as a word of caution, that vegetative propagation techniques are still 'young' compared to the full rotation age of teak. It is therefore required to continue to test the root architecture, long term stability and uniformity of the plants propagated by vegetative means. Multiplication through seed will probably remain an important component of any regional improvement programme, as it allows decentralised seedling production at low cost and thereby ease the delivery of genetic gains to tree planting small holders in farms lands or home gardens. This will especially be the case in areas where teak seeds abundantly (e.g. West Africa).

CONCLUSION

Tree improvement of teak may at present be at a point of 'revitalisation' for several reasons:

- Experience gained from decades of breeding and propagation work in Asia and West Africa has provided an important basis of understanding, large series of field trials and technological development
- Improved heartwood quality and increased heartwood percent are recognised as important means to mitigate the effects of reduced rotation age
- The high, and rapidly increasing, value of teak timber has improved the economics of tree improvement to a stage where even small plantation programmes can benefit from setting up improvement activities.

However, knowledge on the genetic variation, heritability and practical breeding feasibility of different heartwood characteristics is still very limited given the very important potential for breeding. It is therefore advisable to increase the practical research in this area. Due to effort from previous and on-going breeding programmes, progeny trials are now available at an age that allows such investigations.

International transfer of improved germplasm is becoming increasingly restricted by national and international regulation. However, the mutual exchange of basic knowledge, technological findings and practical know-how can be highly beneficial to teak growers (and thereby teak wood users) worldwide. It is therefore important to maintain active research cooperation in the field of teak genetics and breeding.

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RAPD Variation in Indian Teak Populations and its Implications for Breeding and Conservation

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ABSTRACT

Genetic variation in teak populations from Western Ghats and Central regions of India were studied using Random Amplified Polymorphic DNA (RAPD) markers. Ten oligonucleotide primers resolved 90 amplification products of which 66 (73%) were polymorphic. The total genetic diversity detected within the species (H_{sp}) was 0.3. Average gene diversity (H_o) within different populations ranged from 0.185 to 0.261 (mean = 0.233). The Western Ghats populations had more diversity (H_o=0.227 - 0.261) compared to those from Central India (H_o=0.185 - 0.219). Partitioning of genetic diversity into within and between populations showed that 78% of variation existing within populations and the rest between populations. A negative relationship could be observed between latitude and within-population diversity. Nei's genetic distance between populations ranged from 0.053 to 0.264. Genetic distance tended to be low between populations from the same geographic region. The UPGMA dendrogram grouped the Western Ghats and Central Indian populations into two distinct clusters. Increasing selections within populations is likely to capture major portion of genetic diversity existing in teak. A seedling seed orchard based approach is recommended to obtain a broad genetic base and to overcome problems related to flowering and fruiting. They can also be regarded as dynamic *ex situ* conservation stands. Western Ghats and Central Indian regions may be treated as separate genecological zones. Since many subgroups may exist within these broad regions, multiple populations within each of them should be conserved *in situ*.

Keywords: Teak, RAPD markers, polymorphism, genetic diversity, genetic distance, population differentiation.

INTRODUCTION

Teak has a discontinuous natural distribution in India between 8 and 24 °N latitudes. Within this well marked distribution boundary, teak grows in diverse climatic and edaphic conditions resulting in distinct populations. Major teak areas occur in two well-defined geographic regions: the Deccan Plateau which lies between 16 and 25 °N latitude covering most of Central India and the mountainous Western Ghats region, mostly below 16 °N latitude (Troup, 1921). These regions are also referred to as "dry interior" and "moist west coast'" regions (Keiding *et al.*, 1986). Champion and Seth (1968) proposed a more elaborate classification into five subtypes namely very moist, moist, semi-moist, dry and very dry teak based on rainfall, soil and stand composition. Though India is regarded as the center of diversity for teak (Hedegart, 1976), detailed investigations on the amount and distribution of variation have not been undertaken.

Information on the extent, nature and distribution of genetic variation in a species is crucial for developing effective breeding and conservation strategies. In recent years, biochemical and molecular markers are widely used to study the extent and pattern of genetic variation in tree species (Loveless, 1992; Nybom and Bartish, 2000). Many studies have been conducted in teak using isozyme and Random Amplified

Polymorphic DNA (RAPD) markers to estimate genetic diversity and outcrossing rates in selected populations from the natural and cultivation range (Kertadikara and Prat, 1995a and b; Kjaer and Suangtho, 1995; Kjaer and Siegismund, 1996; Kjaer *et al.*, 1996; Changtragoon and Szmidt, 2000). However, only limited populations from India have been covered in these studies (Kertadikara and Prat, 1995a and b; Kjaer *et al.*, 1996). The present study was undertaken to estimate intra-population genetic variation, levels of genetic differentiation and relationships among different teak populations of India using RAPD markers. Implications of the extent and pattern of variation on the teak breeding and conservation programmes in India are discussed.

MATERIALS AND METHODS

Plant Material

Ten populations from Peninsular India were studied for genetic diversity using RAPDs, details of which are given in Table 1. Seven populations came from the Western Ghats region and the remaining from Central India. Seeds of at least 25 trees in each population were collected individually and bulked. These bulked seedlots were sown in water-saturated sand beds to raise seedlings. Nine individuals per population were randomly selected and used for the study.

DNA extraction and quantification

DNA was extracted from young leaves of 2-months old seedlings using the standard procedure (Doyle and Doyle, 1987). DNA samples were treated with 5 ng of RNAse and quantified using DNA Quant Softpac™ module of DU-64 spectrophotometer (Beckman Instruments Inc. USA). In order to maintain uniform concentration, DNA samples were diluted to 12 ng μl^{-1} after quantification.

DNA amplification and primer screening

DNA amplification was carried out in 25 μl aliquots, each containing 24 ng of teak DNA, 100 μM of nucleotides, 5 picomoles of primer, 0.5 unit of DNA-Taq polymerase and 5 μl of Taq polymerase buffer supplied with the enzyme (primers from Operon Technologies, USA and the rest from Bangalore Genei, India). DNA amplification was performed in a programmable thermal controller (PTC-100; MJ Research, Watertown, USA) equipped with a heated lid to minimize sample fluxing. The thermal cycler was programmed to denature DNA at 92 °C for 1 minute, anneal DNA to primer at 37 °C for 1 minute and polymerise DNA for 2 minutes at 72 °C. After 35 cycles, a final extension of 5 minutes was allowed. The amplified products were separated on a 2% agarose gel with 1x TBE buffer. Gels were stained with ethidium bromide, visualized on a uv-transilluminator and photographed using polaroid film 667. Sixty primers of the Operon kits OPB, OPE and OPM were screened with sample DNA accessions. Ten primers, which produced consistent amplifications were selected and used for screening all DNA accessions (Table 2). Ten percent of the amplifications were repeated to check the reproducibility of RAPD profiles.

Table 1. Details of teak populations from India sampled for RAPD assay

S.No.	Location	Latitude (N)	Longitude (E)	Mean annual rainfall (mm)	Stand type
	Western Ghats				
1	Kalakkad	08° 29′	77° 30′	1864	Natural Forest
2	Topslip	10° 33′	76° 50′	2080	Plantation
3	Walayar	10° 52′	76° 46′	1500	Natural Forest
4	Nilambur	11° 18′	76° 18′	2580	Plantation
5	Mudumalai	11° 34′	76° 38′	1429	Natural Forest
6	Tholpetti	11° 39′	76° 16′	2344	Plantation
7	Dandeli	15° 14′	74° 37′	2200	Plantation
	Central India				
8	Alappalli	19° 27′	80° 00′	1520	Plantation
9	Bardipada	20° 44′	73° 40′	1920	Natural Forest
10	Seoni	22° 05′	79° 33′	1363	Plantation

Table 2. Details of primers used to detect variation within and among 10 teak populations.

Primer	Sequence	Amplified products	Polymorphic products	Polymorphism(%)
OPB-04	GGACTGGAGT	10	6	60.0
OPB-15	GGAGGGTGTT	5	2	40.0
OPB-18	CCACAGCAGT	9	7	77.8
OPE-04	CTGACATGCC	8	5	62.5
OPE-06	AAGACCCCTC	8	5	62.5
OPE-15	ACGCACAACC	8	5	62.5
OPM-02	ACAACGCCTC	9	6	66.7
OPM-05	GGGAACGTGT	10	9	90.0
OPM-06	CTGGGCAACT	10	10	100.0
OPM-13	GGTGGTCAAG	13	11	84.6
	Overall	90	66	73.3

Statistical analysis

Amplified products were manually scored for presence (scored as 1) or absence (scored as 0) for each DNA accession regardless of the intensity of the band. POPGENE, version 1.31 (Yeh *et al.*, 1999) was used to determine the frequency of polymorphic bands in each population. Average gene diversity within populations (H_o) was calculated using Shannon's information measure.

$$H_o = - \sum pi \log_2 pi$$

Where *pi* is the frequency of the *i*th RAPD band (King and Schaal, 1989). The between-population diversity component was calculated as $(H_{sp} - H_{pop})/H_{sp}$, where H_{sp} is the total diversity detected in all populations and H_{pop} the mean within-population diversity value. The proportion evident within populations was calculated as H_{pop}/H_{sp}. Genetic distances between populations were calculated according to Nei (1978). An unweighed pair group with arithmetic averages (UPGMA) dendrogram was constructed using Nei's genetic distance matrices (Sneath and Sokal, 1973).

RESULTS

All the selected primers generated sufficient polymorphism (40-100%) both within and between populations. The number of products amplified by different primers ranged from 5 to 13. Primers OPB 4, OPM 5, OPM 6 and OPM 13 generated more products (9-13) than the rest. Highest levels of polymorphism were generated by the primers OPB 18, OPM 5, OPM 6 and OPM 13 (85 – 100%). Out of total 90 RAPD products generated by 10 primers, 66 (73%) were polymorphic (Table 2).

The levels of polymorphism and average genetic diversity (H_o) detected within different populations are given in Table 3. Polymorphism within individual populations ranged from 37 to 55% and the average gene diversity (H_o) from 0.185 to 0.261. In general, populations from Western Ghats region showed higher levels of genetic diversity (H_o = 0.227-0261) than Central Indian populations (H_o = 0.185 - 0.219). Tholpetti, Nilambur, Topslip and Mudumalai populations from Western Ghats recorded the highest gene diversity values (H_o = 0.241 - 0.261) whereas Bardipada population of Central India had the lowest value (H_o = 0.185). The clinal relationship of gene diversity with latitude studied through regression analysis showed a negative trend ($R^2 = 0.581$; $P = 0.01$; Fig. 1). Populations from southern latitudes (*eg.* most of the Western Ghats populations) possessed higher levels of diversity than those from the northern latitudes. The total diversity existing within the species (H_{sp}) was found to be 0.3, higher than within-population diversity (H_{pop}), 0.233 (Table 4). Partitioning of this diversity into within and between populations revealed that 78% of the total diversity was present within the populations and the rest between populations (Table 4). Primers OPB 04, OPB 18 and OPM 13 resolved higher levels of population differentiation (27-37%) than other primers.

The magnitude of genetic differentiation among populations was also confirmed by the Nei's genetic distances among different populations, which ranged from 0.053 to 0.264 (Table 5). In general,

Table 3. Levels of polymorphism and average gene diversity in teak populations of India studied using RAPDs

Population	Polymorphism (%)	Average genediversity (H_o)
Western Ghats		
Kalakkad	49.0	0.241
Topslip	51.1	0.245
Walayar	46.9	0.227
Nilambur	53.1	0.246
Mudumalai	53.1	0.260
Tholpetti	55.1	0.261
Dandeli	46.9	0.230
Mean	50.7	0.244
Central India		
Alappalli	45.0	0.219
Bardipada	36.7	0.185
Seoni	45.0	0.218
Mean	42.2	0.207
Grand Mean	48.2	0.233
All populations	73.0	0.300

geographically proximal populations tended to have low genetic distance between them. For example, the distances between different populations from within Western Ghats and Central India were low, ranging from 0.056 to 0.144. However, large genetic distances (0.127 to 0.264) were observed between Western Ghats populations on one hand and the Central Indian populations on the other. The Central Indian population, Bardipada was genetically the most distant from rest of the populations with genetic distance values ranging from 0.134 to 0.264. The UPGMA dendrogram also showed a similar trend, with two major clusters each for the Western Ghats and Central Indian regions (Fig. 2). Within these major clusters, Tholpetti and Topslip populations from Western Ghats and Seoni and Alappalli populations from Central India grouped separately from rest of the populations.

DISCUSSION

Genetic diversity

Only a few teak populations from India have been subjected to isozyme marker-based studies (Kertadikara and Prat, 1995a and b; Kjaer *et al.*, 1996). The present study using RAPD markers covers the two major teak growing regions in India. Average within-population gene diversity values obtained in this study are comparable with mean values reported in outcrossing woody perennials studied through isozyme and RAPD markers (Hamrick and Godt 1989; Loveless, 1992; Nybom and Bartish, 2000). But these estimates are slightly lower than values reported for teak populations screened in earlier isozyme and RAPD marker studies (Kertadikara and Prat, 1995b; Changtragoon and Szmidt, 2000). However, it is difficult to compare the diversity values reported in these studies due to differences in marker system and population sets.

Considering the wide distribution range of teak in India, greater genetic diversity may be expected than what is reported in the present study. Such a situation has been reported for many tropical trees with widespread distribution. Average within-population genetic diversity values reported for *Casuarina equisetifolia* and *Eucalyptus microtheca* screened by RAPD markers were 0.147 and 0.2 respectively (Yang and Li, 2000; Ho *et al.*, 2002). In fact, it is reported that geographic range showed no significant association with within-population diversity in many plants investigated through RAPD markers (Nybom and Bartish, 2000).

The within-population diversity estimates for natural and plantation populations screened in the present study are similar. Most of the plantations are 60 or more years old and just one or two generations

Table 4. Partitioning diversity in teak into within- and between-population components, using Shannon's Diversity Index

Primer	H_{sp}	H_{pop}	H_{pop}/H_{sp}	$(H_{sp}-H_{pop})/H_{sp}$
OPB-O4	0.179	0.129	0.721	0.279
OPB-15	0.211	0.187	0.886	0.114
OPB-18	0.363	0.265	0.730	0.270
OPE-04	0.272	0.207	0.760	0.240
OPE-06	0.278	0.228	0.820	0.180
OPE-15	0.229	0.187	0.817	0.183
OPM-02	0.317	0.247	0.777	0.223
OPM-05	0.398	0.348	0.874	0.126
OPM-06	0.410	0.324	0.789	0.211
OPM-13	0.339	0.212	0.625	0.375
Mean	**0.300**	**0.233**	**0.780**	**0.220**

Table 5. Nei's genetic distances among 10 Indian teak populations based on 90 RAPD products.

Population	Kalakkad	Topslip	Walayar	Nilambur	Mudumalai	Tholpetti	Dandeli	Alappalli	Bardipada
Topslip	0.129								
Walayar	0.101	0.070							
Nilambur	0.071	0.107	0.090						
Mudumalai	0.081	0.078	0.081	0.057					
Tholpetti	0.144	0.056	0.083	0.095	0.080				
Dandeli	0.082	0.124	0.064	0.080	0.075	0.134			
Alappalli	0.193	0.201	0.189	0.127	0.150	0.197	0.145		
Bardipada	0.264	0.264	0.195	0.227	0.216	0.244	0.257	0.134	
Seoni	0.217	0.196	0.188	0.185	0.184	0.204	0.181	0.053	0.143

removed from the wild populations. Although there is no information available on the origin and composition of seedlots used for raising these plantations, it can reasonably be assumed that the planting stock was locally obtained. Results of the present study shows that these plantations still have substantial genetic base to support long-term breeding and conservation programmes. Kertadikara and Prat (1995b) suggested that early exclusion of selfed genotypes and progressive selection against homozygous trees (suppression followed by thinning) maintain high levels of genetic diversity in successive generations of teak populations.

The present study shows that within-population genetic diversity decreased with increasing latitudes of teak populations in India. Interestingly Varghese *et al.*, (2000) reported a negative trend for wood density and heartwood content in a similar set of populations from India. Negative relationship between diversity and latitude has been reported for tree species occurring over wide geographical range (*eg.* Playford *et al.*, 1993; Ally *et al.*, 2000). Teak populations from southern latitudes occur in the moist regions of Western Ghats whereas those from the northern latitudes beyond 16 °N are from the dry regions of Central India. The moist region is a large tract with high rainfall and suitable soils, considered ideal for teak whereas in the dry region, its growth and distribution is gradually reduced and is replaced by Sal (*Shorea robusta*) beyond 24 °N (Troup, 1921). It is reported that populations at the extremes of the distribution range show reduced levels of diversity and increased levels of inbreeding (Maguire *et al.*, 2000). This trend is further supported by the low reproductive success in dry teak populations. The Central Indian populations are characterized by flower and seed predation, low fruit and seed production and poor germination (Dabral and Amin, 1975; Prasad and Jalil, 1986; Rajput and Tiwari, 2001; Sivakumar *et al.*, 2003).

Significant correlation between fecundity and levels of genetic variation has been reported in plants and animals (Hamrick *et al.*, 1979). Progeny of highly fecund species have greater chances of survival in a range of environments and habitats and thus maintain high levels of intra-population variation. This is supported by the fact that moist teak provenances from Western Ghats region recorded good adaptability and growth in a range of exotic environments (Kjaer *et al.*, 1995). Restricted gene flow through limited seed dispersal can also be cited as a reason for low variation in dry teak populations. Teak fruit, with a felty mesocarp is adapted to water dispersal (Troup, 1921). In moist populations, shedding of fruits is followed by the South West monsoon, which helps in their dispersal. Moisture is severely limited in dry teak populations, which are subjected to low quantum of rainfall and a long dry spell of 7 months. As a result, natural regeneration is high in moist populations but poor and patchy in the dry regions (Champion and Seth, 1968).

Genetic differentiation among populations

Partitioning of genetic diversity into within- and between-population variation in Indian teak revealed that 22% of variation is due to differentiation among populations. This is considerably higher than reported value (9%) using isozyme markers by Kertadikara and Prat (1995a) for nine teak populations from India,

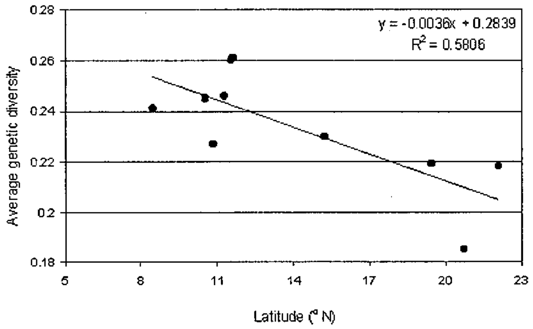

Figure 1. Relationship between latitude and within-population genetic

Thailand, Indonesia, Tanzania and Ivory Coast. However, the higher value obtained in the present study is consistent with the level of between-population diversity (21%) reported for 16 teak populations from Thailand studied using RAPD markers (Changtragoon and Szmidt, 2000). This supports the view that RAPD markers are more efficient in screening variation across geographic range than isozyme markers since they are sensitive to variation in the maximum distances between sampled populations (Nybom and Bartish, 2000). For example, high levels of population differentiation have been reported in wide spread tropical tree species screened with RAPD markers. It is 40% in *Gliricidia sepium* (Chalmers *et al.* ,1992) and 20% in *Swietenia macrophylla* (Gillies *et al.,* 1999) both of which are entomophilous and obligate outbreeders like teak.

As mentioned earlier, populations screened in this study came from two markedly different teak-growing regions: Western Ghats and Central India. The latitude of the population also influences the levels of diversity within population (Fig. 1). High degree of differentiation among teak populations suggests that they have probably evolved in response to prevalent environmental conditions with limited gene flow between populations through pollen and seed movement. Insect pollinators of teak are reported to visit a few trees in a day (often staying long time in the same tree) resulting in mating between adjacent trees (Hedegart, 1976, Mathew *et al.*, 1987). Gene flow across populations through fruit dispersal is also limited since they are mostly dispersed through water. Such low level of gene flow between the two major teak-growing regions is further indicated by the Nei's genetic distance among populations. It is low between populations of the same region and high between any two populations of different regions, consistent with the trend reported earlier (Kertadikara and Prat, 1995a). The UPGMA dendrogram also revealed similar patterns of relationship among populations studied. Geographic distribution-based relationship among populations has been reported in many species investigated through different marker systems (*eg.* Russell *et al.*, 1999; Allnutt *et al.*, 1999).

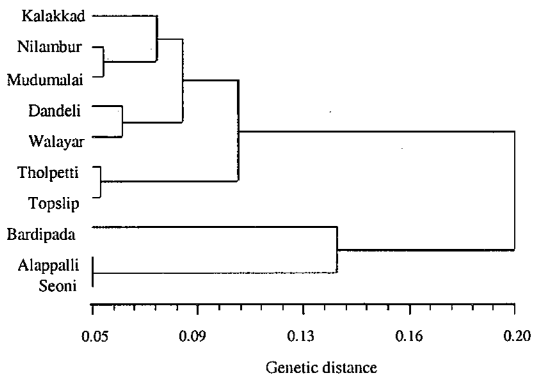

Figure 2. UPGMA dendrogram for Indian teak populations using Nei's genetic distance matrix

Implications for breeding and conservation

Although teak is under cultivation in India for over 150 years, breeding and conservation efforts have been limited. Plantations are still raised with seeds from unknown and unimproved sources because of which, productivity has been low (Pandey and Brown, 2000). Seedlots used for plantation establishment should have adequate genetic diversity to get good survival and growth of trees. For example, *Acacia mangium* provenances with high genetic diversity are reported to perform better than provenances with poor diversity (Harwood and Williams, 1992). A planting programme for teak should ensure that seeds from the ideal source with sufficient diversity are used. Molecular markers like RAPD will be useful in determining the levels of diversity in natural populations, seed stands and orchards. Diversity estimates from orchards and their progeny will be useful to determine whether their genetic base is sufficient for use in long-term breeding programmes.

Genetic improvement of teak in India has essentially been limited to establishing seed production areas (SPA) and clonal seed orchards (CSO). SPAs are selectively thinned out plantations accounting major portion of improved seeds produced. CSOs are established with grafted plants of superior phenotypes ("plus trees") selected from natural forests and plantations. These "plus trees" are selected at a very high intensity (often one in several hundred hectares of forests) with rigorous selection criteria (Emmanuel and Bagchi, 1988; Kumar *et al.*, 1998). As a result, the number of trees eventually making into the CSOs is relatively small, (mean = 30; Kumar *et al.*, 1998; Sharma *et al.*, 2000). Since as much as 78% of variation resides within the population, high intensity phenotypic selections within a population is not an appropriate strategy to exploit the intra-population variation. In order to avoid low genetic base in the CSOs, it is advisable to select as many good trees as possible from individual populations. To facilitate such low intensity selection, the existing selection criteria may be revised to include only the most heritable and economically valuable traits (eg. height, diameter, clear bole height and stem straightness; Sharma *et al.*, 1996). Such a selection strategy is likely to capture most of the genetic variability present within the population. Assembling trees in seed orchards from the same population will also avoid non-synchronization of flowering among clones, a commonly encountered problem in teak CSOs (Subramanian *et al.*, 1993; Gunaga *et al.*, 2000) and increase the levels of outcrossing and seed set.

Narrow genetic base and low reproductive success in CSOs have prevented teak breeding in India from moving to advanced generations. An alternative strategy to counter these problems would be to establish a seedling seed orchard (SSO) using open pollinated seeds of at least 100 superior phenotypes selected within a population. Such an approach will also provide a broad genetic base for multiple generation breeding and minimize flowering-related problems in seed orchards. This strategy can also help in reducing genetic drift and prevent drastic loss of diversity in the first generation. The SSO-approach is further supported by the high levels of reproductive success in teak SPAs, which are thinned out seedling-originated plantations. Outcrossing rates were high in seed stands of Thailand (Kjaer and Suangtho, 1995) and seedlings raised with seeds from seed stands were found to be more vigorous than that from CSO-produced seeds in India (Indira and Basha, 1999).

Though the present study was made in a limited number of populations, information obtained on the pattern of genetic variation in teak can be used for developing conservation strategies. Substantial variation detected within and between populations suggests conservation of multiple populations within the range of natural distribution (Namkoong, 1986; Eriksson *et al.*, 1993). Indian teak provenances have been reported to show significant variation in terms of adaptability, growth and form traits in different locations. In general, the moist provenances (from the Western Ghats region) performed better than those from the dry region (Kjaer *et al.*, 1995). In the present investigation, it is clearly established that the Western Ghats and Central Indian populations are genetically distinct groups with subgroups within each of them. As reported for teak in Thailand, teak-bearing forests in India can be broadly divided into genecological zones and representative populations can be designated as *in situ* conservation stands within each zone (Graudal *et al.*, 1997; Suangtho *et al.*, 1999). It is essential to ensure that these populations have not been subjected to dysgenic felling, which would have already eroded the diversity. In this context, Preservation Plots (PP) earmarked within natural forests to attain climax with no human disturbance can be considered as *in situ* conservation stands (Seth, 1951; Rodgers, 1991). Established mostly during early 20th century, there are 166 Preservation Plots in various forest types of which nearly 20% have teak as a major constituent spread throughout its distribution range (Ghosh and Kaul, 1977; Rodgers ,1991). However, such plots have to be inventoried and categorized to determine species composition and current status of protection before designating as them teak conservation stands (Rodgers, 1991). Teak forests within the boundaries of Tiger Reserves and Wildlife Sanctuaries may also qualify as *in situ* conservation stands since they can be expected to retain much of the original diversity as a result of better protection than other areas.

In many places, natural forests have given way to teak plantations and preservation plots are either absent or small in natural teak forests (Kaul *et al.*, 1975; Khullar, 1992). In such situations, plantations can also be considered as conservation populations provided the origin and composition of seedlot used is known. Though such information is not available for most plantations, it can safely be assumed that plantations established in the late 19th and early 20th centuries used locally collected seeds, most likely from wild populations. These plantations are one or two generations removed from their wild populations and must possess substantial genetic variation (cf. Suangtho *et al.*, 1999). This assumption is supported by the comparable levels of within-population variation found in plantations and natural populations investigated in the present study.

Grafts of superior trees assembled in germplasm banks and CSOs are the only source of *ex situ* conservation for teak in India. Although they are a good collection for static conservation, they represent only a fraction of total genetic variation present within the species. Seedling seed orchards can serve as dynamic *ex situ* conservation stands with sufficiently broad genetic base for breeding and conservation. Poor seed production in phenotypically superior trees and difficulties in getting sufficient seedlings for large number of families are cited as limiting factors to ensure a broad genetic base (*eg.* Kjaer *et al.*, 1999). However, this approach should be possible at least for the moist populations (especially the Western Ghats populations) in which fruit production, seed filling and germination are reported to be high (Jayasankar *et al.*, 1999; Sivakumar *et al.*, 2003; Varghese *et al.*, 2003). Seed originated plantations automatically ensure selection for fertility and hence good flowering and fruiting can be expected from these stands (Varghese *et al.*, 2003). Further, they can be established and managed with limited resources.

Teak needs a national conservation programme in India with the active participation of all teak-growing States. Given the extent and nature of diversity, the existing conservation efforts are inadequate and new initiatives are necessary to widen them. With the accumulation of information on genetic structure, reproductive dynamics and mating system, and the experience gained in Thailand, it should be possible to evolve and implement a nationally coordinated conservation strategy for teak in India.

CONCLUSION

Moderate levels of genetic diversity exist within ten teak populations of India. The magnitude of population differentiation is also high. Populations from the Western Ghats region are more diverse than those from the Central region. A negative trend in within-population genetic diversity with increasing latitude was observed. Genetic distance between geographically proximal populations is low and high between the distant ones. Breeding and conservation strategies should be revised to capture and preserve both within- and between-population genetic variation in teak.

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Molecular Characterization of Teak Seed Sources Using RAPD's

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ABSTRACT

Teak seed sources from thirty locations (28 from India and one each from Lao PDR and Bangladesh) were characterized using RAPD's with 17 primers. Jaccard's similarity index revealed that a highest genetic distance of 0.457 was observed between Kerala III and Uttranchal. The resultant phenotic tree indicated that the populations from each state were found to be grouped within the same sub-clusters barring a few seed sources revealing the identity of each population.

Key words: Teak, molecular characterization, RAPD, diversity.

INTRODUCTION

Teak (*Tectona grandis* L.f.), a species of worldwide reputation as paragon among timber trees belongs to the family Verbenaceae and is distributed predominantly in tropical or sub tropical regions (Tewari, 1992). The main purpose of breeding programme in teak is to produce genetically improved planting materials suitable for growing in moist, semi moist and dry teak site types as defined by Seth and Khan (1958). Since, teak grows over huge areas of India and South East Asia, the various seed origins or provenances differ from one another. There is general evidence of inherent variation in this species for various characteristics studied (Kedharnath and Mathews, 1962). Much of the variation observed in teak is inherent and therefore can be exploited by foresters and tree breeders (Subramanian, 1997). The nature and degree of divergence in the base population is a pre-requisite for any improvement and conservation strategies (Ayad *et al.*, 1995; Gradual *et al.*, 1999). The genetic diversity has been assessed traditionally either by provenance testing using Mahalanobis D^2 statistics and Canonical analysis or eletrophoretic analysis of enzymes (Anon, 1991). However, the major limitation in the use of isozyme system is the availability of fewer numbers of loci and environmental influence in its expression. Study of metric characters in field trials was earlier the dominating technique and it is still today the most robust and valid way of assessing genetic variation. Information from field experiments is very valuable, because assessed adaptive genetic variation is still the best for breeding and conservation activities (Eriksson, 1995). Recently, DNA based molecular markers have increasingly been applied in tree improvement programmes for quantification of genetic diversity. These markers have little been affected by environment and developmental stages (Hanies and Martin, 1995). Markers also have important immediate application in supportive research for tropical hardwoods and non-industrial species mainly for quantification of genetic diversity. Successful application of RAPD in the assessment of genetic diversity has been documented in many tree species (Gillies *et al.*, 1999; Esselman *et al.*, 2000). But the use of molecular markers for genetic diversity studies in teak is dismally modest. Hence the present study.

MATERIALS AND METHODS

The experimental material for the present study consisted of 30 seed sources of *T. grandis*, which included 28 Indian sources and one each from Lao PDR and Bangladesh. The regulations for provenance seed source sampling concerning minimum number of trees and distance between parent trees were followed (Lauridsen and Olesen, 1990). Seeds from individual trees were mixed and used as seed source in the present investigation. The actual locations of the seed sources and their geographic features are presented in Table 1.

Attempts were made to study the genetic diversity using RAPD analysis for the assembled 30 seed sources of the teak. Various steps followed for RAPD analysis are detailed below.

Isolation of genomic DNA

Leaf tissues of 200 mg were washed in distilled water thoroughly and ground in liquid nitrogen using pestle and mortar. The powdered leaf was used for DNA extraction of following the method of McCouch *et al.*, (1988).

The buffers used for DNA extraction and their compositions are furnished in Table 2.

To the powdered leaf bits, 25 ml of preheated extraction buffer was added and kept in water bath for 15 minutes at 65°C with intermittent shaking for every 5 minutes. After this, 10 ml of 5 M potassium acetate was added and incubated in ice for 20 minutes under shaking. The incubated materials were centrifuged at 3000 rpm for 20 minutes in a refrigerated centrifuge. After centrifugation, the samples were filtered using mira cloth. To the filtrate, 2/3 volume of chilled iso-propanol was added and shaked lightly which resulted in the precipitation of DNA. The DNA was hooked out and washed with 70% ethanol and dried. The DNA was then dissolved

Table : 1. Details of the seed sources

S.No.	Source	Location	State	Country	Latitude	Longitude
1.	Lao-PDR	Syyabur	-	Lao PDR	23°31′N	100°05′E
2.	Bangaledesh	Chittagong	-	Bangaladesh	22°19′N	91°41′E
3.	Uttar Pradesh	Tarai	Uttar Pradesh	India	24°39′N	78°12′E
4.	Uttranchal	Dehra Dun	Uttranchal	India	30°20′N	78°02′E
5.	Madhya Pradesh	Kottiwara	Madhya Pradesh	India	20°29′N	74°08′E
6.	Assam	Lanka	Assam	India	27°58′N	89°45′E
7.	Meghalaya	Tura	Meghalaya	India	25°31′N	90°13′E
8.	Tripura	Bagafa	Tripura	India	23°25′N	91°35E
9.	Orissa	Kariar road, Nuapada	Orissa	India	20°48′N	82°32′E
10.	Maharashtra-I	Jimalgatt	Maharashtra	India	19°05′N	80°10′E
11.	Maharashtra-II	Umari	Maharashtra	India	20°06′N	78°58′E
12.	Maharashtra-III	Darekasa	Maharashtra	India	21°15′N	80°35′E
13.	Maharashtra-IV	Dongargaon	Maharashtra	India	20°04′N	80°17′E
14.	Maharashtra-V	Hiwara	Maharashtra	India	21°31′N	79°28′E
15.	Maharashtra-VI	Paoni	Maharashtra	India	20°30′N	79°22′E
16.	Andaman	Wimberligunj	Andaman and Nicobar Island	India	11°45′N	92°43′E
17.	Karnataka	Sampangi	Karnataka	India	12°29′N	75°33′E
18.	Tamil Nadu-I	Mudumalai	Tamil Nadu	India	11°37′N	76°34′E
19.	Tamil Nadu-II	Siruvani	Tamil Nadu	India	10°55′N	76°41′E
20.	Tamil Nadu-III	Topslip	Tamil Nadu	India	10°27′N	76°50E
21.	Tamil Nadu-IV	Courtrallum	Tamil Nadu	India	8°55′N	77°16′E
22.	Tamil Nadu-V	Kalakkad	Tamil Nadu	India	8°30′N	77°32′E
23.	Kerala - I	Wadu-Konni	Kerala	India	9°13′N	76°51′E
24.	Kerala – II	Padam-Konni	Kerala	India	9°13′N	76°51′E
25.	Kerala – III	Kallaley-Konni	Kerala	India	9°13′N	76°51′E
26.	Kerala – IV	Karalai Nilambur	Kerala	India	11°16′N	76°13′E
27.	Kerala – V	Nellikuthu-Nilambur	Kerala	India	11°16′N	76°13′E
28.	Kerala – VI	Chatanpura-Nilampur	Kerala	India	11°16′N	76°13′E
29.	Kerala – VII	Tholpatty-Wynad	Kerala	India	11°39′N	76°16′E
30.	Kerala – VIII	Chettivara-Parambikulam	Kerala	India	10°23′N	76°48′E

Table 2. Composition of buffer used for DNA extraction

Buffer	Composition
i) Extraction buffer	Tris 100 mM (pH 8.0) EDTA 50 mM (pH 8.0)$NaCl_2$ 500 mM Sodium Dodecyl Sulphate 1.25% (w/v) Sodium bisulphate 0.38 g per 100 ml of buffer
ii) TE buffer	Tris – HCl – 10 mM Disodium EDTA – 1 mM(pH made up to 8.)

in 5 ml of TE buffer; 0.5 ml of sodium acetate was added into the contents. Then the contents were mixed and two times the volume of chilled absolute ethanol was added. The genomic DNA was isolated for 30 samples and stored at – 20°C for use as a template for PCR amplification.

Electrophoresis of genomic DNA in agarose gel

The isolated genomic DNA was verified for size, intactness, homogeneity and purity by the following technique. The materials used were

Tris borate buffer (TBE) – IX

1. Tris-HCl-0.9 M
2. EDTA Na^{2+} - 0.025 M
3. Boric acid – 0.9 M

Agarose

4. Agarose 0.8 per cent w/v in TBE 1x

Gel loading buffer

5. Sucrose – 39 per cent w/v
6. Bromophenol blue – 0.25 per cent w/v
7. Xylene cyanol FF – 0.25 per cent and all w/v in TBE 1x

Staining solution

8. One mg of ethidium bromide per ml of TBE (1x)

Agarose of 0.8% was melted to dissolve completely and the gel was cast using gel casting plate. DNA samples were loaded in each well along with 2 ml of loading dye and run at a constant voltage of 75 V. The gel was placed over an UV trans-illuminator and viewed at 300 nm. The nucleic acid appeared as orange coloured intact band owing to the fluorescence of ethidium bromide.

Amplification of genomic DNA through polymerase chain reaction (PCR)

The isolated genomic DNA was subjected to polymerase chain reaction (PCR). The steps involved in PCR amplification of RAPD reaction are presented in Table 3.

The materials used were:

1. Genomic DNA : (25-30 ng)
2. Taq DNA polymerase
3. Taq assay buffer (10x) – (3 – Tris methyl amino propane sulphonic acid, pH 8.8, 8-100 mM; $MgCl_2$-15mM; KCl-500 mM; Gelatin-0.01%)
4. Sterile Milli – Q water
5. dNTP working stock – 10 mM (dATP:dTTP:dctp in 1:1:1:1 parts)
6. Random primers (decamer) (OPERON Technologies, Alameda, Calif., USA).

The reaction master mix for 15 ml PCR was prepared and are presented in Table 4.

Table 3. Details of steps involved in PCR amplification of RAPD reaction

S.No.	Steps	Temperature	Time	Cycles
1	Initial denaturation	94°C	2 minutes	-
2	Denaturation	92°C	1 minute	45 cycles
3	Annealing	36°C	1 minute	45 cycles
4	Extension	72°C	2 minutes	45 cycles
5	Final extension	72°C	10 minutes	-
6	Stand by	4°C	Infinity	-

Table 4. Reaction mixture for amplification

Reaction mix	Quantity
Template DNA	2.0 ml
dNTPs	1.2 ml
Assay buffer 10 x	1.5 ml
$MgCl_2$	1.0 ml
Primer	1.2 ml
Taq DNA polymerase	0.2 ml
Sterile Milli – Q water	12.9 ml

The reaction mixture was taken in PCR tubes and shaken gently. The tubes were placed in a thermo cycler (MJ Research Model : PTC 100) machine. The conditions for PCR are detailed in Table. 3 and the random OPERON primers used for DNA amplification furnished in Table. 5.

After the reaction was complete, the tubes were taken out and the PCR amplified products (1.5 ml) were subjected to electrophoresis in 1.5% agarose gels in 1 X TBE buffer at 120 V for 3.5 h using Hoefer ® Super submarine electrophoresis unit (Pharmacia Biotech).

RESULTS AND DISCUSSION

Genetic similarity index for all pair wise combination of seed sources were computed using binary data and are presented in Table 1. The lowest similarity coefficient value of 0.543 (highest genetic distance 0.457) was observed between seed sources Kerala III and Uttranchal (Table 1) followed by Kerala III and Tripura, which expressed the similarity value of 0.548 (genetic distance 0.452). The highest similarity coefficient was observed between Maharashtra V and Maharasthra IV (0.818) and between Kerala IV and Kerala II (0.818). Both these pair wise combinations expressed the lowest genetic distance of 0.182.

Table 5. The random OPERON primers used for DNA amplification

S.No.	Name of the primer	Sequence of the primer
1	OPO 2	5' ACGTAGCGTC 3'
2	OPO 9	5' TCCCACGCAA 3'
3	OPO 13	5' GTCAGAGTCC 3'
4	OPO 20	5' ACACACGCTG 3'
5	OPR 2	5' CACAGCTGCC 3'
6	OPR 6	5' GTCTACGGCA 3'
7	OPR 10	5' CCATTCCCCA 3'
8	OPR 11	5' GTAGCCGTCT 3'
9	OPR 15	5' GGACAACGAG 3'
10	OPM 11	5' GTCCACTGTG 3'
11	OPM 13	5' GGTGGTCAAG 3'
12	OPAP 9	5' GTGGTCCAGA 3'
13	OPAP 7	5' ACCACCCGCT 3'
14	OPAP 13	5' TGAAGCCCCT 3'
15	OPAW 16	5' TTACCCCGCT 3'
16	OPY 15	5' AGTCGCCCTT 3'
17	OPY 17	5' GACGTGGTGA 3'

Based on the genetic similarity matrix (Table 2) of 17 oligonucleotide arbitrary decamers a phenotic tree was constructed and presented in Figure 1. From the phenotic tree two major clusters could be visualized at a coefficient level of 0.61. Cluster A was the largest with 29 seed sources and the cluster B had only one seed source.

At a coefficient level of 0.64, the major cluster, A resolved into two sub clusters viz., A1 and A2. Among the two sub clusters A1 was the largest with 27 seed sources followed by A2, which contained only 2 seed sources. Cluster A1 was further resolved into three sub clusters viz., A11 and A12 and A13 at a coefficient level of 0.66. Among these three sub clusters, the sub cluster A13 had a maximum of 20 seed sources followed by A11, which had 6 seed sources, and A12, which possessed into a single seed source.

All the seed sources from Maharashtra were grouped into a single sub cluster A13. Similar trend was also noticed for all the seed sources from Tamil Nadu, which grouped under a single sub cluster. Also seed sources from Kerala grouped under a single sub cluster A13 barring Kerala III. Similarly allseed sources from Tamil Nadu and Maharashtra were grouped under the same cluster A13.

The cluster analysis revealed that some seed sources were clustered based on their geographic distribution (Tamil Nadu, Kerala and Maharashtra) barring a few seed sources, which were intermingled with the other seed sources.

DNA based RAPD techniques have been successfully utilized to detect polymorphism in many genera and species of forest trees (Mohapatra and Singhal, 2000). These techniques are instrumental in delineating accessions at several levels of differentiation starting from varieties, cultivars, land races to subspecies and species Furman *et al.* (1996) used DNA polymorphism to distinguish six closely related taxa of pines. A taxonomic relationship in different species of poplar was thoroughly investigated using this techniques (Castiglione *et al.*, 1993). Chen and Defillipps (1996) used 20 arbitrary primers to analyze the relationship among 4 accessions of Eucalyptus microcorys and their differences to *E. dalrympleana* and *Grevellia elegance*. They had also observed within species variation in *Robinia pseudoacacacia* in the same study.

In the present study, 17 arbitrary primers were used and genetic diversity was assessed. All the 17 primers expressed polymorphism and expressed variation between the seed sources. A maximum number of 14 amplified products were observed in the profile of primer OPR-10. The reproducibility of RAPD markers and their ability to differentiate between individual genotypes for verification of clonal identities were assessed in four separate studies using *Eucalyptus* (Keil and Griffin, 1994) and distinguished even very closely related genotypes. Such type of species delineation and clonal identification were performed on many other species viz., *Eucalyptus grandis* (Lang *et al.*, 1993), poplar and willow (Lin *et al.*, 1994; Auriol *et al.*, 1994). In the present study, using arbitrary primers 74 per cent of polymorphism was obtained. Similarly Chalmers *et al.* (1992) used RAPD markers to partition the genetic variation in *Gliricidia sepium* and *G. maculata* using 11 primers and obtained 60 per cent of the genetic variation between the population and 40 per cent within population. Using 15 to 18 random primers, Lakshmi *et al.* (1997) recorded polymorphism of 3.8 to 7.3 per cent in 48 genotypes of *Acanthus illicifolius*. All these studies are in corroboration with the present findings.

In the current investigation, using Jaccard's index a highest genetic distance of 0.457 was observed between Kerala III and Uttranchal and the lowest genetic distance of 0.182 was observed between Maharashtra IV and Maharashtra V and between Kerala IV and Kerala II (Table 1). Similar results had also been reported by Chalmers *et al.* (1992) using RAPD markers in *Gliricidia* species and estimated levels of genetic variation between 0.4 and 0.7. Similar trend was also observed in *Avecinia* (Parani *et al.*, 1997). Several tropical trees had also been reported to exhibit low levels of genomic variations within and between populations. Despite being sampled from geographically distinct locations, species that had wide distribution might show very low genomic variation. (Lakshmi *et al.*, 1997) and species introduced from a small genetic base could have more genomic variation also (Varghese *et al.*, 1997).

In the present study, phenotic tree indicated that the populations from each state were found to be grouped within the same cluster barring few seed sources revealing the identity of each population. The phenotic tree resolved into two major clusters (A and B) while cluster A was largest with 29 seed sources and the cluster B had only one seed source. The tree also indicated that all seed sources of Tamil Nadu and of Maharashtra were grouped into the same sub cluster A13 that revealed the similarity within the seed sources of the State. However, Nesbitt *et al.* (1995) observed that most of the variation in *Eucalyptus globulus* remained within the localities. But, variations between the localities and regions were also found to be significant. Using RAPD profiles in *Meconopsis paniculata* and *M. simplicefolia*, intra species genetic homogeneity was evident with respect to a number of primers both within and between populations (Sulaiman and Hasnain, 1996). Such low genetic variation was frequently observed in plant species due to their reproductive strategies such as selfing and vegetative propagation (Waller *et al.*, 1987), which was further reduced in small isolated population (Schwaegerle and Schaal, 1979). Similar observation of genetic variation had also been reported in the endangered plant species *Eucalyptus recurva* (Crisp, 1988) and *Pedicularis forlischae* (Waller *et al.*, 1987).

In the present investigation also, low to moderate genetic distance was observed between seed sources and low genetic distance within seed sources, which underscored further evaluation using more number of primers and also using other molecular techniques.

Statistical analysis

For all statistical analysis the computer software NTSYSpc version 2.02i developed by Rohlf (1994) was used.

RAPD data analysis

From the binary code matrices obtained from RAPD markers, the Jaccard's similarity index was computed for all pair wise combinations of teak seed sources using SIMQUAL programme of NTSYSpc as follows:

Jaccard's (1908) similarity index $Sl_{ii} = a / (n-d)$
Where,
Sl_{ii} = Similarity between ith and jth samples
a = Number of electromorphs / traits commonly shared
b = Number of electromorphs/traits present in i^{th} samples but absent in j^{th} sample
c = Number of electromorphs/traits present in j^{th} samples but absent in i^{th} sample
d = Number of electromorphs/traits absent in i^{th} and j^{th} samples but present in other samples
n = (b+c) i.e., the number of unmatches.

Estimation of genetic diversity using RAPD
Scoring of amplified products

Attempts were made to study the genetic diversity using RAPD analysis. Out of 17 arbitrary primers used for this purpose, all of them gave electromorphs across seed sources. The electromorphs were scored for their presence or absence among the seed sources in binary codes of 1 and 0 respectively.

The amplified products varied in number and intensity among the seed sources. The details of amplified products revealed by 17 primers are furnished in table 20. All together 144 amplified products were observed in the profiles of 17 primers. The maximum numbers of amplified products of 14 were observed in the profile of primer OPR 10 followed by OPO 13, OPR 15 (13) and OPY 15 (11). Out of 144 amplified products observed in 17 polymorphic primers, 107 products were polymorphic which accounted to be 74 per cent. Three primers viz., OPO 2, OPO 20 and OPO 9 were highly polymorphic in nature, which exerted 100 per cent polymorphism.

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Fertility Variation and Dynamics of Two Clonal Seed Orchards of Teak

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ABSTRACT

Fertility differences between clones were estimated in two 25-year-old Clonal Seed Orchards (CSO) of teak in South India. CSO I located at Topslip in Tamil Nadu has 15 clones and CSO II at Walayar in Kerala has 20 clones selected from Karulai (KLK), Nilambur (KLN), Sungam (KLS) and Thunakadavu (TNT) regions in Western Ghats and Bhadrachalam (SBL1) in Andhra Pradesh. In CSO I, 51% ramets of 14 clones were fertile whereas only 20% ramets of 14 clones were fertile in CSO II. Diameter growth, number of flowering branches and inflorescences per primary branch were greater in CSO I. But trees in Walayar CSO produced less inflorescence and hence despite having 21% more flowers, and twice the number of fruits in an inflorescence, produced 61% less flowers than Topslip trees. Fruit set in CSO II (947 fruits per tree) was comparable with CSO I (1024 fruits per tree). Fruit yield in both orchards was however low compared to that of a 60-year-old Seed Production Area (SPA; 4573 fruits per tree) in Nilambur. Clones selected from Karulai and Nilambur were more fertile than those from Thunakadavu and Sungam in both orchards. In CSO I, KLK1 with most number of fertile ramets, produced 17% of flowers in the orchard followed by clones KLS4, TNT7 and TNT4 together accounting for 55% of the total fruits produced. KLN1 produced maximum flowers per tree, as it had the largest number of inflorescences per primary branch and flowers per inflorescence. In CSO II, a single clone, SBL 1 produced 68% of flowers and 56% fruits in the orchard. KLK1 (22%) and KLN2 (7%) were the other major seed bearers. Drastic differences in reproductive output between clones in a CSO cause over representation of a few clones and an orchard seed bulk is likely to result in low offspring diversity and gain. Imbalance in relative flower and fruit production in clones as indicated by a Mating index, alters the mating system in the orchard.

Key words: Tectona grandis, Clonal seed orchard, Fertility, Diversity and Coancestry

INTRODUCTION

Domestication of teak in India started with the establishment of plantations as early as 1844 in Kerala state. Efforts were made to identify growth differences among seedlots collected from various natural forests in India. Identification of suitable seed sources, which included all the major teak types, for different regions was taken up in a big way with the establishment of national level provenance trials in 1973 (Kjaer *et al.*, 1995). Clonal seed orchards (CSO), which are used to combine the desirable traits and evolve new varieties, were initiated in 1962 as the main genetic improvement strategy for teak (Kedharnath and Matthews, 1962). Grafts of plus trees were used to establish over 1000 ha of CSO for conventional breeding and tree improvement (Kumaravelu, 1993). Most of the clonal seed orchards have however been plagued with poor and erratic flowering (Kumar *et al.*, 1997) and low seed output that hardly any orchard seed is used in plantation programmes. Thus seed from all available sources have been used and productivity of teak plantations has been declining steadily with each rotation.

Most of the seed for planting today comes from good plantations thinned to retain the best trees and maintained as seed stands. Seed production has been low in clonal seed orchards and large variation in phenology and seed production has also been reported (Gogate, 1993). Many of these orchards have clones selected from different ecotypes resulting in considerable asynchrony in flowering. It is generally recommended that, as many good clones from the same ecotype or provenances should be used (Nicodemus *et al.*, 2000) to have high genetic diversity in offspring (Subramanian *et al.*, 1994).

Seed orchards are production populations that transfer the gain from breeding programmes into plantations. Two aspects that determine the genetic quality of seed are the genetic value and mating system of the orchard trees. Equal contribution from each clone would result in panmixis and high genetic diversity in orchard progeny. On the other hand, variation in fertility and sexual symmetry of clones in different locations would cause differences in seed crop and hence reduction in gain. The objectives of the present study were to describe the fertility status and dynamics of two clonal seed orchards of teak, to compare the mating conditions in the orchards with that of a productive seed production area and to

Table 1. Mean values of flowering traits in teak CSO and SPA

				Top slip CSO I			
Clone	*DBH(cm)*	*Infl/ PriBr*	*Fruits/infl*	*PriBr*	*Flrs/Infl*	*Fruits/ tree*	*Flrs/tree*
KLK1	35.27	7.50	32.0	8.0	3100	1960	188550
KLK2	46.18	6.5	16.0	7.57	2204	695	139006
KLN1	35.19	11.0	30.0	6.50	4452	1960	319124
KLN2	33.01	5.0	22.0	8.67	1522	945	64144
KLS1	36.62	4.0	30.0	6.75	2512	1083	83540
KLS2	46.26	6.50	39.0	7.75	2733	1822	124118
KLS3	34.39	1.75	28.0	4.25	3999	514	50701
KLS4	38.77	4.50	22.0	7.25	3062	1000	135594
TNT2	41.88	4.50	32.0	3.25	2883	502	59370
TNT3	35.67	3.0	28.0	3.67	3000	327	28722
TNT4	33.68	8.50	23.0	7.50	2929	2150	216539
TNT5	47.29	2.75	16.0	3.75	1839	165	22536
TNT6	33.92	4.0	15.0	4.25	2644	357	57544
TNT7	36.54	7.50	18.0	6.0	2862	863	140950
Sed	4.242	2.205	9.75	1.961	690.9	841.5	75147
Mean	38.19	5.54	25.0	6.09	2839	1024	116460
				Walayar CSO II			
KLK1	33.40	3.50	87.0	4.30	5310	2072	116068
KLK2	36.0	1.0	69.0	1.0	4450	69	4450
KLN1	25.0	3.0	16.0	8.0	2660	382	63840
KLN2	36.90	2.0	111.0	4.30	2269	927	19194
KLN4	25.87	1.67	49.0	3.0	2418	233	13584
SBL1	30.15	7.30	37.0	8.30	3307	1826	174637
TNT1	31.50	1.67	77.0	3.30	2739	516	18599
TNT10	40.50	1.0	67.0	1.0	4448	67	4448
TNT11	31.0	1.5	71.0	3.0	4505	320	20275
TNT15	19.80	2.0	51.0	4.0	1748	408	13983
TNT16	34.80	1.60	68.0	3.0	3289	469	16722
TNT20	35.10	2.0	36.0	3.50	4980	284	42453
TNT5	22.60	2.0	41.0	3.0	2080	246	12480
TNT6	39.90	3.0	51.0	5.50	2487	840	47763
Sed	2.438	1.241	24.06	1.002	1270	769	42167
Mean	31.53	3.40	58.0	4.90	3436	947	72363
Nilambur SPA							
Mean	54.76	10.53	44.0	9.0	3051	4573	290207

Table 2. Mean values of the flowering traits of regions of origin in two CSOs

Region	*DBH(cm)*	*Infl/ PriBr*	*Fruits/infl*	*PriBr*	*Flrs/Infl*	*Fruits/ tree*	*Flrs/tree*
Top slip CSO I							
Karulai	40.72	7.25	23.0	7.83	2652	1328	163778
Nilambur	34.10	8.0	26.0	7.58	2987	1452	191634
Sungam	39.01	4.19	29.0	6.50	3077	1105	98488
Thunakadavu	38.16	5.04	22.0	4.74	2693	727	87610
Sed	3.0ns	1.60*	6.89ns	1.132*	696ns	631ns	53640ns
Mean	38.19	5.54	25	6.09	2839	1024	116460
Walayar CSO II							
Karulai	34.70	2.30	77.0	2.70	4879	1069	60258
Nilambur	29.30	2.20	58.0	5.10	2449	490	32206
Thunakadavu	32.0	1.90	56.0	3.30	3110	404	22350
Bhadrachalam	30.20	7.30	37.0	8.30	3307	1826	174636
Sed	1.829*	0.931**	18.04ns	0.751**	952.3ns	577ns	31626**
Mean	31.53	3.40	57	4.9	3436	947	72363

predict the extent of inbreeding in the orchards.

MATERIALS AND METHODS

The seed orchards

The study was conducted in two 25-year-old clonal seed orchards of teak located in South India. CSO I, located in Topslip (10^0 25'N, 76^0 50'E; 2080mm rainfall), Tamil nadu has 15 clones of plus trees selected from natural forests of Karulai (KLK), Nilambur (KLN), Sungam (KLS) and Thunakadavu (TNT) regions of Western Ghats. CSO II is located at Walayar (10^0 50'N, 76^0 50'E; 1500mm rainfall) in Kerala state. This orchard has 19 clones selected from the same regions as CSO I, and one clone (SBL1) selected from Bhadrachalam in Andhra Pradesh. A random row column design with singletree plots was used in both orchards. CSO I had 20 ramets of each clone established at a spacing of 5m and CSO II had 35 ramets for each clone at a spacing of 5m It was assumed that there was no pollen contamination in the orchard and that the clones were not related.

Recording fertility of trees

All ramets in both orchards were scored according to high, medium and low fertility classes during periodic visits made from May to November 2002. Six ramets of each clone (2 each for high, medium and low fertility classes) were assessed using methodology of Bila *et al.* (1999) for estimating flower and fruit production. The number of primary branches bearing flowers was recorded from the ground. The number of secondary branches bearing inflorescences in a primary branch and the number of inflorescences in a representative primary branch was recorded by climbing the trees and carefully cutting and lowering the branch. The number of fruits per primary branch was recorded in each tree. The number of flowers in a sample inflorescence was estimated during the bud stage using the methodology of flower arrangement in a dichasia (Nagarajan *et al.*, 1996). The number of flowers and fruits per tree was extrapolated from the above estimates (Bila *et al.*, 1999). The DBH was recorded for each tree.

15 randomly selected trees in a 60-year-old seed production area (Nellikutha, Vazhikadavu range) in Nilambur (11^0 17'N, 77^0 14'E; 2580mm rainfall) were studied using the same methodology to estimate the flower and seed production in each tree.

Data analysis

DBH and the estimated parameters – Inflorescences per primary branch (*Infl/ PriBr*), Primary branches with inflorescences (*PriBr*), Fruits per inflorescence (*Fruits/ infl*), Flowers per inflorescence (*Flrs/ infl*), Fruits per tree (*Fruits/ tree*) and Flowers per tree (*Flrs/ tree*) were statistically analysed using the software Genstat. Analysis of variance was performed for each trait to study the differences between clones and

Table 3. Flower and fruit production and mating index of CSO and SPA

Top slip CSO				Walayar CSO				Nilambur SPA			
Clone	% Flowers	% Fruits	Mating-index	Clone	% Flowers	% Fruits	Mating-index	Tree	% Flowers	% Fruits	Mating-index
KLK1	18.42	21.56	1.17	KLK1	15.92	22.08	1.39	T41	9.90	6.80	0.69
KLK2	9.51	5.35	0.56	KLK2	0.11	0.13	1.17	T42	27.14	25.10	0.92
KLN1	6.24	4.31	0.69	KLN1	3.18	1.21	0.38	T43	5.64	6.72	1.19
KLN2	1.88	3.12	1.66	KLN2	1.92	7.18	3.75	T45	5.11	4.87	0.95
KLS1	4.08	5.96	1.46	KLN4	2.37	3.15	1.33	T46	2.91	2.14	0.74
KLS2	9.70	16.0	1.65	SBL1	67.50	54.81	0.81	T47	1.70	1.05	0.62
KLS3	1.98	32.26	1.14	TNT1	0.93	2.0	2.16	T49	3.19	1.89	0.59
KLS4	14.57	12.10	0.83	TNT10	0.06	0.06	1.17	PT	8.98	5.61	0.63
TNT2	1.74	1.65	0.95	TNT11	0.25	0.31	1.22	T50	3.92	5.51	1.40
TNT3	1.40	1.80	1.28	TNT15	0.17	0.40	2.27	T52	1.33	0.98	0.74
TNT4	10.58	11.82	1.12	TNT16	0.63	1.36	2.18	T53	5.67	14.37	2.54
TNT5	2.20	1.81	0.82	TNT20	2.65	1.38	0.52	T54	5.94	4.78	0.80
TNT6	3.94	2.75	0.70	TNT5	0.16	0.24	1.53	T55	7.92	7.35	0.93
TNT7	13.77	9.49	0.69	TNT6	4.17	5.69	1.37	T56	5.84	10.51	1.80
								T44	4.80	2.33	0.49
Mean			1.05				1.52				1.00

between regions of origin of clones by nesting clones within regions. The estimated values of flower and fruit production in each clone were used to determine the overall male and female contribution of a clone in a CSO and different trees in the SPA. A mating index was computed as the ratio of percentage fruit production to percentage flower production of the clone and trees in SPA. This mating index was used to study the mating conditions in the orchard.

Results

The two clonal seed orchards differed in some of the flowering traits. CSO I (Topslip) produced more flowers (1,16,460) per tree compared to CSO II (72,363 flowers) but fruits produced per tree were comparable (1024 per tree in CSO I and 947 fruits in CSO I) in both orchards (Table 1). Topslip CSO also had trees with larger DBH and more Primary branches with inflorescences and inflorescences per primary branch. CSO II however produced more flowers and fruits per inflorescence.

CSO I (Topslip)

51% of ramets belonging to 14 clones were fertile in this orchard. Only one clone TNT1 (selection from Thunakadavu) was not fertile. More than 50% ramets in most clones had flowered. Only three clones namely TNT2, KLN2 and KLN1 had many non-flowering ramets (up to 72%). Significant variation was observed in number of inflorescences per primary branch and flowers per inflorescence but comparatively less variation was seen in fruits per inflorescence or overall fruits produced per tree. There was also not much difference in the number of inflorescence - bearing primary branches. Three TNT clones (TNT2, 3 and 5) had comparatively lower number of productive primary branches. KLN1 had significantly more inflorescences per primary branch (11) compared to KLS3, TNT3 and TNT5 (2 -3).

The flowers produced per tree have high correlation to the number of primary branches and inflorescences per primary branch (Table 4). The number of fruits produced per tree is highly correlated to flowers per tree and inflorescences per primary branch but less correlated to fruits per inflorescence. The clones KLK1, KLS4, TNT4, TNT7 and KLS2 were the major seed (10 -17%) and flower (9-22%) producers in the orchard.

CSO II (Walayar)

Only 20% of existing ramets in 14 clones were fertile in this orchard. Six clones namely KLS 1, 2, 3 and 4 (selections from Sungam region) and TNT 3 and 4

Table 4. Phenotypic correlation between reproductive and growth traits in CSO and SPA Walayar CSO

	DBH	*PriBr.*	*Infl/ PBr*	*Fruits/ infl*	*Flrs/ infl*	*Fruits/ tree*	*Flrs/ tree*
DBH	1						
PriBr.	-0.268	1					
Infl/PBr	-0.118	0.824	1				
Fruits/infl	0.474	-0.446	-0.307	1			
Flr/infl	0.520	-0.299	-0.041	0.176	1		
Fruits/tree	0.110	0.560	0.779	0.239	0.171	1	
Flr/tree	-0.020	0.757	0.950	-0.227	0.216	0.857	1
Topslip CSO							
DBH	1						
PriBr.	-0.093	1					
Infl/PBr	-0.098	0.573	1				
Fruits/infl	-0.044	0.094	0.121	1			
Flr/infl	-0.351	-0.174	0.312	0.433	1		
Fruits/tree	-0.211	0.709	0.792	0.488	0.348	1	
Flr/tree	-0.197	0.544	0.934	0.184	0.538	0.835	1
Nilambur SPA							
DBH	1						
PriBr.	0.597	1					
Infl/PBr	0.558	0.454	1				
Fruits/infl	0.207	0.067	0.054	1			
Flr/infl	-0.294	-0.330	-0.230	0.285	1		
Fruits/tree	0.646	0.687	0.873	0.351	-0.197	1	
Flr/tree	0.462	0.596	0.884	0.037	0.043	0.873	1

(selections from Thunakadavu region) were not fertile. Clones differed markedly in diameter growth and number of primary branches with inflorescences (Table 1). The clone SBL1 had the largest number of inflorescence bearing primary branches (8.3) and inflorescences per primary branch (7.3). Though not significantly different, SBL 1 produced less flowers per inflorescence (3307) compared to KLK1 (5310) and TNT20 (4980).

Though the clones did not vary much in number of fruits produced per tree, there was considerable difference in overall flowers and fruits produced by all ramets of each clone. SBL1 (with 91% fertile ramets) produced 68% of the flowers (Fig 4) and 56% of total fruits produced in the orchard (Fig. 3). KLK1 was the other major productive clone (16% flowers and 22% of fruits) in the orchard. The clone KLN2 also contributed more to fruit production (7%) than pollen (2%) in the orchard. Five clones namely TNT15, TNT11, TNT10, TNT5 and KLK2 had only few fertile ramets (4-9%) and hence contributed less than 1% flowers produced in the orchard (Table 3). As seen in CSO I, fruit production per tree is highly correlated to flowers per tree and number of primary branches bearing fruits but not with number of fruits per inflorescence. Flower production per tree is influenced mostly by number of productive primary branches and inflorescences per primary branch.

Nilambur SPA

Trees in the 60-year-old SPA were larger than the orchard trees with greater number of fruit bearing primary branches and inflorescences per primary branch, thus producing more flowers (2,90,207) and fruits (4573) per tree. The number of fruits and flowers per inflorescence was on par with the CSO II but produced more fruits than Topslip CSO. Tree wise contribution of flowers and fruits among the 15 trees in the SPA varied from 1-27% flowers and 1-25% fruits (Table 3). Among the 15 trees, 4 trees contributed 54% flowers and 50% of total fruits produced. A plus tree (PT) marked in the SPA contributed only 9% flowers and 6% of fruits (Table 3). Phenotypic correlation values of fruits and flowers produced per tree with other traits are more or less similar as in CSOs. There is however a higher correlation of flower and fruit production with the diameter of the tree as the trees are of seed origin.

Region of origin of clones

Clones in the clonal orchards represent four regions in the Western Ghats (KLK, KLN, KLS and TNT) and one region near the Eastern Ghats (SBL). The Western Ghats regions could be classified into two – Karulai (KLK) and Nilambur (KLN) as one and Sungam (KLS) and Thunakadavu (TNT) as another group. This trend was evident in CSO I where KLK and KLN clones had more inflorescences per primary branch compared to KLS and TNT clones (Table 2). This trend was less prominent in the number of primary branches bearing flowers where TNT clones had fewer productive primary branches. Though not statistically significant, such a trend was evident also in flowers and fruits produced per tree. There was however no significant region specific difference in diameter growth of trees and fruits and flowers per inflorescence.

In CSO II, all the KLS clones as well as 2 TNT clones were not fertile. No definite region wise trend was observed in any of the parameters in this orchard. SBL1 had significantly more productive primary branches and inflorescences per primary branch thus producing large number of flowers per tree compared to the other regions. There was however no significant difference in the number of fruits and flowers produced per inflorescence or tree.

Mating index

Mating index value that explains the relative female and male contribution of trees in the orchard is close to 1 in CSO I and SPA (Table 3). This indicates equal male and female function of trees and uniform contribution of trees in the stand. Considerable variation in values (0.38-3.75) was observed among clones in CSO II (with a mean value of 1.52) indicating imbalance in female and male function of clones.

DISCUSSION

Despite the fact that teak planting has been in practice for more than a century, domestication of this important timber species is still in its infancy. The major problems encountered in successful domestication are high fertility differences between trees; non-synchronous flowering and poor seed set (coupled with poor germination) that will result in enormous gene loss with each successive generation. Much of the gene loss occurs in the first generation when the species is shifted from the native forests to a modified environment.

Fertility status of seed orchards

Many clonal seed orchards of teak established in India have a few clones (mean= 30) selected from different teak regions (Kumar *et al.*, 1998). Clones when shifted across regions tend to retain the reproductive phenology of the parent location resulting in asynchrony or poor overlap in flowering (Vasudeva *et al.*, 2000). Thus selection of suitable clones for a particular location assumes considerable importance. This is evident from the results obtained in the two CSOs. SBL1 shifted from a semi moist eastern location has shown high fertility but comparatively low fruit set per inflorescence in CSO II (see Table 2). The large number of flowers produced by this single clone not only leads to inbred progeny resulting from early flowering of the clone (Nicodemus *et al.*, 2000) but also lowers the genetic diversity of the orchard progeny. This has been demonstrated in the poor growth of SBL1 offspring in progeny trials (Nagarajan *et al.*, 1996b) The Topslip CSO produced 8% more fruits and 61% more flowers per tree than CSO II. The genetic quality of the seeds obtained would be very different due to the fact that 68% of the flowers produced in the orchard are from one single clone. Comparison of fruit production in clones common to both orchards shows that three clones KLN2, TNT5 and KLK1 have similar performance in both orchards, indicating a genetic influence where as two clones KLN1and KLK2 show better fertility at Topslip and TNT6 behaving the opposite way. Clones selected from Karulai and Nilambur (which are located geographically very close) have higher fertility than clones selected from Sungam and Thunakadavu. It is interesting to note that clones selected from regions proximal to Topslip (Sungam and Thunakadavu) have low fertility in the CSO at Topslip. Similar results were reported in studies conducted in CSO in Karnataka (Gunaga and Vasudeva, 2002). Teak is believed to have an inherent problem of low fruit set (Nagarajan *et al.*, 1996a). A comparison of seed production in both CSOs revealed that 3 traits, which decide the quantity of flower and fruit production, are 1. Number of primary branches bearing inflorescence, 2. Number of inflorescences per primary branch and 3. Number of flowers and fruits produced per inflorescence. Of these traits, the number of fruits set per inflorescence seems to be less variable between clones for a location (see Table 1). In CSO II, a few clones (KLN2 and KLK1) had big inflorescences and hence comparatively more fruits per inflorescence. SBL1, which produced large number of inflorescences, had low fruit set in an inflorescence. This trait however varies drastically between locations and in general there is greater variation in CSO II for this trait (see Table 2). This may be because of the lower number of inflorescences produced per primary branch (63% less) in CSO II (except SBL1). Fruit production per inflorescence reported in a CSO in Karnataka tally with the values obtained in CSO I (Gunaga and Vasudeva, 2002).

Breeding options in teak

Teak forest is considered to have adequate genetic diversity with substantial between and within population differentiation (Kjaer *et al.*, 1995). Conventional breeding strategies aim to select outstanding trees and transfer the gain obtained to the next generation. Tree improvement however needs genetic diversity for continued gain in subsequent generations and loss in diversity essentially means loss of options for adapting to changes in environment (Suangtho *et al.* 1999). Low intensity and high intensity breeding options can be considered to have an aggressive or conservative breeding strategy (Lindgren, 2000). Clonal seed orchards established from intensively selected trees are high intensity breeding strategies. Extensive Breeding Seedling Orchards (EBSO) established from bulked seed collections from large number of good trees (Kjaer *et al.*, 1999) is a low intensity breeding option that gives modest gains but are efficient in conserving diversity as they may retain progeny of large number of parent trees even after phenotypic thinning (Harwood *et al.*, 1996). Low intensity breeding is also useful to capture the within-population variation (about 80% of total variation in teak) as shown by isozyme and RAPD marker studies (Kertadikara and Prat, 1995; Changtragoon, 2000).

The present study can be used to compare the breeding options in teak. Since seed production tends to be low in teak, fertility status of the tree should be considered while selecting trees. The plus tree (PT) identified in Nilambur SPA if selected would not be a good seed producer (Table 3). Thus very intensive selection of a few trees without considering the fertility status would not really increase gain. Instead, if the best seed producers (T 42, 53, 56, 55, 41 and 43) were also selected after a round of thinning to eliminate the inferior trees (the SPA has been rouged to retain good trees), better seed production would be possible in the orchard with reduced genetic drift during domestication. Large number of trees can be included in an orchard only if low intensity breeding strategies are adopted in the initial stages of domestication. Moreover since seeds are used for raising the orchard, selection for fertility is achieved automatically. When the number of inflorescences is less, they tend to be large as seen in CSO II leading to greater chances of self-pollination. Efforts should be to have large number of inflorescences in all the trees. This would provide adequate pollen pool in the orchard and reduce chances of pollen contamination. The number of productive primary branches and inflorescences per primary branch has a high positive correlation with flowers and fruits produced per tree in both CSOs and the SPA. Similarly there is a high correlation between flowers and fruits produced per tree. Thus efforts should be to enhance the number of flowers and fruits produced in each tree. In the SPA, the traits like productive primary branches, inflorescences per primary branch and flowers and fruits produced per tree are positively correlated to tree growth (diameter). This trend is not seen in the CSOs, which seems to be the major hurdle in increasing seed production in clonal orchards. Grafted trees tend to behave differently from seed origin trees, which results in atleast 4 times greater seed production in the SPA.

The performance of clones in different orchards would have to be monitored closely before collecting seeds for planting. Also there may not be enough seeds to meet the requirement. Hence much of the seed requirement has to be met from rouged plantations (often regenerated from few parent trees) used as SPAs (Nagarajan *et al.*, 1996a). A low input strategy like ESBO would enable not only sufficient seed (as fertility of trees is ensured) supply but also promote outcrossing resulting from pollen produced from several trees. Thus large seed production areas will have to be established for adequate seed supply since grafted seed orchards have limitations, which are not fully, understood (Kjaer *et al.*, 1999).

Mating conditions in seed orchards

Variation in flower production and the relative contribution of each clone in seed production will decide the extent of deviation from panmixis in an orchard. The mating conditions in the two CSOs and SPA differ mainly with regard to the relative contribution of flowers and fruits of trees. A general lack of flower and fruit production in many clones in CSO II (84% of flowers produced by just two clones) would lead to over representation of a few clones in orchard progeny. Differential gamete production will have a serious impact on genetic diversity and effective population size (Lindgren and Mullin, 1998) of the orchard. The group co-ancestry in such an orchard will be very high leading to increased inbreeding in subsequent generations (Kang and Lindgren, 1999). This can also be understood from the Mating index values of clones and the orchard. High or low mating index values indicate unequal contribution of gametes to the orchard progeny. This would result in high genetic drift with each generation. Inbreeding is reported to be high when flowering is poor and unbalanced among clones (Kjaer, 1996).

The mating conditions in CSO I and SPA appear to be similar with identical relative contribution of trees – 27% of clones contributed 57% of flowers in CSO I as against 54% of flowers and from the same percentage of trees in the SPA. The different trend is indicated by the Mating index values of CSO I and SPA compared to CSO II (10% clones producing 84% flowers). Bila *et al.* (1999) reported similar values (20% trees contributing 55% gametes) in a 60-year-old exotic teak plantation in Mozambique, though fruit set is reported to be high there.

Excessive fertility in certain clones can be controlled by intentionally adjusting the number of ramets in those clones (Kang *et al.*, 2001). If information on the fertility of each clone is available, the desired gamete contribution can be obtained by fixing the number of ramets in each clone (Hodge and White, 1993). When information from progeny tests are available, the number of ramets in each clone could also be fixed taking into account the breeding value of the clone. Genetic thinning can be done to reduce the number of ramets of clones with low breeding values (Bondesson and Lindgren, 1993). Progeny performance will however be decided by the mating conditions in the orchard as seen in recent progeny data of SBL1 in CSO II (Nagarajan *et al.*, 1996b). Reliable family information would be obtained if seeds of the mother tree were also collected for progeny testing along with the grafts for orchard establishment. Measures like equal seed collection from all clones (Kang and Lindgren, 1999) and retaining additional pollen parents (Varghese *et al.*, 2002) are also useful in correcting impact of fertility differences in orchards. When progeny tests of large number of parent trees is done, based on early evaluation, combined parent and offspring seed orchards (Hodge and White, 1993) can be considered, where backward selection of outstanding parents and forward selection of remaining families would be done. This would take care of adequate supply of pollen in the orchard.

CONCLUSION

Fertility of the selected trees, suitability of clones to a particular location and site conditions are important in determining seed output from an orchard. Quantum of rainfall seems to be an important factor as seen in this study for selecting a site for an orchard. Trees should be selected from the same geographical location for synchronised and uniform flowering. Mating conditions in a CSO would approach that of an SPA (as seen in Top slip CSO) when locally selected clones are located in the same region. Shifting of clone to a different location (as seen in Walayar CSO) may not help in improving the quality of planting stock. With all these precautions seed production may still be low in a CSO as seed produced is dependent on the number of primary branches bearing inflorescences and number of inflorescences in a branch, which can be increased with better growth in seed origin trees. Until sufficient seed from ideal orchards is available, planned seed production areas will continue to be the viable alternative for meeting the seed requirement. Orchards should be large enough with sufficient isolation to prevent pollen contamination. Suitable growth promoters can also be tried to enhance seed production. Thus judicious selection of clones, locating them in ideal conditions and inducing flowering along with collection of equal quantities of seed from each clone are the options available for production of quality planting stock in teak.

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Why Teak Seed Orchards are Low Productive?

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ABSTRACT

The efforts made to produce improved seeds through teak seed orchards have become a futile exercise since, contradictory to the tree breeders' expectations, the grafts in teak seed orchards in general are not flowering and fruiting sufficiently. Kerala Forest Research Institute has established three pilot teak clonal seed orchards at three different locations in Kerala, India to examine various factors affecting the growth as well as flowering and fruiting potential of these grafts in addition to the economic value of improved seeds. The observations show that the percentage of grafts in flower varies from place to place with a value of almost zero to 11.5 even after 15 years of establishment. Observations also show that soil properties as well as spacing between grafts affect flowering. Interaction between orchard site and clone origin is also seen. When plus trees are selected, the flowering and fruiting behaviour are not properly cared for, since these trees are mainly selected for vegetative vigour and tree form with less branching. The correlated response if any, that increases the juvenile period and decreases the flowering, is not accounted for during seed orchard establishment. This paper analyses the factors affecting flowering of teak grafts such as choice of plus trees, rootstock and planting site, the light intensity, soil fertility and growth vigour. By controlling these factors, an increase in flowering and fruiting is expected in teak seed orchards.

Keywords: Flowering in teak grafts, Effect of light on flowering, Effect of spacing on flowering, choice of root stock

INTRODUCTION

Teak (*Tectona grandis* Linn.f.) is one of the most valuable tropical timber species naturally grown in few countries of South-East Asia. Due to its unique wood properties, it also has been widely planted outside its natural range. Today it is of major importance in many plantation programmes throughout the tropics. Teak, being adapted to a wide range of climatic and edaphic conditions, is preferred for large scale plantation programmes in India. Teak improvement programmes were started in India during early sixties and through these programmes seed production areas and seed orchards were established through out the teak growing states in India. Open pollinated seeds from these stands are expected to produce high yielding progenies but the poor flowering and low seed production has shattered the expectations of the teak breeders. At present there is an acute shortage of high yielding and good quality teak seeds though seed production areas and seed orchards are established in various states in a large scale. Though thousands of flowers are produced per tree in plantations and natural forests, only less than 1 percent turn to mature fruits. In seed orchards the situation is still worse where flowering also is found be very low. As a result, the forest managers are forced to raise planting materials from whatever seeds are available. In such a situation the breeding programmes will become a futile exercise.

The poor flowering and fruit setting in Teak seed orchards in Kerala and elsewhere needs to be investigated in detail in the light of experience in other species as well as the observations taken from teak seed orchards. The observations taken from the experimental teak seed orchards established by KFRI is anlysed in this paper, which will be helpful in solving the problems of low flowering in teak seed orchards.

MATERIALS AND METHODS

KFRI has established three pilot teak seed orchards in different localities of Kerala State for experimental purpose. They are located in North, Central and Southern regions. The number of clones, locations and the planting area are given in Table 1. The buds from the upper one- third crown of the plus trees were collected and grafts were prepared during February and March. The rootstocks were collected from the forest nurseries. The grafts were planted with 8 x 8m quincuncial spacing (actual spacing between two ramets is 5.7m, when the grafts were 3 to 4 months old. The soils from all the three seed orchards were collected and analysed for estimating the organic carbon, pH and exchangeable bases, gravel, sand, silt and clay. Observations and measurements were taken on survival, growth and flowering and fruiting behaviour.

OBSERVATIONS AND DISCUSSION

During the first four years, only very few ramets/ clones flowered. On 5th year a survey was conducted to collect the data on flowering (Table 2). At Palappilly only one ramet each of 3 clones (0.5%) were flowered while at Arippa 14 clones with a total of 42 ramets (7.8%) flowered. At the age of 10 years, 62 ramets belonging to 19 clones (11.5%) flowered at Arippa whereas in Palappilly, 43 ramets belonging to 15 clones (8%) flowered. At the age of 15 years only 15 ramets of 10 clones (2.8%) flowered in palappilly and 6.1% of the total ramets flowered in Arippa. In Nilambur orchard, the grafts had stunted growth and flowers were not initiated for many years. When the grafts were 10 years old, one ramet each of 3 clones and at 15th year 5 ramets of 3 clones were flowered. In general in all the years the number of clones and ramets flowered at Arippa were higher.

Interaction between orchard site and clone origin was also seen. At 10th year 6 out of 8 Nilambur clones were flowered at Palappilly (though not all the ramets), where as at Arippa only 3 out of 12 clones from Nilambur were flowered. The percentage of Arienkavu clones flowered was almost same at both the localities, viz. 6 out of 9 clones at Palappilly and 6 out of 10 clones at Arippa (Fig. 1 and 2). Hence, care should be taken while assembling the clones in the orchard.

In the production seed orchard established by the Kerala Forest Department (KFD) at Kalluvettamkuzhi near Arippa, flowering and fruiting is slightly higher than the pilot teak seed orchard established by KFRI at Arippa. In the orchard at Kalluvettamkuzhy, spacing is wider than KFRI orchards. But nowhere profuse flowering is seen.

The analysis of soil properties of the orchard sites revealed that the soil at Arippa has more organic carbon (2.13%), pH (6.02) and more exchangeable bases (13.14 me/100g^1) which are some of the factors that improve growth of teak (Table 3). The values for organic carbon, pH and exchangeable bases at Palappilly are 1.1%, 5.66 and 6.1 me/100g^1 and that of Nilambur are 1.47%, 5.9 and 7.24 me/100g^1. Though the surface soil at Nilambur is fertile, the soil down is lateritic at this particular site. Moreover water logging also affected the growth of grafts. The soil has only 3.8% silt and 17% gravel where as the

Table. 1 Details of Pilot Teak Seed orchards

Locations and Forest Divisions	Nilambur Nilambur	Palappilly Chalakudy	Arippa Trivandrum
Latitudeand Longitude	110 9'N760 E	100 26' N760 24'E	80 50'N770 9'E
Altitude (m)	35	40	100
Rainfall (mm)	2600	3000	3000
Temperature (^{0}C)	16-35	18-41	16-35
Number of clones	17	20	25
Area in ha	2.5	1.8	1.8
Year of planting	1979 and1980	1981	1981

Table 2. Flowering in seed orchards

Year after Establishment	Percentage of clones in flower		
	Arippa	Palappilly	Nilambur
5th year	7.8	0.5	No clone
10th year	11.5	8.0	0.3
15th year	6.1	2.8	0.5

soil at Arippa has 5.2 % silt and 41.4% gravel and that of Palappilly has 7% silt and 34.8% gravel.
In the light of our observations as well as the experience of others in teak and other species, the reasons for low flowering and fruiting in teak seed orchards are discussed below.

Tree breeders' priority

In an orchard of horticultural species, one or two clones, selected intensively for heavy flowering and fruit set are planted. On the other hand, a forest tree breeder deals with many clones in an orchard, selects trees for huge size, less branching and good tree form. The flowering and fruiting behaviour is often not properly cared for when plus trees are selected. According to (Linhart *et al.*, 1979)since trees are selected for higher vegetative vigour, any correlated response that increases the juvenile period and decreases the flowering would push backward the success of seed orchard . They also pointed out that tree breeders have two conflicting interests. By using the same plus trees, tree breeders want to reduce the juvenility in seed orchards while trying to extend the juvenility in plantations for more biomass.

The choice of rootstock

In fruit trees, proper choice of rootstocks is commonly practised to shorten the juvenile period. An inhibition of vegetative growth, a shorter juvenile period, an increase in number and quality of flowers and fruits are the expected influence of rootstocks on grafts. Krusche and Melchior (1977) have reported that Norway spruce grafts planted at a forest site were not flowered even 24 years after grafting. They noted wide variation in height growth, flowering and fruiting behaviour between different graft combinations (scion-rootstock combination) of the same grafted clone. Early flowering individuals as rootstocks can stimulate flowering and fruit setting and additionally shorten the juvenile period (Zimmermann, 1972). Hence, early and heavy flowering and fruiting trees should be tested on their

Fig. 1 Flowering in Teak clones at Palappilly

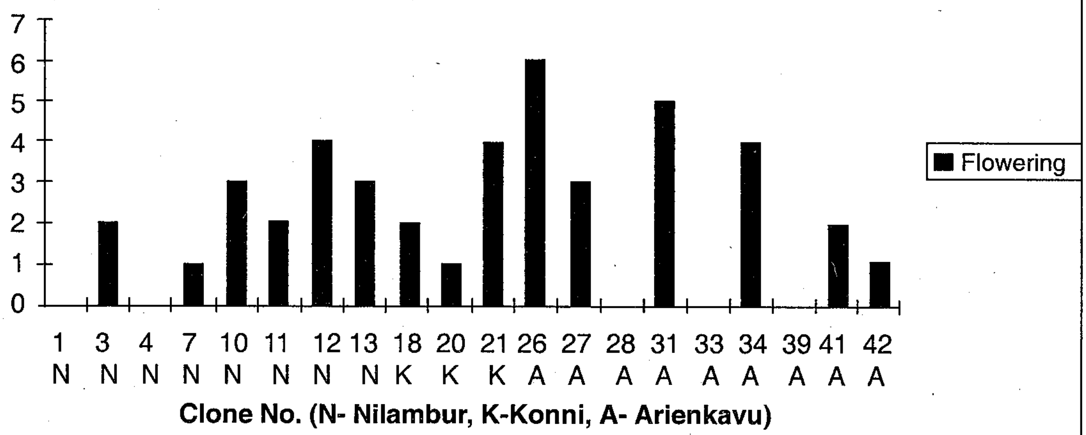
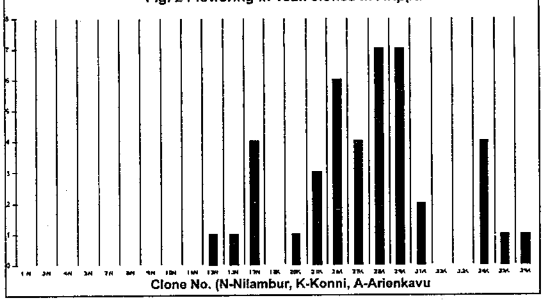


Fig. 2 Flowering in Teak clones in Arippa



influence as rootstock on flower stimulation and shortening the long juvenile phase.

Site variation

Site variation has a profound effect on flowering. Our observations show that among the three orchard sites, Arippa is the best one for more flowering and fruiting followed by Palappilly (Table 3). But at Arippa, clones from Nilambur are not flowering properly which implies clone-site interaction. The plants in the seed orchard at Nilambur have stunted growth and practically no flowering is seen even after 20 years. Ramachandra *et al.* (2001) reported that teak clonal seed orchards in good sites in Karnataka, India, produce about 30 to 50 kg seed/ ha while in the wet zone the quantity of seeds produced is lower. Hence, new orchards are established in the transitional dry zone of the state assuming to produce more quantity of seeds. Sweet and Krugman (1977) also suggest the correct choice of site for good flowering and fruiting. They also added that in *Pinus radiata,* cone production per ha in good sites was 7 times more than average sites and 40 times more than the poor sites. Proper choice of sites also reduces the periodicity of flowering in some species. Kaosa-ard and Kjaer (1998) have found that clonal seed orchards established in unsuitable areas in Thailand is one of the reasons for low fruit productivity.

Fertility of soil

Krusche and Melchior (1977) have reported that Norway spruce grafts growing on the forest site flowered differently depending on the soil. Flowering was found to be more on the fertile soil while it was found to be poor in the rather infertile soil. So also is our observation with teak orchards. The site at Arippa is more fertile than the other two sites.

Cultural treatments such as the application of nitrogen fertilizer, plant growth substances, and physical treatments to root, stem and crown have all been successful in increasing the total flower production (Sweet and Krugman, 1977). They also noted that the existing treatments generally increase flowering in clones, which already flower well, but they have minimal effect on poor flowering clones. The second problem is the clone- treatment interaction reported by many workers.

Water availability

Water availability is a critical factor in the initiation of flowering in most tropical trees. Wood (1956) reported that the Dipterocarps in peat swamps may flower less frequently when compared to those in more fertile dry land areas. As mentioned earlier, Teak clonal seed orchards in the wet zone of Karnataka state produce less the quantity of seeds (Ramachandra *et al.*, 2001).

Light intensity

Nanda (1962) reported that teak trees growing in close stands are tall and having very few branches and noted that in these stands flowering is seen only in dominant and co-dominant trees and is confined to the upper parts which are exposed to sunlight. Hedegart (1976) and Bila *et al.* (1999) also reported that in teak stands,

Table. 3 Effects of site variation on flowering

Character	Arippa orchard	Palappilly orchard	Nilambur orchard
Organic Carbon	2.13	1.1	1.47
pH	6.02	5.66	5.7
Exchangeable bases	13.4	6.1	7.24
Silt	5.2	7	3.8
Gravel	41.4	34.8	17
Sand	83.4	81	85.4

flower and fruit production are higher in dominant and co-dominant trees and that the best competitors are the successful parents. Curtailment of light delays not only the initiation of flower buds but also their development into flowers as well as in production and ripening of fruits. High solar irradiance also enhances flowering in branches of teak. In the seed orchard at Kalluvettamkuzhy where more flowering is seen, the spacing is 10 x 10m whereas in orchards at Nilambur, Arippa and Palappilly, where less flowering is observed, it is around 5.7 m. Hence, it is very essential to thin the seed orchards, give wider spacing and manage the crown accordingly to expose them to maximum sunlight.

Correlation between growth and flowering

Our observations indicate that teak plus trees in general show low flowering and fruiting, probably due to less number of branches. A weak, positive and significant correlation between growth and number of inflorescences and fruits was reported in teak (Bila *et al.*, 1999). Experiments by them also show that, though vigorous trees tend to produce more inflorescences and flowers, much of the reproductive variation has causes other than the overall size of the tree or the suppression by neighbouring trees. In *Pinus taeda*, negative genetic correlation between flowering and stem growth up to an age of ten years was reported by Schmidtling (1981).

CONCLUSION

From the observations it could be inferred that, a combination of many factors affect flowering and fruiting in teak seed orchards. Care should be taken to select the best site with fertile soil and to give wider spacing when seed orchards are established. When plus trees are selected, flowering and fruiting characters of the trees should also be given importance. Correct choice of rootstock also should be practiced when grafts are prepared.

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Quality Timber Products of Teak from Sustainable Forest Management pp 352-358

Causes for Low Fruit Production in Clonal Seed Orchards of Teak (*Tectona grandis* L.f): A special reference to India

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ABSTRACT

Seed orchards are important in tree improvement programme, which are intended to produce quality seeds in abundant quantity. The main assumption made while establishing a seed orchard is that diverse genotypes are highly compatible and completely overlap their flowering phenology. However, the fruit production among seed orchards are very low. This paper deals with the causes for low fruit production in seed orchards; it reviews the available literature on the topic and attempts to suggest a few management practices.

Keywords: Clonal seed orchard, Teak, Clone, Plus tree, Pollination, Phenology, Flowering, Non-flowering

INTRODUCTION

A seed orchard is a collection of phenotypically superior and diverse individuals of a species, which are managed to produce a genetically superior seed crop through the process of open pollination (Askew, 1986). Establishment of seed orchard is one of the important objectives of any tree improvement programme. The main purpose of establishing a seed orchard is the mass production of genetically superior seeds, which are abundantly produced and easily collectable.

The assumption made while establishing a seed orchard is that diverse genotypes are highly compatible and completely overlap their flowering phenology and the process would lead to a big genetic gain. Overlap in flowering among clones in a seed orchard helps to increase the random pollination and results in high genetic gain and it also reduces the foreign pollen contribution. The above assumption unfortunately has not been tested among the seed orchards. In an idealized seed orchard the following requirements are assumed to be fulfilled.

1. The orchard is completely isolated from the influence of out side, undesirable pollen from untested origin.
2. Clones are equally productive in male and female flowers (in case of unisexual species).
3. Pollen flight and female flower receptivity coincides
4. Natural self-pollination occurs only in insignificant amounts
5. The gamete contributions of the parents are in the same proportions as they were in the orchard (an equal contribution from each parent which obviously are not fulfilled generally)

REASONS FOR FAILURE OF SEED ORCHARD CONCEPT IN TEAK

There are several reasons that causes for low fruit production in teak seed orchards. Several authors have studied on seed orchards of different species such as pine, fir, popular *etc.* but very few reports are available on tropical tree species like teak.

Asynchronous flowering in seed orchard

The knowledge of flowering phenology is the fundamental for the successful operation of any seed orchard (Weir and Zobel, 1975). For this reason knowledge of the phenology and variability of the orchard clones should be a standard practice in orchard management and tree improvement programs (Askew, 1986). Clearly several techniques are needed to promote seed production in a seed orchard. Usually three types of flowering patterns are observed in seed orchard *i.e.*, perfect synchronous flowering[1], perfect asynchronous/non-synchronous flowering[2] and anywhere in between these two extremities. In monoecious and dioecious species, there should be overlap between pollen dispersal and female receptivity.

For production of genetically superior seed, abundant and synchronized flowering of all clones in a seed orchard is very much necessary, other wise the genetic superiority of seed crop cannot be guaranteed. Rawat, *et al.* (1992) have reported asynchronous flowering in teak seed orchard established at New forest, Dehra Dun and recognised that these patterns may result in lower fruit production in the seed orchard.

In a recent study, Palupi and Owens (1998) found that the teak clones that synchronized their flowering with other clones in a clonal seed orchard (CSO), had better fruit set compared to those clones which either flowered early or flowered late in that season. Asynchronous pattern of flowering was also observed in this seed orchard of teak in Java. Asynchronous flowering has also been reported from seed orchards of teak from Karnataka. Gunaga *et al.* (2000) have shown, in a teak clonal seed orchard at Manchikeri in northern Karnataka, two distinct peak flowering seasons *viz.*, 2nd fortnight of June (southern clones) and 2nd fortnight of July (northern clones). Clones from northern provenance flowered later when compared to southern clones (Fig. 1.) Gunaga, 2000.

Effect of heavy rainfall during blooming period

Flowering phenology alone is not important but also environmental factors such as rainfall effect on flower

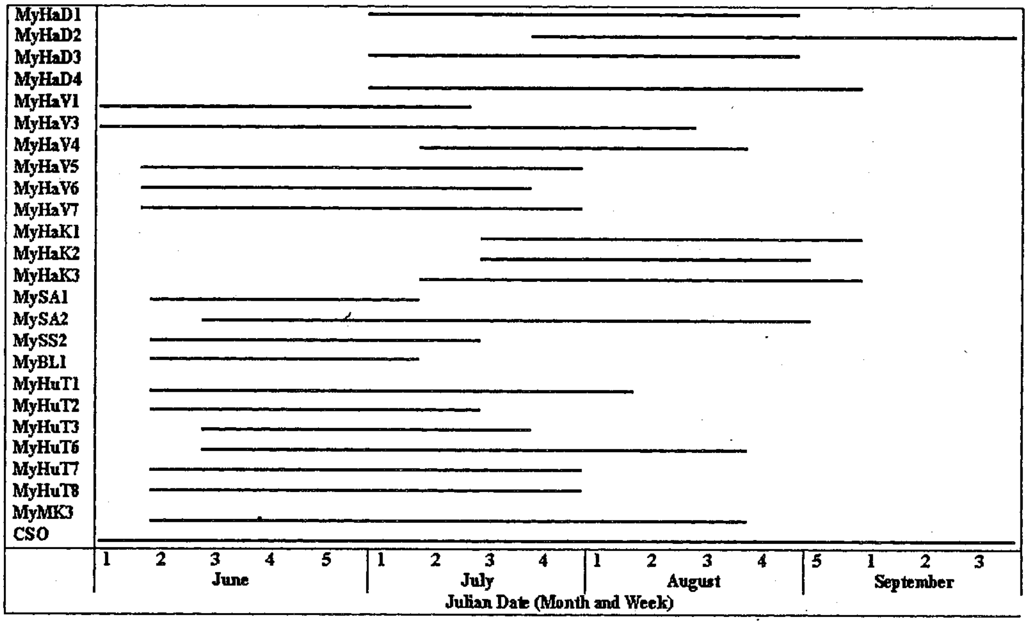

Figure1. Phenogram showing clonal variation for peak flowering period in a clonal seed orchard of teak at Manchikeri, South Karnataka

1 Overlap flowering among the clones within prescribed period of season. 2 Bearing of flower at different time intervals or non-overlap flowering with in a time interval

production, pollination, fertilization and fruiting *etc.* in seed orchards. Palupi and Owens (1998) and Gunaga (2000) have shown that teak clones that coincide of flowering with heavy rainy season, produces lower fruit production. Rainy condition that dominate during flowering time also bring down insect activity resulting in poor fruit set as apart from causing dropping of flower/ inflorescence. In an interesting study, recently Indira and Mohandas (2002) have reported that around 95 per cent flowers were pollinated with an average pollen load of 8.25 in a tropical sunny day. However, on rainy days only 45 per cent flowers were found to be pollinated with low pollen load of 1.90. This was due to low insect activity during heavy rain. These studies suggest to avoid selection of orchard site in heavy rainfall zones.

Lover number of clones

Asynchronous flowering pattern observed in seed orchard may be because of geographical variation with respect to origin of different clones used in the orchard. Hence local clones with known phenological patterns should be selected to achieve synchronous flowering. For example in Fig. 1, local clones established at Manchikeri seed orchards *i.e.* clones from Dandeli (MyHaD- series) and Kulagi (MyHaK-series) behave differently with clones of Virnoli (MyHaV- series) origin for flowering phenology. To know the relationship between such clones, a study on characterization of teak clones by molecular marker is necessary. It suggests that relativeness among the clones based on cluster analysis.

Pollination and Pollinator

Density of pollinator population is an important factor that contributes to fruit production in seed orchard. Teak is highly cross-pollinated tree species, mostly pollinated through insects. Through natural out crossing only 0.2 to 1.3 (about 1%) percent flowers set into fruit (Bryndum and Hedegart, 1969; Hedegart, 1973) depending upon the environment and genotype. Experimental cross-pollination might result in 10 (Indira and Mohandas, 2002) to 12 per cent (Hedegart, 1973) fruit set. This clearly suggests that pollination limitation is one of the reasons for low fruit productivity in teak.

A variety of insect groups such as Hymenopteran, Dipteran, Coleopteran, Lepidopteran, Hemipteran and Thysonpteran have been identified to be important pollinators in teak. Of these groups, the hymenoptera was often identified as the dominant and potential pollinator (Indira and Mohandas, 2002). Mathew *et al.* (1987) and Indira and Mohandas (2002) have reported that the hymenopterans, particularly the solitary bees, *Prosopsis pratensis, Allodape marginate, Halictus tectonae* to be the most effective pollinators visiting teak flowers during blooming stage. Apidae species like *Heriades parvula* and *Ceratina hieroglyphica* are also important teak pollinator reported by Hedegart and Lauridsen (1975). Some of the solitary bees such as *Anthophora zonata and A. niveo cincta,* and Stingless bees such as *Apis florae, A. mellifera* and *A. indica* were observed to visit the inflorescence of teak. Usually the insect activity increased from the morning hour as the temperature increased, till noon. Then it gradually decreased. The maximum insect activity between 9 AM and 12 noon. In general intra tree flight as the habitual nature of these insects resulting in geitonogamy or selfing (Bryndum and Hedegart, 1969; Hedegart, 1973). However, the bigger wasps, which move very fast among the inflorescence of a single tree as well as to the adjacent trees.

Mass flowering and large inflorescence display size generally attract a number of insect visitors with diverse species like *Asclepias sp.*and *Hybanthe prunifolius,* but end up in restricting the flower visitors to a single tree promoting self pollination and inbreeding (Willson and Price, 1977; Augspurger, 1980).

Presence of non-flowering ramets among seed orchard

One of the causes for poor fruit production among teak (*Tectona grandis*) Clonal Seed Orchards is the presence of a substantial percent of matured non-flowering ramets. Gunaga (2000) reported that there was significant difference among the clones for percent non-flowering ramets for two tested sites in Karnataka, South India, while the year-to-year variation within a site was only significant for one site (Fig.2). The overall variation for percentage of non-flowering ramets ranged from 3.84 to 82.60 per cent. He has also reported that percent non-flowering ramets was significantly influenced by site conditions

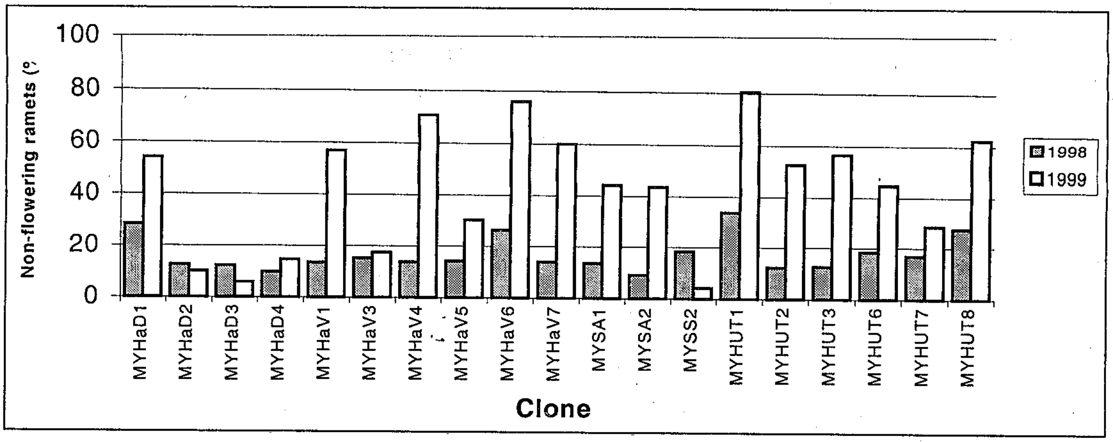

Figure 2. Clonal variation for percent non-flowering ramets in teak seed orchards at two locations across two years

(seed orchards). Considering the mean of two years, the range of variation for percent non-flowering ramets was between 9.07 and 33.35 per cent in Site-1 (CSO-Manchikeri). While the same for Site-2 (CSO-Karka), ranged from 4.18 to 80.43 per cent. The significant interaction term in the analysis of variance suggests that the clones differ highly significantly in their response in two sites.

Site factor

The production of fruit in the seed orchard also depends on the site condition such as soil type, physical (pH, CEC, texture, bulk density, water holding capacity *etc.*) and chemical (soil nutrition, minerals availability, *etc.*) parameters. Clones growing on poor soil conditions affect the growth of plant such as height, diameter, branching habit, *etc.*, that also influence on lower fruit production of in seed orchard. Detailed studies are to be conducted to know the performance of clones in different soil conditions with respect to flowering and fruit production in teak. In general, soils rich in nutrient, minerals, organic carbon, more aeration are suitable for site of establishment of seed orchard.

Inflorescence abortion due to fungal infection during flowering season

Fruit abortion is one of the frequently documented phenomenon in angiosperms, which results in lower fruit set. Several proximate mechanisms have been attributed to fruit abortion ranging from non-pollination to parent offspring conflict. In a recent study, Mohandas *et al.* (1999) have reported that the 'fall off of maturing fruits during the month of June, technically called as "June Drop". This has been mainly due to the incidence of fruit rot disease caused by fungi, *Phomopsis sp.* and *Collitotrichum sp.* A survey conducted at various teak plantations in Kerala showed that seed infection caused by *Phmopsis sp.* is widely distributed in the state. While teak plantation in dry zone like Chinnar also showed large percentage of flowers and fruit fall caused by fungal infections. Further, fungal infection which begins from early stages of the fruit setting was also observed on the stalk of the inflorescence which resulted in the total wilting or drying of the inflorescence. Later, Indira and Mohandas (2002) reported that fungicidal treatments using Mancozeb 75% and QP (Indofil M 45) @ 0.25 per cent concentration given during the early budding stage till maturity of fruits controlled the infection. A further detailed study is to be taken to know the clonal resistance and percentage infestation against fruit rot and their control measures.

Mismanagement after grafting of clones

Ramets of a clone, by definition, are genetically same. Hence, any variation within a clone is generally attributed to the failure of grafting (dropping/ drying of scion) during early stage of development. Kerala Forest Research Institute, Peechi and Rajiv Gandhi

Centre for Biotechnology, Thiruvananthapuram conducted an experiment on teak to study the relationship between existing clones (grafting of scion from plus trees) and original plus trees. Materials were collected from 20-yr old clonal seed orchards and from plus trees located at different parts of Kerala were used. Preliminary investigations by George Thomas and Seethalakshmi have shown that there is no 100 per cent genetic similarity between plus trees and the putative clones derived from them, suggesting a physical admixture of the ramets, wrong in labeling of each ramets, or graft failure (Personal Communication). The available data on past history of root stock (whether all root stock from same seed source or different seed sources) is scanty; it is difficult to analyze the relationship between rootstock with scion and with respective plus trees by RAPD (random amplified polymorphic DNA) marker. However, further detailed study is to be taken to test the relationship among these three groups with different sites by using large clonal samples.

Insect/ pest of teak

Seasonally teak is severely defoliated by two major insect pests, namely *Hyblea puera* and *Eutectona machaeralis*, however, their effects on defoliation on flowering and fruit production are unknown. The larvae of *Pagida salvaris* (Pyralidae) have, in certain years, been observed to cause serious damage to the flowers. The larvae of this insect feed on developing flower buds, which then fail to develop into fruits. Attempts to find suitable selective insecticides, which avoid killing the pollinating insects also, have so far proved unsuccessful (Hedegart, 1973). Prasad *et al.* (1990) reported that larval populations of the teak defoliator and skeletonizer in teak CSO were reduced by combined treatment of insecticide and hormone like T1 (monocrotophos at 0.02% + 40 p.p.m. NAA), T2 (monocrotophos at 0.02% + 40 p.p.m. NAA+0.5% Rallis Tracel-2; a micronutrient) and T3 (monocrotophos at 0.02% + 0.5% Rallis Tracel-2).

Internal factors such as physiological changes and hormone release

Flowering is affected and controlled by a range of various factors. Some of which are external to the plants, such as light, temperature, rainfall and others are internal factors such as nutrition, stress condition, endogenous level of hormones, *etc.* In Nilambur, teak trees growing near by river generally produce abundant flowers than trees growing away from the rivers (Rajesh Gunaga, Personal observation). This may be due to availability of more light along the riverbank and possibility due to sufficient water availability. Nanda (1962) reported that branches of teak trees exposed to sunlight produce profuse flowering when compared to branches that are not exposed to light. He also found that the emergence of branches and their subsequent flowering appear to be related to ageing or completion of the developmental process of the main shoot or the branch on which these are produced. Available literature on these aspects in the case of teak is scanty. However, further detailed study is required to understand the physiological process leading to flowering and fruiting

Management of flowering synchrony in a seed orchard

Research efforts in this direction are as old as seed orchards themselves. We need more flowers in seed orchards and when we have the flowers, we need means of protecting the crop from flower, fruit and seed losses. Following are some important management practices, which can be followed to get higher fruit production in seed orchards of tropical species.

Selection of clones

Select clones belonging to a provenance often overlap flowering among themselves rather than with others. Gunaga (2000) reported that clones from central and southern provenances showed synchronization in flowering and peak flowering in a teak CSO, Manchikeri, it suggests that, for establishment of new seed orchard, select only clones which are overlap flowering among themselves.

Orchard design

Teak is a cross-pollinated tree species, which is pollinated mainly through insects and to certain extent through wind. For such species orchard should be designed in such a way that a minimum of relatedness will result from crossing among the parents (clones), and so that parent trees will have an opportunity to mate freely with each other. A good orchard design must have flexibility for the improvement of the genetic quality of the orchards by rouging as well as to minimize the potentials for inbreeding. Orchard design is an important key to determine the proper number of desired individuals in a seed orchard is to have enough to allow for rouging the proper genotypes, to have the desired spacing, to maximize seed production by having enough good trees to have a adequate pollination and to ensure for a minimum of relatedness. Each clone should be represented by approximately equal frequencies per unit area with proper randomization and avoid 'repeatative neighborhoods,' in which the same clonal pattern is repeated several times.

Silviculture practices

A number of management practices are followed in the western countries that not only encourage profuse flowering as well as promote synchronization of flowering among clones. Silvicultural practices such as weeding, irrigation, fertilizer application, growth hormone treatment, partial girdling or banding, root pruning, crown pruning, pollinator management are the routine management practices of seed orchards.

Fertilizer application

Usually, seed orchards are fertilized for maximum growth and vigour when young, the application is changed to favour flowering at a later stage. To obtain regular and good harvests, regular fertilizer scheme should be planned. Most of the researchers cite that nitrogen and phosphorous as major key elements to induce flowering, however even microelements may stimulate flowering (Sweet, 1982). Particularly the foliar spray of 1 percent potassium nitrate has been suggested by the physiologists.

Irrigation

Like fertilization, irrigation can be provided at young ages in seed orchard in order to maintain optimal growth and vigour. To accomplish this, irrigation is used at any time during the year when the soil is dry enough to warrant it. Time of first flowering appears to become very crucial for irrigation. A few researchers have reported that irrigation sometimes delays flowering, fruit/ cone maturity and increase pollen production; it has been used effectively to prevent freezing of flowers during critical periods in temperate countries. However, before installing an irrigation system, it is important to have proper equipment to determine when and how much to irrigate.

Stem and root treatment

Generally the objective of these treatments is to create a higher carbohydrate level, which is believed to promote flowering. Such treatment may be root pruning, partial girdling of stem or banding. On a short-term basis these treatments may provide an important tool to increase flowering and fruits (particularly in horticulture crop). However, they may also have a long-term negative effect (Sweet, 1982). Ploughing in orchards site helps in soil reclamation and root pruning of orchard trees, which results in gregarious flowering and fruiting. It has been noticed in a teak CSO in northern Karnataka (Vasudeva, Personal observation)

Pollinator management

In case of limitation of the pollination in seed orchards, it would be advisable to increase the cross-pollination by placing beehives during the blooming period. Taking up commercial bee attractants such as Bee-Q could encourage visitation of local pollinations.

Growth hormone treatment

In recent years several reports have been published on the effect of hormone application on flowering in a few species of the family Cupressaceae and Taxodiaceae. There are also reports on increase in flowering for Pinaceae members, for example, by the application of gibberelic acid 4/7 mixture (Pharis and Ross, 1976). However, the time and stage of bud development is crucial for effective use. Smith (1998) reported that spraying of Paclobutrazol on *Picea mariana* showed positive response, where that chemical promoted cones of both male and female sexes equally, resulting in sex ratio. However, in

Eucalyptus globulus stem injection of Paclobutrazol showed significant increase in the mean number of flower buds per meter samples (Hetherington *et al.*, 1993). The spray of commercial NAA (such as Planofix) at the rate of 1-2 per cent would be ideal. In general, it is assumed that costs of these hormones are too inhibitive to be used on a commercial scale. Use of non-cultural treatments is still to be worked out for tropical hard wood species. For this reason, the knowledge of phenology and variability of the orchard clones should be a standard practice in orchard management and tree improvement programme.

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Peculiar Trees of Teak at Nilambur, Kerala

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ABSTRACT

Conolly and Chatu Menon made the earliest attempt of artificial regeneration of teak in India in the year 1844. As a result of their efforts, the world's oldest teak plantation now exists at Nilambur, Kerala. Apart from these earliest plantations at Nilambur, several other teak plantations of later origin also exist where plus trees have been selected and seed production areas (SPA) have been established. In this area, peculiar trees of teak were noticed both in the Chatu Menon's plot and in adjoining plantations. The observed plantations were in the range of 45 to 156 years in age. These peculiar trees are not similar to those, which exhibit 'water-blister' phenomenon, as reported from the 1846 teak plantation. The water blisters on teak trees were noticed at a height of 0.5 to 3 m from ground level. However, such water blisters did not occur on trees standing away from the riverbed. The peculiar trees reported in this paper exhibited distinct markings (pits/pin holes) and swellings in regular pattern on the root, stem and branch portions of one and the same teak tree. Teak trees without spiral grain, fluting, epicormic branches, pronounced buttresses, etc. are selected as plus trees. The pitted/pin holed trees, trees with swellings and bulging due to epicormic buds are also negative traits in the selection of plus trees. It is interesting to note that trees with such negative trait were noticed in large numbers in the SPA's and in the adjoining plantations from where seeds are collected for raising teak plantations. Series of plantations raised from the above seed sources in the later years showed the presence of peculiar trees in abundance, depicting the inheritance of these traits.

Keywords: Peculiar traits, tree breeding, plus trees, heritability

INTRODUCTION

Conolly and Chatu Menon were the first to attempt artificial regeneration of teak in India in the year 1844. As a result of their efforts, the world's oldest teak plantation now exists at Nilambur, Kerala. Apart from the above plantations at Nilambur, several other teak plantations of later origin also exist where plus trees have been selected and seed production areas (SPA) have been established. In this area, peculiar trees of teak were noticed both in the Chatu Menon's plot and in adjoining plantations. The observed plantations were in the range of 45 to 156 years in age. These peculiar trees are not similar to those, which exhibit "water blister" phenomenon as reported from the 1846 teak plot (Surendran, 1977). The water blister on teak trees was noticed at a height of 0.5 to 3 m from ground level. However, such water blisters did not occur on trees standing away from the riverbed. The peculiar trees reported in this paper exhibited distinct markings (pits/pin holes) and swellings in regular pattern on the root, stem and branch portions of one and the same teak tree.

PECULIARITIES OF TEAK TREES

Pitted teak tree

Teak trees having pits/pin holes occurred in a very low frequency (3.25%). One such tree having 162 cm GBH, 40 m total height and 25 m clear bole, standing in *Pericopsis mooniana* plantation near Arivakodu Timber Depot, showed pits/pin holes along the

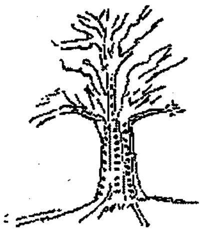

Figure 1

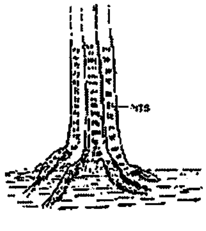

Figure 2

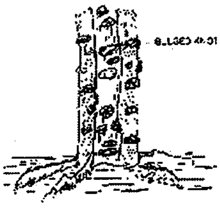

Figure 3

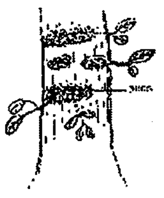

Figure 4

entire length of the tree (on roots, buttresses, stem and branches). These pits run uniformly and regularly in four parallel rows placed diametrically opposite in four furrows and alternating the four ridges on the stem (Figs. 1,2). Each location had four to six pits and was placed one above the other at a more or less constant distance (10 to 12 cm). These pits/pin holes were obovate in shape and on an average measured 2.0 - 0.25 cm in length and 0.5 - 0.26 cm in width. The pitting pattern appears to be not on account of epicormic bud scars as it appeared very regular and in a row. In case of teak, the phyllotaxy is opposite dicussate and the stem form in the seedling stage is squarish. Occasionally, old and mature trees exhibit squarish or rectangular stem form. Especially the stem of the buttressed tree exhibits 4 ridges and 4 furrows. The pitting pattern was observed in one such tree.

Similar phenomenon when analyzed anatomically in pitted/pin holed type of sandal (*Santalum album* L.) tree, it revealed in the pit/pin hole region, presence of giant multi-cellular medullary rays along with uni- and biseriate medullary rays surrounded by fibers. While, the normal sandalwood tree without pit/pin hole marks showed only uni or bi seriate medullary rays (Kulkarni and Muniyamma, 1996).

Teak with regular undulating bulged stem

In the 1846 Chatu Menon's plot, few trees showed bulged stem portions. One tree having 2.8 m GBH and 45 m total height showed uniformly localized swellings throughout the bole (22 cm). Peculiarly, this bulging again occurred by four rows placed diametrically opposite, running regularl uniformly throughout the tree (Fig. 3). This kind of pattern in the tree appears to be caused by localized cambial activity in anomalous secondary growth. Few other trees showed such bulging but it was not regular and in rows.

Teak trees with knots on stem due to epicormic buds

Majority of trees, both in Chatu Menon's plantation as well as in the adjacent plantations at various places in Nilambur showed trees with knots. In this case, the bulging appeared not exactly in well-defined rows but was irregular. The bulging was however, noticed throughout the bole of the tree. The bulged portions on the stem gave an appearance of a knot (false knot). Each bulged portion showed numerous buds (Fig. 4). Out of several buds, only one or two epicormic shoots develop into small branches. The rest of the buds either lie dormant or perish leaving a deep scar and this eventually forms a pit giving an appearance of teeth mark.

Teak trees of this type are common in occurrence in other teak forests of India. Teak trees without spiral grain, fluting, epicormic branches, pronounced buttresses, etc. are selected as plus trees. The pitted/pin holed trees, trees with swellings and bulging due to epicormic buds are the added negative traits in the selection of plus trees. It is interesting to note that trees with such negative trait were noticed in large numbers in the SPA's and in the adjoining plantations from where the seed is collected for raising teak plantations. Series of plantations raised from the above seed sources in the later years show presence of peculiar trees in abundance depicting the inheritance of these traits.

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TEAKDIV – Developing Know-how for the Improvement and Sustainable Management of Teak Genetic Resources

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ABSTRACT

Although teak has great potential as a plantation forest tree for the production of quality hardwood, our knowledge about its genetic resources is still fragmentary. TEAKDIV is a European Union funded research project that aims to develop specific DNA marker tools that can be used in tree breeding programmes and in management of genetic resources. The project has three objectives: (i) to trace and quantify genetic diversity of teak within its natural range, (ii) to evaluate the amount of contemporary gene flow through pollen and seed, and (iii) to assess the influence of human disturbance. Nuclear and chloroplast DNA markers will be used to assay the current distribution of genetic diversity within and between populations, historical migration patterns and mating system. Hypervariable microsatellite DNA markers will be developed for parentage analysis. The molecular work will be complemented by field observations on insect pollinators of teak. The genetic diversity in teak forests that have been undisturbed, lightly or heavily disturbed will be assessed and compared for both population genetic diversity and contemporary gene flow processes. The information generated will be integrated to draft guidelines for the future conservation and management of teak genetic resources in nature, and for the efficient use of these resources in breeding and plantation programmes in Asia, Africa and Latin America.

Keywords: Teak, genetic resources, DNA markers, plantation programme, sustainable management.

INTRODUCTION

The unsustainable extraction of timber from tropical forests and the concomitant destruction of biodiversity have become a major cause for concern (Bowles *et al.*, 1998) and calls for a greater effort to produce timber in plantations and for management of the remaining forests in a sustainable way. The demand for quality hardwood products from tropical regions, estimated at 123 million m^3 (ITTO, 1998), will not decrease in the near future. Plantations of quality hardwood species under sustainable management are seen as an alternative to timber extraction from natural forests.

Teak (*Tectona grandis* L. f.) is an important tree species in the natural forests of India, Myanmar, northern Thailand and Indonesia. It is widely planted by smallholders and used in agroforestry systems in Asia. Teak is also a very important quality hardwood species used in plantations in tropical regions of Asia, Africa and Latin America.

It is estimated that teak plantations account for 5 to 8 per cent of the total forest area planted in the tropics (Ball *et al.*, 1999), but account for 90 per cent of all of the quality hardwood plantations for timber production (Granger, 1988).

A genetic improvement programme is an essential component of a successful and sustainable plantation project. Knowledge of the existing genetic diversity forms the basis of tree improvement programmes (Zobel and Talbert, 1984). Methods of tree breeding for higher quality and resistance to stress rely on the availability of a diverse genetic basis. Teak improvement programmes have been initiated in several countries (e.g., since 1960's in Thailand, Keiding, 1966), but are hampered in their progress by a number of biological factors. In spite of research efforts (e.g., Tangmitcharoen and Owens, 1997; Palupi and Owens, 1996a, b) the pollination mechanism of teak is still unclear and nothing is known about the distance over which pollen and seed are dispersed. Overall, understanding of the genetic diversity for teak is still fragmentary (Kjaer and Siegismund, 1996; Chantragoon and Szmidt, 1999) and any relationship with location, soil and climate has been little studied. The origins of teak seed that have been introduced into Africa and Latin America are also uncertain. Also during the last 50 to 100 years,teak genetic resources have been dramatically altered through uncontrolled logging and movement of planting materials. The area of natural teak forests has drastically reduced over the last 50 years and the remaining forests are still under threat from illegal logging and other forms of forest destruction. The impact of these anthropogenic disturbances on the maintenance of the teak germplasm is unknown.

Using teak as a model system, DNA marker tools will be developed to obtain information on genetic diversity processes that are the basis of genetic improvement and sustainable management of this important forest resource. In addition, research will investigate the influence of anthropogenic disturbances on forest genetic resources, and will examine aspects of the ecosystems requirements for maintenance of genetic diversity (insect pollinators, pollen and seed dispersal). Specific nuclear and chloroplast DNA markers are being used to compile information on the geographical distribution of genetic diversity and on gene flow at different spatio-temporal scales and in forest stands with different levels of human impact. This will be the first study on an important tropical hardwood species where all aspects of gene flow will be investigated: historical migration and gene flow, contemporary dispersal of pollen and seed and the effect of human disturbance on these processes. Both nuclear and chloroplast DNA markers will be used to study the genetic variation within teak over its entire range and within undisturbed and disturbed mixed species populations. F-statistics will be calculated from the allele frequency data and compared to information obtained from private alleles (Barton and Slatkin, 1986; Wolf and Soltis, 1992). This will give information on the long-term factors that have shaped the genetic diversity in teak. Both the biparentally inherited nuclear genes (pollen and seed dispersal) and the maternally inherited chloroplast markers (seed dispersal only) will be used for this purpose, and comparison of the two allows useful ratios of pollen to seed dispersal to be calcualted (Asmussen and Schnabel, 1991; Ennos, 1994).

METHODS

Development of specific nuclear DNA markers

Based on the alignment of gene sequences from a wide variety of other plant species, conserved regions in expressed nuclear genes have been identified. Using these conserved sequences, degenerate primers for polymerase chain reaction (PCR) amplification of the respective genes have been designed. Several of the primer sets amplify a single fragment or a small number of fragments in some or most plant species, including teak. The amplified DNA fragments have been cloned and sequenced. Based on the specific teak DNA sequences, new primers for PCR amplification of unique DNA fragments have been designed. The selected fragments cover one or several introns in the coding regions. Diversity at each of the selected loci is detected by PCR amplification followed by single strand DNA conformation polymorphism (SSCP) analysis. Different alleles at each of the loci are being cloned and sequenced to give information about the evolutionary relationships between alleles for use in phylogeography and coalescent analysis. The developed markers are being used to measure the current distribution of genetic diversity within and between populations, historical migration patterns and mating systems.

Development of microsatellite markers

Teak genomic DNA was digested with MseI restriction enzyme and ligated to a linker sequence. After PCR amplification using the linker sequence as a primer, microsatellite containing fragments were selected by hybridisation to a biotinylated repeat sequence probe. The fragments attached to the probe were magnetically separated from the DNA fragments that did not bind the probe. After a new round of PCR amplification the resulting fragments were cloned. Sequencing of 85 inserts revealed 70 inserts containing one or more of the selected dinucleotide repeats. Sixty-eight of the sequences have been deposited with EMBL/ GenBank/DDBJ. Analysis of the microsatellite containing sequences revealed that several of them are located in or close to putative genes. Primers have been designed for 21 of the microsatellites and for 3 additional microsatellites discovered in intron sequences of specific genes. Polymorphism at several of the loci has been detected.

Contemporary gene flow in teak

Teak flowers regularly and abundantly. Still, seed

Table 1. Genes / loci for which primer sets were developed and status of current research

Marker	Name	Cloning/sequencing	Polymorphism	remarks
psaA		Y	Y	Chloroplast marker
rpoA		Y	Y	Chloroplast marker
matK		Y	Y	Chloroplast marker
trnT-L		Y	Y	Chloroplast marker
rpl16		Y	Y	Chloroplast marker
ndhA		Y	Y	Chloroplast marker
IDH	Isocitrate dehydrogenase	2 clones	Y	1 locus so far
ADH	Alcohol dehydrogenase	2 clones	Y	2 loci so far
CAT	Catalase	2 clones	?	1 locus so far
AATcy	Aspartate aminotransferase	1 clone	Y, Confirmed by sequencing	Cytoplasmic isoform1 locus so far
AATm	Aspartate aminotransferase	Several clones	Y, Confirmed by sequencing	Mitochondrial isoform 1 locus\
G3PDH	Glycraldehyde-3-phosphate dehydrogenase	Several clones	Y, Confirmed by sequencing	3 loci: 1 coding for a plastidic isoform, 2 coding for cytoplasmic isoforms
G6PDH	Glucose-6-phosphate dehydrogenase	1 clone	-	1 locus so far
CAD	Cinnamyl Alcohol Dehydrogenase	1 clone	-	1 locus so far
MnSOD	Mn Superoxide dismutase	In progress	-	1 locus so far
GBSS	Granule-bound starch synthase	In progress	Y	1 locus
PP2A	Protein phoshatase type 2A	Several clones	Y, Confirmed by sequencing	2 loci
IPI	Isopentenyl pyrophosphate isomerase	In progress	Y	2 loci
FAE	Fatty acid elongase	2 clones	-	2 loci so far
CHIT	Chitinase	1 clone	Y	1 locus so far
CPI	Cystein proteinase inhibitor	3 clones	Y, Confirmed by sequencing	1 locus so far
EDS1	Signal transduction in defense	2 clones	-	1 locus
ABP	Auxin binding protein	Several clones	Y, Confirmed by sequencing	1 locus

yield per tree is very low. It is believed that inefficient pollination combined with self-sterility is to blame for the low seed set. Many insects visiting teak flowers have been identified. However, most of them are considered to be inefficient pollinators. In spite of many decades of research, it is not known what insect vector is responsible for efficient pollen transfer between trees, or how far the insect vector carries pollen. This information is essential to devise strategies for conservation of natural teak populations, and to increase the efficiency of pollination in seed orchards.

To evaluate the amount of contemporary gene flow through pollen, a microsatellite library has been developed. Seventy-one microsatellite loci have been identified and deposited in publicly accessible databases. Genetic parentage analysis using microsatellites and observation of insect pollinators will be undertaken in natural populations, disturbed stands and in a few plantations. The information obtained from the genetic study will be compared to the information obtained from the insect pollinator study to check whether genetically estimated pollen dispersal curves are compatible with the behaviour of the visiting pollinators, and vice versa to confirm identification of the effective pollinators. Progeny arrays will be collected from individual mother trees, as developing embryos and as mature seed. Through paternity assignment in local populations it will be possible to assess the level of selfing and outcrossing. Once the pollen donors have been identified, it will be possible to establish the distance pollen has been transported. This information will then help us in focus on insect groups that might be responsible for the pollen dispersal. Genetic data and insect behaviour observations will be combined, and guidelines for the establishment and management of breeding orchards will be drafted. It will be possible to estimate the minimum viable population size and tree density and have information on the minimum ecological requirements that are necessary for the maintenance of teak genetic diversity.

Teak phylogeography

Teak grows naturally in two disjunctive regions: India south of 26° N, and Myanmar, Northern Thailand and adjacent areas. In addition teak grows in Indonesia. However, it is still unsure whether Indonesian teak is a separate natural population, or whether teak has been introduced from India to Indonesia long time ago.

To trace and quantify genetic diversity of teak within its natural range, DNA markers for specific nuclear and chloroplast DNA sequences have been developed. Chloroplast markers have been developed based on conserved coding sequences flanking intervening regions that contain mononucleotide repeats in other plant sequences. Sequencing of the PCR amplified fragments revealed that the selected regions also contain mononucleotide repeat sequences in the teak chloroplast genome. Such mononucleotide repeat sequences have been shown to be highly polymorphic in other plant species. Initial results indicate that the ndhA, matK, rpl16 and rpoA regions show polymorphism in teak.

Assessment of human impact on genetic diversity

To assess the influence of human disturbance on the genetic diversity, teak forests that have been lightly undisturbed or heavily disturbed have been included in the study and will be compared for both population genetic diversity using conserved gene markers and contemporary gene flow processes using microsatellites.For both contemporary gene flow and population genetic diversity analysis, diversity in natural forests will be compared to the diversity in disturbed forests, so that the impact of logging will be estimated. Levels of genetic diversity are usually not drastically altered directly by human interference in the short term but are manifest only after a few generations. However, immediate disruptions to the normal processes of contemporary gene flow can be expected. The joint analysis of the influence of anthropogenic disturbance on both long-term genetic diversity and contemporary gene flow patterns, will allow us to draft guidelines for sustainable management of remaining natural teak forests.

CONCLUSION

The practical outcome of this project will be to evolve:

1. tools for identification of teak genetic diversity in breeding programmes;
2. guidelines for the number, location and size of conservation units;
3. recommendations for the sustainable management of the remaining forest resources; and
4. recommendations for obtaining satisfactory pollination and seed set in seed orchards.

The use of well-defined DNA fragments will facilitate the exchange of genetic data between the partners in this consortium, and at later stages also potential users in Africa and Latin America. To make exchange of data even more efficient, the different alleles that have been found will be cloned and distributed to all participants to be used as standards in the analysis of genetic polymorphism.

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Variation in Non-flowering Nature among Teak (*Tectona Grandis* L. f.) Clones in Seed Orchards

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ABSTRACT

One of the causes for poor fruit production among teak (*Tectona grandis*) Clonal Seed Orchards (CSOs) is the presence of a substantial per cent of matured non-flowering ramets. We studied this aspect in two teak CSOs established during 1980 in Southern India for two flowering seasons i.e. 1998 and 1999. Nineteen clones that were identical in these two CSOs were considered. Variation among clones in both the years and site effect as well as their interaction was significant. Within a clone, the ramets, which flowered, and those did not had similar girth at breast height and also found healthy. There was no specific pattern with respect to spatial distribution of these ramets in a CSO suggesting tree vigour or conditions within a clonal seed orchard may not be important in controlling this trait although genotypes may respond to broad environmental variations. Broad sense heritability values for per cent non-flowering ramets among clones ranged between 0.646 to 0.911 (individual year basis) and 0.785 to 0.954 (year mean basis) when separate analysis was done for each site suggesting a genetic control. Therefore attention must be paid for this trait whenever the clones are selected for establishing CSOs or for rouging. We discuss this intra clonal variation in the light of 'genetic load hypothesis'.

Keywords: Clone, seed orchard, non-flowering ramets, *Tectona grandis*, genetic load hypothesis, ortet,heritability.

INTRODUCTION

Strong selection for vegetative growth among forest trees may lead to altered reproductive traits in the resultant progeny through a correlated genetic response (Sedley and Griffin, 1989). Time taken for first flowering in the improved progeny is one such trait, which is affected by previous selection in several economically important tree species. Across a range of plants, it is true that there is antagonism between vegetative growth and flowering. In *Pinus taeda*, Schmidttling (1981) showed a negative genetic correlation between flowering and stem growth upto an age of 10 years. Barclay & El-Kassaby (1988) have drawn similar conclusion for Douglas fir. Linharte *et al.* (1979) demonstrated that in a natural stand of *Pinus*, high cone production was associated with reduced diameter growth. Since trees selected for higher vegetative vigour (i.e. through plus tree selection) are often employed in a seed production orchard, any correlated response that reduces the flowering and/or increases juvenile period would push backwards the success of a seed orchard by at least one step. For the same reason, over-coming juvenility among seed orchard trees is an important criterion. However, extending juvenility among plantation trees would increase biomass accumulation. Hence these two interests of a tree breeder often are conflicting. This aspect is of major significance for clonal forestry that is based on pre-selected matured trees (Sedley and Griffin, 1989). Their importance lies chiefly in understanding whether such variations are genetically modifiable. All the aspects of reproductive biology are variable and influenced by some degree of genetic control. Period of juvenility also varies greatly among forest trees. Some *Eucalyptus* species may initiate regularly flower buds in the first year it self, but among European Beech vegetative juvenile phase may be as high as 30-40 years (Mathews, 1963). It is well known that the time at which the tree gains ability to flower is subjected to pronounced genetic and environmental influences although, this aspect of flowering has not been subjected to thorough testing.

Management of seed orchard trees such as pruning may also affect reproduction. The onset of flowering in a number of tropical tree genera such as *Tectona, Terminalia, Cedrela* has been shown to be affected by tree form, specially with the change from a single main stem to a more strongly branching growth habit (Longman, 1976). During our investigations on the variations for flowering phenology among the clones of teak in seed orchards, we identified that substantial proportion of ramets in several clones that had not initiated flowering, despite attaining maturity age and sufficient growth (Gunaga, 2000). The same was also found to be true in several other seed orchards. We, perhaps for the first time, attempted to characterize teak clones for the variation in non-flowering nature. Further a possible genetic analysis, effect of site conditions and effect of growth of ramets on non-flowering nature was also assessed.

MATERIALS AND METHODS

The Clonal Seed Orchards (CSOs)

The present investigation was undertaken in two clonal seed orchards established at Manchikere and Karka in the Uttara Kannada district of Karnataka State in Southern India (Vasudeva, 2000). These CSOs were established during 1980 and comprise of 24 and 25 clones respectively. Eighteen clones were common to both CSOs. These clones were derived from the plus trees earlier selected for their phenotypic superiority from three provenances of Karnataka State. Completely Randomized Design was adopted with unequal replications while planting these clones. Table 1 shows the locality conditions of the two CSOs.

Statistical Evaluation

Based on a thorough phenological study for two years, data on number of ramets within a clone that had not flowered were computed and expressed as per cent of the total ramets within a clone. Arc-sine transformation of the data was done before they were subjected to analysis in order to normalize the variance. Data from each year were analyzed separately for both the sites and variance components calculated. Since this ANOVA suggested that there was no year to year variation, year-wise data was considered as replications while analyzing the site x clone effect. The details of separate/combined analysis and expected mean square are presented in the Table 2.

Among-clone component of variance was interpreted as the total genetic variance within the population. Estimates of broad sense heritability were obtained on a clonal mean basis are as follows:

Analysis done separately for two sites

$$H^2_1 = \frac{s^2_c}{s^2_c + s^2} \text{ (yearly basis)}$$

$$H^2_2 = \frac{s^2_c}{s^2_c + s^2/y} \text{ (based on mean of two years)}$$

Combined analysis of data over both the sites

$$H_1{}^2 = \frac{s^2_c}{s^2_c + s^2_{y.c} + s^2} \text{ (yearly basis)}$$

Table 1. Description of the locality conditions of clonal seed orchard sites.

Sl. No.	Clonal Seed Orchard site	Latitude (North)	Longitude (East)	Altitude (m above msl)	Mean Annual rain fall (mm)	Mean temperature of the coldest month	Dry season
1	Manchikere	14° 52'	74° 49'	626	2400	23° C	Nov- May
2	Karka	15 °17'	74° 30'	610	1398	23° C	Sept-June

$$H_2^2 = \frac{s^2_c}{s^2_c + s^2_{.c.l}/y + s^2/y.l}$$ (based on mean of two years)

Estimates of standard error for heritability can be calculated by using following formula

$$\boxed{SEH^2_1 = \sqrt{\frac{2(n-1)(1-H_1^2)^2\{1+(n_0-1)H_1^2\}}{n_0(n-c)(c-1)}}}$$

Where c = number of clones
n_0 = coefficient of clonal variance
$= å\, n_i - \{å\,(n_i-1)/n_i\}$,
where n_i = no. of remets per clone
n = total number of observations
H^2_1 = broad sense heritability

RESULTS AND DISCUSSION

ANOVA done separately for each site showed that clonal differences for per cent non-flowering ramets was significant, while the year to year variation within a site was only significant for Karka CSO (Table 4). Variations for per cent non-flowering ramets in two teak clonal seed orchards for two years are presented in Table 3. The overall variation for per cent non-flowering ramets ranged from 3.84 to 82.60 per cent. Considering the years as replication, two-way analysis of variance was done to find out the effect of clones, sites and their interaction. The analysis indicated that the site, in which a clone is grown, significantly influences the trait (Table 4). There were significant variations among the clones. In Manchikere CSO, considering the mean of two years, the range of variation for per cent non-flowering ramets was between 9.07 (MySA2) to 33.35 (MyHuT1) percent. While the same for the Karka, ranged from 4.18 (MySS2) to 80.43 (MyHuT1) per cent. In general, as evident from the table there was a higher per centage of clones that were not flowering in Karka than in Manchikere. The significant interaction term in the analysis of variance suggests that the clones differ highly significantly in their response in two sites.

The spatial distribution of per cent non-flowering ramets within Manchikere CSO revealed that there was no specific pattern of distribution of these individuals (Gunaga, 2000). This suggests that conditions within the seed orchards may not have a great role in determining flowering in teak. Since it is known that the flowering is affected by bole

Table 2. Expected mean squares for separate and combined –over-site analyses of variance

Sl. no	Source	d.f.	Expected mean square
	Analysis done separately for two sites		
1	Replications (Year)	(y-1)	
2	Clone	(c-1)	$s^2 + y(s^2_c)$
3	Error	(y-1)(c-1)	s^2
	Combined analysis of data over both the sites		
1	Replications (Year)	(y-1)	
2	Site	(s-1)	
3	Clone	(c-1)	$s^2 + y.s(s^2_c) + + y(s^2_{.c.s})$
4	Clone x Site	(c-1)(s-1)	$s^2 + y(s^2_{.c.s})$
5	Error	s(c-1)(y-1)	s^2

Where,
y = number of years; c = number of clones; s = number of sites s^2 = sum of squares due to error (environmental variance), s^2_c = sum of squares due to clones (genotypic variance), $s^2_{.c.s}$ = sum of squares due to interaction of clones with sites

Linear model:

$$Y_{ij} = Y + C_i + S_j + E_{ij}$$

Where Y = general mean, C_i = effect of i^{th} clone, S_j = effect of j^{th} season, E_{ij} = random error characteristics of teak, we compared the Girth at Breast Height (GBH) of flowering and non-flowering individuals of each clone in Manchikere CSO (Table 5). Individual 't' test indicated that among 18 clones tested, in only five of them the non-flowering individuals have significantly smaller GBH compared to flowered individuals. Considering only numerical superiority among six clones, the non-flowering ramets had larger GBH compared to those that flowered. This suggests that GBH alone will not determine the non-flowering nature.

Broad sense heritability values for per cent non-flowering ramets was 0.646 ± 0.11 and 0.911 ± 0.114 for two sites based on individual tree basis. While heritability values for year mean basis was 0.785 and 0.954 in the same two sites. The corresponding values for pooled data was 0.239 ± 0.095 and 0.42 for individual year basis and year mean basis respectively (Table 4). This suggests that per cent non -flowering ramets is under strong genetic control and hence can be modifiable through selection. Therefore great attention must be paid while selecting the clones for establishing new seed orchard or for rouging.

The ramets of a clone are, by definition, genetically same. Hence any variation with-in a clone, is generally attributed to the environmental origin. In the present study it has been shown that a substantial per cent of ramets within a clone do not flower even at the age of twenty years after planting. Hence it is intriguing to explain this variation. A clone should consist of genetically similar individuals. However, evidence is now accumulating to pointing that age of the ortet may have significant genetic effect on the nature of the ramets. It is argued that among woody plants, there will be accumulation of deleterious mutations with the age of the tree, in the growing meristems due to copying errors of the Dna (Ledig, 1986; Klekowski, 1988). As consequence, the genetic constitution of vegetative tissues within a tree may substantially differ. Generally the tissues derived

Table 3. Clonal variation for per cent non-flowering ramets in teak clonal seed orchards at two sites across two years

		SITE					
		Manchikere			Karka		
Sl. No	Clone number	Year 1998	Year 1999	Mean	Year 1998	Year 1999	Mean
1	MYHaD1	25.00 (30.00)	31.25 (33.96)	28.13	48.00 (43.85)	60.00 (50.77)	54.00
2	MYHaD2	11.10 (19.46)	13.88 (21.89)	12.49	08.00 (16.40)	12.00 (20.27)	10.00
3	MYHaD3	12.12 (20.36)	12.12 (20.36)	12.12	03.84 (11.24)	07.66 (16.11)	05.75
4	MYHaD4	08.70 (17.16)	10.87 (19.28)	09.79	16.60 (24.04)	12.50 (20.70)	14.55
5	MYHaV1	10.10 (18.53)	16.67 (24.12)	13.39	52.30 (46.32)	61.54 (51.65)	56.92
6	MYHaV3	17.40 (24.65)	13.04 (21.22)	15.22	11.53 (19.32)	23.07 (28.73)	17.30
7	MYHaV4	18.20 (25.25)	09.09 (17.56)	13.65	68.18 (55.67)	72.72 (59.50)	70.45
8	MYHaV5	16.70 (24.12)	11.11 (19.46)	13.91	20.00 (26.56)	40.00 (39.23)	30.00
9	MYHaV6	33.30 (35.23)	19.04 (25.92)	26.17	72.00 (58.05)	80.00 (63.44)	76.00
10	MYHaV7	11.10 (19.46)	16.67 (24.12)	13.89	70.00 (56.79)	50.00 (45.00)	60.00
11	MYSA1	13.30 (21.39)	13.33 (21.29)	13.32	48.00 (43.85)	40.00 (39.23)	44.00
12	MYSA2	13.60 (21.64)	04.54 (12.25)	09.07	47.00 (43.28)	40.00 (39.23)	43.50
13	MYSS2	18.20 (25.25)	18.18 (25.25)	18.19	04.00 (11.54)	04.35 (12.11)	04.18
14	MYHUT1	26.70 (31.11)	40.00 (39.23)	33.35	78.26 (62.24)	82.60 (65.35)	80.43
15	MYHUT2	13.80 (21.81)	10.52 (18.91)	12.16	45.83 (42.59)	58.33 (49.78)	52.08
16	MYHUT3	12.50 (20.70)	12.50 (20.70)	12.50	50.00 (45.00)	62.50 (52.24)	56.25
17	MYHUT6	18.20 (25.25)	18.18 (25.25)	18.19	43.00 (40.98)	46.15 (42.82)	44.58
18	MYHUT7	16.70 (24.12)	16.67 (24.12)	16.69	17.39 (24.65)	39.13 (38.70)	28.26
19	MYHUT8	27.30 (31.50)	27.27 (31.50)	27.29	54.17 (47.41)	70.83 (57.29)	62.50
F Ratio **Clones : 4.64** **					**Clones: 21.56** **		
Analysis done separately for each site		**Years : 0.09 NS**			**Years: 5.48** **		

Values in the parentheses are arc sine transformed.

from the vegetative parts of longer chronological age (upper branches) may suffer to a greater extent than those with lesser age (lower branches). Hence differences in the collection of the vegetative buds for grafting may result in genetic differences among ramets of the same clone. This may also explain why position of the crown of the plus trees from which scions were originally taken also influences the flowering behaviour in several tree species.

Some of the strongest evidence in support of this hypothesis comes from the comparisons of per generation mutation rates occurring in short and long-lived species (Klekowski, 1988; Klekowski & Godfrey, 1989). Recently Aizen & Rovere (1995) have shown in a dioecious conifer (*Austrocedrus chilensis*) that the proportion of aborted pollen increased with age and /or the size of the tree supporting the 'genetic load with-age accumulation model'. Recently, Mathew and Vasudeva (2003) have shown that there was a perfect negative correlation between the age of the ortet and seed germination in teak. Further Hanumantha and Vasudeva (2001) have also hypothesized that pollen germination among teak clones may be influenced by the age of mother tree from which the clones were originally derived.

The CSOs in which the study was conducted were established about 20 years back and the records of the age of the plus trees and crown positions from which the vegetative parts were collected is not available. However we used the GBH of the plus trees (as a surrogate of age) to assess the effect of ortet age on non-flowering nature. Data on GBH of ortets was available only for 14 clones of Manchikere CSO which were used to run a rank correlation with the respective percentage of non-flowering ramets. The Spearman's rank correlation computed suggested that clones derived from plus trees with larger GBH had a tendency to have higher percentage of non-flowering ramets within

Table 4. Analysis of variance, components of variance and heritability estimates for the Per cent non-flowering ramets in teak clonal orchards

Analysis done separately for two sites				
Sl.no	**Source**	**d.f.**	**Mean squares (for two CSOs separately)**	
			Manchikere	**Karka**
1	Replications (Year)	1	1.88	291.74**
2	Clone	18	94.46**	1147.52**
3	Error	18	20.34	53.22
Parameters				
s^2 =			20.34	53.22
s^2c =			37.06	547.14
H_1^2 =			0.646 ± 0.110	0.911± 0.114
H_2^2 =			0.785	0.954
Combined analysis of data over both the sites				
Sl.no	**Source**	**d.f.**	**MeanSquares**	**P Level**
1	Replications (Year)	1	123.37	NS
2	Site	1	12686.15	<0.01
3	Clone	18	14202.77	<0.01
4	Clone x Site	18	8152.8	<0.01
5	Error	36	1494.16	
Parameters				
σ^2 =			1494.16	
σ^2c =			1512.49	
σ^2cs =			3329.32	
H_1^2 =			0.239 ± 0.095	
H_2^2 =			0.420	

Table 5. Girth at Breast Height (GBH; cm) of flowering and non-flowering ramates of Manchikere teak CSO

Sl.no	Clone number	Flowered Ramets			Non-flowered Ramets			t-value for comparing flowered and non flowered
		n	Mean	SD	n	Mean	SD	
1	MYHaD1	21	93.61	±26.80	9	80.03	±15.06	1.34
2	MYHaD2	33	91.93	±26.07	5	75.25	±16.20	1.38
3	MYHaD3	30	86.64	±25.79	4	49.19	±15.97	2.81**
4	MYHaD4	43	90.49	±22.66	4	69.45	±9.280	1.82
5	MYHaV1	15	105.69	±27.36	3	62.83	±09.35	2.64**
6	MYHaV3	19	96.90	±20.35	3	65.77	±30.11	2.33*
7	MYHaV4	18	86.05	±21.52	3	96.17	±32.25	0.71
8	MYHaV5	15	89.08	±22.33	2	79.25	±08.13	0.60
9	MYHaV6	14	81.41	±20.41	2	96.50	±14.85	0.99
10	MYHaV7	9	95.09	±27.05	6	95.75	±33.88	0.59
11	MYSA1	16	93.33	±26.82	3	101.3	±16.65	0.49
12	MYSA2	18	86.23	±22.59	3	70.33	±08.02	1.18
13	MYSS2	7	109.44	±32.35	3	109.8	±64.41	0.01
14	MYHUT1	15	96.04	±31.25	4	65.86	±14.85	1.85
15	MYHUT2	42	79.038	±22.53	7	73.80	±23.66	0.60
16	MYHUT3	27	87.356	±22.46	7	87.69	±17.92	0.04
17	MYHUT6	30	86.08	±21.80	7	59.86	±12.48	3.05**
18	MYHUT7	12	87.71	±23.62	2	59.50	±0.707	4.13**
	MYHUT8							

n = sample size* Significant at 0.05 P level ** Significant at 0.01 P level

them when grown in seed orchards (rs=0.56 $P<0.05$ at 12 d.f. for Manchikere CSO; rs=0.45 $P<0.05$ at 17 d.f. for Karka CSO; rs= 0.54 $P<0.05$ at 12 d.f. for data pooled over both the CSOs). The range of the GBH of plus trees was quite large enough (94 cm to 225 cm) not to be an artifact of growth conditions. With the limitations of the using GBH as a surrogate of the age, the observed pattern may still act as a sign post for further fine tuned studies.

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Variation in Germination and Early Vigour among Half-Sib Families of Teak (*Tectona grandis*) Clones of Karnataka

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ABSTRACT

Families of eight teak clones of diverse origin, collected from a 20-year-old Clonal Seed Orchard (CSO), were studied at the College of Forestry, Sirsi, to understand the family variation for seed germination and early vigour. The study aimed at understanding the genetic basis these variations. Large variations were observed among families of different clones for germination percentage. Families of clone $MySA_1$ (11.09%), clone $MyHaV_5$ (8.65%) and clone $MyHaV_3$ (8.46%) were superior in overall germination at the end of the study period. Germination was under genetic control as suggested by high narrow sense heritability and also showed high genetic gain (171.7%). There was a perfect negative association between age of the ortet (mother tree) from which the clonal material was originally derived and the per cent germination of its progeny supporting the hypothesis that deleterious mutations might be accumulated with age ("genetic load accumulation with-age hypothesis"). Hence care must be taken not to include clones of older ortets in the future CSOs. Family variation for morphometric traits was not statistically significant, however, root traits and biomass traits differed significantly among families. Leaf area is the most important trait contributing to divergence of half-sib families, which also had higher narrow sense heritability (0.772) and was significantly associated with biomass traits. Hence leaf area per plant could be the most important trait for early selection in teak progeny trials. In general, families of clones of southern provenance had higher mean values with respect to number of lateral roots, plant height, collar diameter and biomass indicating a potential for early adaptation in field. Hence these clones could be given importance while establishing newer CSOs.

Keywords: clone, seed orchard, genetic load hypothesis, ortet, heritability, early vigour, family, seed germination

INTRODUCTION

Teak (*Tectona grandis* Linn. f.) has a long history as an important plantation species because of its valuable timber. The teak plantation at Nilambur in Kerala, South India, established during 1844, is popularly known as the first teak plantation in India. However, as early as in the seventeenth century itself, the Vice Admiral of Shivaji, Sri Konhoji Angre raised a teak plantation of India in the present-day Ratnagiri district of Maharastra, in order to supply quality timber to his navy (Gunaga, 2000). Today, teak ranks among the top five tropical hardwood species in terms of plantation area established worldwide.

Recently concepts of intensive management and applied genetics are being effectively adopted in order to increase productivity of teak plantations. Seed improvement programme on teak in India was started in 1962, when Kedharnath and Mathews formulated a teak improvement program. Since then, seed orchards have been viewed as links between tree improvement and reforestation program since they are intended to deliver abundant yields of improved seed. Ideally, progeny testing of phenotypically selected trees should precede the establishment of seed orchards. This serves the tree breeder's principal objective of generating optimum breeding population to create cumulatively better genotypes. However, in order to meet the immediate demand for quality seeds, and considering the long rotation period of teak, the progeny testing is either conducted simultaneously with the establishment of seed orchards, or at a later stage using seeds collected from the seed orchard itself.

Although clonal influence on wood density (Indira and Bhat, 1998), flowering phenology (Gunaga and Vasudeva, 2002), fruit set (Gunaga *et al.*, 2000), and on gametophyte traits (Hanumantha and Vasudeva, 2001) are well documented in teak, there is hardly any information on the degree and extent of clonal influence on seed germination and early vigour at seedling stage (Mathew, 2001). Since seed crop obtained from an orchard are distributed for commercial use, it is imperative to assess the clonal influence on variation for seedling traits. With this background the present investigation was conducted to assess the family variation for germination and early vigour in teak and to understand the genetic basis of these variations among half-sib progenies.

MATERIAL AND METHODS

The teak clonal seed orchard at Manchikere forest in Yellapura Forest Division situated in northern part of Karnataka was considered in this study. It was established during 1980 and is well isolated from natural/artificial stands of teak trees by over five kilometers. It is being managed by the Karnataka Forest Department adopting standard orchard techniques to encourage higher flowering and fruiting (Vasudeva, 2000). Seeds for the present study were collected directly from three individual trees (*i.e.* three ramets) each from eight clones of teak originated from diverse provenances of Karnataka. The details of the clones considered and their origin is shown in Table 1.

In this study, seeds were subjected to pre-sowing treatment with cow dung slurry (Chacko *et al.*, 1997) and due care was taken to keep the identity of each ramet intact during the treatment period. At the end of the treatment, mesocarp (outer cottony layer) was removed by thrashing. Then the seeds were soaked in water overnight before sowing in nursery bed at the College of Forestry, Sirsi. The location is situated at 14° 36' N latitude and 75° 53' E longitude and an altitude of 619 m above MSL. Mean annual rainfall is 2657 mm, most of which is received between June to October. Such pre-treated seeds were sown separately on standard raised beds, at depth equivalent to smallest diameter of seed. Minimum of 500 seeds were used per ramet. Daily germination counts were recorded for a period of 30 days from the start of germination trial and then onwards observations were taken once in a month upto six months after sowing. The germination data were expressed as the percentage of seeds that had germinated at the end of 21 days after sowing (DAS) as well as at 140 DAS. Three months old seedlings were transplanted to polythene bags from the nursery bed and monthly data were recorded on plant height and collar diameter for a period of one year.

At the end of the experiment shoot length, root length, number of leaves, leaf area and dry weight of stem, leaf and root were measured on five randomly selected seedlings from each ramet using an electronic balance to the nearest 0.01 mg. Leaf area was determined based on dry weight basis. Leaf area was measured on randomly selected 30

Table 1. Details on provenance location of teak clones used in the study

Clone	Identity Number	Forest range	Provenance region	Latitude (N)	Longitude (E)	AltitudeM above msl
MyHuT8	24	Vijarpet	South	76° 00′	12° 15′	850
MyHuT3	19	Vijarpet	South	76° 00′	12° 30′	865
MyMK3	37	Kakanakote	South	76° 10′	11° 55′	690
MySA1	13	Arasake	South	75° 29′	13° 48′	600
MyHaK1	32	Haliyal	North	74° 40′	15° 18′	500
MyHaV3	7	Haliyal	North	74° 37′	15° 12′	573
MyHaV5	9	Haliyal	North	74° 25′	15° 12′	573
MyHaD2	2	Haliyal	North	74° 25′	15° 12′	573

fully expanded leaves from all ramets using a leaf area meter and then leaves were completely dried to get the dry weight of each leaf. A regression line fitting leaf area and dry weight was computed (y = 7.981 + 137.704 x., where, y = leaf area in cm^2, x = dry weight of leaf in g). The Pearson's correlation coefficient showed a high degree of association between the two variables ($r = 0.967$; P level < 0.001). Using this relation, leaf area on individual seedling basis was computed non-destructively.

The data were analyzed as per Completely Randomized Design (CRD) after checking for normality and the homogeneity of variances. The per cent germination data were subjected to arc sine transformation before analysis. No attempt was made to separate the block effect since the observations were taken on potted plants raised in a nursery. For analytical purposes the members of the individual families were assumed as half-sibs. This assumption should be reasonable since teak is a highly out-crossed species (Indira and Mohandas, 2002). Variance among the half-sib families was interpreted as genetic variance. The variation among families of different ramets within a clone, was considered as environmental variance since random mating is ensured among clones in the orchard. The heritability and other genetic parameters were computed following Matziris (1994). The following simple model was adopted:

Sl.No.	Source	d.f.	Expected mean square
1	Family	(c-1)	$s^2+rs^2_C$
3	Within-family	(r-1)(c-1)	s^2

Where,

- c = number of half sib families
- s^2 = sum of squares due to error
- s^2_c = sum of squares due to families (interpreted as genotypic variance)
- r = number of replications

From this analysis, following genetic parameters were estimated (Kanowski et al. 1991):

$$\text{Narrow sense heritability } (H_1^2) = \frac{4s^2_c}{(s^2_c+s^2)} \quad \text{(Individual ramet basis)}$$

$$\text{Narrow sense heritability } (H_2^2) = \frac{4\,s^2_c}{(s^2_c+s^2/r)} \quad \text{(family mean basis)}$$

Phenotypic and genotypic coefficient of variation were calculated as suggested by Burton (1952). Genetic gain expressed in percentage of mean was calculated using the formula given by Johnson *et al.* (1955). General combining ability (GCA) was calculated by using the formula as suggested by Zobel and Talbert (1984).

RESULTS AND DISCUSSION

Seed germination

Large and significant variations with respect to percentage germination at 21 Days After Sowing (DAS) as well as at 140 DAS were found among the teak clones of Karnataka (Fig 1). To understand the relationship of this clonal variation with other fruit traits such as

Table 2. Association of germination percentage with seed traits^{S} among different teak clones

Per cent Germination	Fruit diameter	100 fruit weight	Fruit Density	Mesocarp thickness	Endocarp thickness
Pearson's Correlation coefficient					
At 21DAS	0.847**	0.747*	-0.564^{ns}	0.691*	0.736*
At 140 DAS	0.432^{ns}	0.637^{ns}	-0.514^{ns}	0.388^{ns}	0.594^{ns}
Rank Correlation coefficient					
At21 DAS	0.833**	0.643^{ns}	-0.559^{ns}	0.691*	0.684^{ns}
At 140 DAS	0.286^{ns}	0.310^{ns}	-0.417^{ns}	0.523^{ns}	0.506^{ns}

^{S}= These seed traits have been obtained by an earlier study (Vasudeva, 2000); ** Significant at 0.01 P level; * Significant at 0.05 P level; ^{ns} Non-significant diameter, thickness of mesocarp, 100 fruit weight and density, we did a correlation analysis (Table 2). Per cent germination at 21 DAS was significantly influenced by fruit diameter and 100 fruit weight; however, this initial association did not hold at 140 DAS suggesting that variation in seed traits alone cannot explain the clonal differences in germination.

Interestingly, overall seed germination percentage was on the lower side. Several authors have also reported poor germination of seeds from clonal seed orchards compared to that from natural stands (Prasad and Jalil, 1986; Indira and Basha, 1999). Reasons for poor and delayed seed germination of fruits derived from seed orchards are still not very well understood although prolonged 'after ripening period' and influence of 'germination inhibitor' present in the mesocarp have been implicated. Since, in this study only the fully matured and about-to-drop seeds were collected and stored for just one year before sowing, low germination may not be due to the prolonged 'after ripening period'. Further, mesocarp of fruits were physically removed before sowing hence, influence of a putative water-soluble germination inhibitor present in the mesocarp is precluded.

It is known that among woody plants, deleterious mutations accumulate with the age in growing meristems due to copying errors of the DNA (Klekowaski, 1988; Ledig, 1986). Since trees do not have 'germ-line' these accumulated errors may enter gametes through the process of meiosis (Klekowski and Godfrey, 1989). In other words the genetic load would increase with the age of the 'plus tree', which would pass on to the clonal orchard through vegetative propagation. Hence poor germinability among seeds of CSOs may be related to the higher 'physiological age' of the mother plants from which these clones are derived.

In order to test whether the age of the ortets (mother tree from which the ramets were derived) has any influence on the seed germination of respective families, age of the ortet (obtained from the records of the Forest Department) and per cent germination at 21 DAS and at 140 DAS were plotted. It is interesting that there was a perfect negative association between the two (correlation coefficient r= -0.902 and -0.756, respectively, significant at 0.05 P level), suggesting that progenies derived from older ortets tend to show lower seed germination. Further, in the present study, since open pollinated seeds from the CSO are used, it is logical to assume that genetic load may also have been contributed via male gametes also. However, this effect would be random in all the clones. Recently, Hanumantha and Vasudeva (2001) have also hypothesized that pollen germination among different teak clones may be influenced by the ortet age.

Family variation for seedling growth and vigour

Among the morphometric characteristics plant height, collar diameter, and number of leaves did not show significant differences at family level at

Table 3. Variation in root characteristics among different families of teak clones at the end of the study. Values are Mean±S.D.

Family (Clone) I.D.	Tap root length (cm)	Max. Diameter of Tap root (mm)	Length of longest lateral root (cm)	No. of lateral roots
MyHuT8 (24)	23.2 ± 2.8	17.32 ± 1.6	17.1 ± 0.6	12.30 ± 2.7
MyHuT3 (19)	23.3 ± 6.0	16.51 ± 1.5	16.8 ± 0.3	10.65 ± 0.5
MyMK3 (37)	20.4 ± 4.8	19.11 ± 0.4	14.6 ± 0.4	9.13 ± 2.0
MySA1 (13)	23.4 ± 2.8	13.54 ± 1.6	15.8 ± 1.4	6.30 ± 0.1
MyHaK1 (32)	22.8 ± 5.4	13.32 ± 2.4	17.4 ± 0.1	5.90 ± 0.4
MyHaV3 (7)	23.2 ± 2.7	14.56 ± 0.7	18.6 ± 0.7	7.73 ± 1.8
MyHaV5 (9)	21.5 ± 0.9	12.87 ± 0.7	18.4±1.4	8.03±1.2
F test	NS	*	*	*
CD	—	2.25	1.58	2.85
SEM(±)	0.78	0.44	0.39	0.57
CV(%)	17.02	8.51	5.10	18.36

NS= Non-significant; *= Significant at 0.05 P level; CD= Critical Difference at 0.05 P.level; C.V.= Coefficient of Variation (%)

the end of the study (data not shown) except for leaf area per plant. However, significant variations were found with respect to most of the root characteristics such as maximum diameter of tap-root, length of longest lateral root and number of lateral roots (Table 3). Family of clone 24, which recorded the highest value, was significantly superior to all others tested while, that of clone 32 which, recorded the least value, was significantly inferior to all others (Table 3).

Progenies of different clones differed significantly for biomass characteristics (on dry weight basis) and the differences were very large (Table 4). The family of clone 24 had highest total biomass (39.99 g) and that of clone 32 had the least (12.31 g), which was far below the clonal average. Families did not show statistically significant differences for shoot-root ratio. This suggests that although the total biomass varies among families, the distribution of biomass into above and below ground parts is similar.

With respect to all biomass characteristics, families of clone 24, clone 19 and clone 7 registered higher values. Biomass of clone 24, which obtained highest value, was found to be many times larger than the family of poorest performer, family of clone 32. Hazara and Tripathi (1986) reported that biomass production is a function of the photosynthetically active radiation received by the leaves. As optimal leaf mass levels increase, biomass production would substantially increase. Families of clone 24, clone 19 and clone 7 may have higher potential for photosynthetic carbon fixation as they posses higher leaf area per plant. This was reflected by a larger amount of dry matter production (total biomass, shoot and root) by seedlings from these families in comparison to other half-sib families.

Estimation of heritability and genetic parameters

Narrow sense heritability of germination per cent was on higher side (0.721 and 0.896, respectively at family mean basis and individual basis) suggesting that a strong genetic basis for the observed variation (Table 5). Very low value of standard error of heritability (0.084) indicates that the estimates were robust. Among the root traits, length of the longest lateral root showed highest heritability. Since root traits influence performance of seedlings derived from stumps, it is necessary to consider this trait for improvement. Total biomass (dry weight) had higher genetic gain among biomass traits studied, even though narrow sense heritability for this trait was moderate (Table 5). Wierland (1985) noted that plants with higher leaf area had higher photosynthetic efficiency and growth potential. Superior performance of clone 24 (My Hu T8) with regards to morphometric and biomass characteristics could be attributed partially to higher leaf area. The study also clearly suggests that leaf area per plant could be one of most important traits for early selection among progeny trials.

Heritability estimates are reliable only when they are accompanied by a high genetic gain. The high

Table 4. Variation in leaf area and biomass traits (per plant in g) among families of different teak clones on dry weight basis. Values are Mean ± S.D.

Family (Clone) I.D.	Leaf area per plant (cm^2)	Root biomass	Shoot biomass	Total biomass	Shoot/root ratio
MyHuT8 (24)	1521.3± 465.4	22.0±9.6	17.99±5.19	39.99±14.7	0.84±0.13
MyHuT3 (19)	1167.4±479.1	13.4±2.8	13.10±4.86	26.44±7.67	0.97±0.16
MyMK3 (37)	814.0±44.2	9.69±3.5	8.51±0.85	18.21±4.30	0.93±0.23
MySA1 (13)	730.9±75.9	7.48±1.8	7.41±0.52	14.89±2.36	1.02±0.20
MyHaK1 (32)	562.9±149.9	5.96±0.3	6.35±2.50	12.31±2.79	1.04±0.38
MyHaV3 (7)	995.8±103.6	11.9±3.3	10.88±2.03	22.78±5.28	0.93±0.07
MyHaV5 (9)	608.4±132.1	8.81±3.5	6.41±1.72	15.21±4.88	0.78±0.02
F	*	*	*	*	NS
CD	441.23	7.56	4.91	11.96	
SEM(±)	86.58	1.39	1.06	2.4	0.04
CV(%)	25.83	37.38	27.44	31.36	20.24

NS= Non-significant; *= Significant at 0.05 P level

Table 5. Estimation of variance and genetic parameters for different traits

Sl. No.	Variable	s^2c	h^2_1	$SE(h^2_1)$	H^2_2	PCV'	GCV	Genetic advance	Genetic gain(%)
1	Seed Germination	6.28	0.721	0.084	0.895	93.10	39.52	10.89	171.7
2	Max. diameter of tap root	0.35	0.478	0.178	0.732	11.78	4.07	2.58	17.7
3	Longest lateral root length	0.37	0.665	0.124	0.856	8.82	3.60	2.65	15.5
4	Leaf area	15182	0.531	0.164	0.772	37.74	13.76	537.7	60.0
5	Dry wt. of leaf	0.80	0.532	0.164	0.772	38.11	13.89	3.90	60.6
6	Dry wt. of root	3.16	0.423	0.191	0.686	49.21	16.01	7.73	69.6
7	Dry wt. of shoot	2.44	0.573	0.152	0.800	42.01	15.90	6.81	69.3
8	Total biomass (dry wt.)	11.30	0.511	0.169	0.758	44.89	16.06	14.67	70.1

s^2c = Variance between families which is interpreted as the total genetic variance; h^2_1 = Narrow sense heritability on individual basis; h^2_2 = Narrow sense heritability on family mean basis; SE (h^2_1) = Standard error for h^2_1 (Kedharnath, 1982); PCV = Phenotypic co-efficient of variation; GCV = Genotypic co-efficient of variation

Table 6. Estimation of general combining ability (GCA) of different clones for different traits

Family (Clone) I.D.	Leaf area per plant	Dry wt. of leaf	Dry wt. of root	Taproot length	Max. dia. of tap root	Length of longest lateral root	No. of lateral roots
MyHuT8 (24)	+606.94	+4.44	+10.82	+0.81	+2.72	+0.13	+2.54
MyHuT3 (19)	+253.05	+1.87	+2.16	+0.91	+1.92	-0.16	+0.44
MyMK3 (37)	-100.39	-0.69	-1.48	-2.01	-0.19	-2.63	+0.38
MySA1 (13)	-183.47	-1.29	-3.70	+1.01	-1.04	-1.16	-1.85
MyHaK1 (32)	-351.47	-2.51	-5.21	+0.40	-1.79	+0.44	-1.31
MyHaV3 (7)	+81.38	+0.62	+0.72	+0.76	+0.09	+1.69	-1.01
MyHaV5 (9)	-306.03	-2.42	-3.30	-1.90	-1.71	+1.69	+0.84

heritability along with higher values of genetic gain observed in the study for germination percentage (Table 5) indicates the effectiveness of selection. Panse (1957) and Reddy *et al.* (1996) attributed such a nature to prevalence of additive gene action. Jayasankar *et al.* (1999) have shown a similar trend in teak; Abrecht (1985) in *Eucalyptus pauciflora* and Farmer (1980) in six deciduous tree species. In the present study, clones 24, clone 19 and clone 7 were the best considering the *per se* performance as well as GCA effects for taproot length, number of leaves and biomass traits (Table 6). It means good *per se* performers are also the good general combiners. Thus, parents may be selected on the basis of their performance, which is a good indicator of their combining ability. Hence propagules from the families of clone 24 (My Hu T8), clone 19 (My Hu T3) and clone 7 (My Ha V3), which are the best general combiners for height and collar diameter, can be used for further improvement programmes.

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Seed Source Evaluation in Teak *(Tectona grandis* L. f.)

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ABSTRACT

Studies were carried out in teak to elicit information on performance and genetic variability of different seed sources. Thirty seed sources, viz., 28 from India and one each from Lao PDR and Bangladesh were assembled and the performances of seed sources were studied in nursery and under field conditions. Significant differences were observed between seed sources for various biometric traits investigated both in nursery and under field conditions. Superiority in plant height was observed for nine seed sources at nursery level. Considering all other growth parameters conjointly, viz., collar diameter, dry weight, sturdiness quotient and volume index at 210 DAS, the seeds from Madhya Pradesh proved superior. The seed sources from Maharashtra III had also performed well for a minimum of three biometric traits. Under field conditions, four seed sources, viz. Kerala V, Kerala VII, Tripura and Tamil Nadu III proved superior for all the traits investigated and those four sources can be exploited for future improvement programmes. Volume index registered highest PCV, followed by number of leaves, plant height and collar diameter. Volume index also registered high GCV, followed by number of leaves, plant height and collar diameter. Number of leaves expressed highest habitability estimate, whereas, it was low to moderate for other parameters. The GA as per cent over mean was high for volume index, followed by number of leaves, plant height and collar diameter.

Keywords: Teak, seed sources, variability, heritability, volume index

INTRODUCTION

Variability is the most important phenomenon for bringing in genetic improvement of any species. In teak, a wide range of natural variation occurs due to its wide distribution throughout India and also in other South East Asian countries (Tewari, 1992). Since teak grows over huge areas within and outside the country, the various provenances or seed sources differ from one another. The evidence of variations in this species for various characteristics was reported to be inherent (Kedharnath and Mathews, 1962) and these variations can be exploited by breeders and foresters (Subramaniam, 1997) for further improvement. Testing of provenances of teak provides a quick and cheap way of identifying superior provenance, which already exists in India. The All India Teak Provenance Trial conducted during 1931 has given some useful information (Mathuda, 1954). However, these older experiments may not fulfill the current demand for accurate identification of seed sources and statistically valid experimental design and layout. Hence, the present study was carried out to collect various seed sources within and outside the country to examine the extent of variability among the seed sources.

MATERIALS AND METHODS

The experimental material for the present study consisted of 30 seed sources of *Tectona grandis*, which included 28 Indian sources and one each from Lao PDR and Bangladesh. The regulations for provenance / seed source sampling concerning minimum number of trees and distance between parent trees were followed as far as possible in the present investigation. Seeds from individual trees were mixed and used as seed source.

A seed source evaluation trial has been laid out at Forest College and Research Institute, Tamil Nadu, India (11°56' and 11° 20' N latitude and 76° 57' E longitude at an altitude of 300 m above sea level). Seedlings of 30 different seed sources were planted in a randomized block design (RBD) with ten replications. The plot size and spacing adopted were 9 x 9 m and 3 x 3 m respectively with 9 seedlings per plot. The observations (height, collar diameter and number of leaves) were recorded on all the nine seedlings at 3 months after planting (3 MAP) and 6 months after planting (6 MAP). Volume index was derived following the method of Hatchell (1985) and Manavalan (1990).The data gathered from the field experiments were subjected to statistical analysis and estimates of mean, variance and standard error were worked out after Panse and Sukhatme (1978). The significance test was carried out by referring to the standard 'F' table of Snedecor (1961). Phenotypic and genotypic variances were estimated as per the method described by Johnson et al. (1955) and heritability in the broad sense was calculated according to Lush (1940).

RESULTS AND DISCUSSION

The results of present study indicated significant variations among seed sources for various characters investigated. At 3 MAP, seven seed sources, viz., Tripura, Tamil Nadu III, Tamil Nadu IV, Kerala V, Kerala VI, Kerala VII and Kerala VIII recorded significantly greater plant height compared to the general mean (23.19 cm). At 6MAP barring Kerala V, all other six sources mentioned

Table 1. Details of the seed sources

Sl. No.	Seed source	Location	State	Country	Latitude	Longitude
1	Lao-PDR	Syyabur	-	Lao PDR	23°31'N	100°05'E
2	Bangaledesh	Chittagong	-	Bangladesh	22°19'N	91°41'E
3	Uttar Pradesh	Tarai	Uttar Pradesh	India	24°39'N	78°12'E
4	Uttranchal	Dehra Dun	Uttranchal	India	30°20'N	78°02'E
5	Madhya Pradesh	Kottiwara	Madhya Pradesh	India	20°29'N	74°08'E
6	Assam	Lanka	Assam	India	27°58'N	89°45'E
7	Meghalaya	Tura	Meghalaya	India	25°31'N	90°13'E
8	Tripura	Bagafa	Tripura	India	23°25'N	91°35E
9	Orissa	Kariar Road, Nuapada	Orissa	India	20°48'N	82°32'E
10	Maharashtra-I	Jimalgatt	Maharashtra	India	19°05'N	80°10'E
11	Maharashtra-II	Umari	Maharashtra	India	20°06'N	78°58'E
12	Maharashtra-III	Darekasa	Maharashtra	India	21°15'N	80°35'E
13	Maharashtra-IV	Dongargaon	Maharashtra	India	20°04'N	80°17'E
14	Maharashtra-V	Hiwara	Maharashtra	India	21°31'N	79°28'E
15	Maharashtra-VI	Paoni	Maharashtra	India	20°30'N	79°22'E
16	Andaman	Wimberligunj	Andaman and Nicobar Islands	India	11°45'N	92°43'E
17	Karnataka	Sampangi	Karnataka	India	12°29'N	75°33'E
18	Tamil Nadu-I	Mudumalai	Tamil Nadu	India	11°37'N	76°34'E
19	Tamil Nadu-II	Siruvani	Tamil Nadu	India	10°55'N	76°41'E
20	Tamil Nadu-III	Topslip	Tamil Nadu	India	10°27'N	76°50E
21	Tamil Nadu-IV	Courtrallum	Tamil Nadu	India	8°55'N	77°16'E
22	Tamil Nadu-V	Kalakkad	Tamil Nadu	India	8°30'N	77°32'E
23	Kerala - I	Wadu-Konni	Kerala	India	9°13'N	76°51'E
24	Kerala – II	Padam-Konni	Kerala	India	9°13'N	76°51'E
25	Kerala – III	Kallaley-Konni	Kerala	India	9°13'N	76°51'E
26	Kerala – IV	Karalai Nilambur	Kerala	India	11°16'N	76°13'E
27	Kerala – V	Nellikuthu-Nilambur	Kerala	India	11°16'N	76°13'E
28	Kerala – VI	Chatanpura-Nilampur	Kerala	India	11°16'N	76°13'E
29	Kerala – VII	Tholpatty-Wynad	Kerala	India	11°39'N	76°16'E
30	Kerala – VIII	Chettivara-Parambikulam	Kerala	India	10°23'N	76°48'E

above expressed significantly higher plant height in addition to Karnataka (Table 2). The plant height at six MAP ranged from 20.01 cm to 68.31 cm with the average being 49.99 cm. The seed source Kerala VI recorded the maximum height of 68.31 cm.

Considering two growth stages at field conditions, six seed sources, viz. Tripura, Tamil Nadu III, Tamil Nadu IV, Kerala VI, Kerala VII and Kerala VIII consistently recorded significantly increased plant height over to that of general mean (Table 2).The collar diameter ranged between 0.65 cm and 1.51 cm. Compared to the general mean at 3 MAP. Three seed sources, viz., Tripura, Kerala VI, Kerala VII recorded significantly higher collar diameter compared to the general mean (Table 2) at 3 MAP. At 6 MAP, the collar diameter ranged between 0.93 cm and 2.27 cm. The average collar diameter recorded was 1.70 cm. Compared to the average collar diameter, five seed sources, viz. Kerala VII (2.27 cm), Kerala VI (2.17 cm), Karnataka (2.17 cm), Tamil Nadu III (2.16 cm) and Tripura (2.13 cm) recorded significantly higher collar diameter (Table 2). Considering two growth stages, three seed sources viz., Tripura, Kerala VI and Kerala VII proved superior to general mean.

At 3 MAP, nine seed sources viz., Tripura, Tamil Nadu III, Kerala I, Kerala II, Kerala IV, V, VI, VII and VIII expressed superiority compared to general mean

Table 2. Mean performance of seed sources – plant height and collar diameter

Sl.No.	Seed source	Plant height (cm)		Collar diameter (cm)	
		3 MAP	6 MAP	3 MAP	6 MAP
1	Lao-PDR	21.61	47.52	1.31	1.81
2	Bangaladesh	19.11	47.74	1.20	1.76
3	Uttar Pradesh	15.92	41.91	1.09	1.56
4	Uttranchal	14.71	35.60	1.22	1.50
5	Madhya Pradesh	10.25	20.01	0.65	0.93
6	Assam	20.46	49.45	1.32	1.81
7	Meghalaya	23.92	49.87	1.32	1.95
8	Tripura	33.58*	63.88*	1.43*	2.13*
9	Orissa	15.55	42.51	1.00	1.47
10	Maharashtra-I	12.88	33.06	0.86	1.23
11	Maharashtra-II	13.69	32.41	0.76	1.17
12	Maharashtra-III	14.81	31.59	0.85	1.28
13	Maharashtra-IV	16.39	38.45	0.91	1.38
14	Maharashtra-V	16.68	41.98	0.90	1.50
15	Maharashtra-VI	14.58	40.17	0.87	1.43
16	Andaman	28.13	57.32	1.37	1.88
17	Karnataka	26.03	66.29*	1.33	2.17*
18	Tamil Nadu-I	25.04	56.54	1.19	1.83
19	Tamil Nadu-II	26.24	53.69	1.11	1.65
20	Tamil Nadu-III	31.72*	67.21*	1.30	2.16*
21	Tamil Nadu-IV	28.68*	64.07*	1.29	1.83
22	Tamil Nadu-V	16.32	31.73	1.01	1.35
23	Kerala - I	27.69	56.43	1.34	1.84
24	Kerala – II	26.09	52.59	1.20	1.75
25	Kerala – III	25.98	55.57	1.29	1.73
26	Kerala – IV	27.39	52.53	1.24	1.78
27	Kerala – V	32.60*	62.36	1.40	2.04
28	Kerala – VI	35.42*	68.31*	1.42*	2.17*
29	Kerala – VII	38.63*	73.21*	1.51*	2.27*
30	Kerala – VIII	35.51*	66.07*	1.39	1.90
	SEd	2.58	6.89	0.12	0.17
	CD	5.01	13.58	0.23	0.34

*Significant at 5% level

for number of leaves trait. The number of leaves at 6 MAP ranged from 10.51 (Madhya Pradesh) to 35.58 (Kerala VII) (Table 3). The average leaf number recorded was 29.19. At 6 MAP, eight seed sources viz., Tripura, Tamil Nadu III, IV, Kerala I, II, V, VI and VII expressed superiority over general mean. Considering two growth stages, the seed sources viz., Tripura, Tamil Nadu III, Kerala I, II, V, VI and VII expressed superiority consistently.

At 3 MAP, seven seed sources, viz., Tripura, Andaman, Tamil Nadu III, Kerala V, VI, VII and VIII proved superior to general mean (40.73 cm^3). At 6 MAP, the volume index ranged from 21.21 cm^3 (Madhya Pradesh) to 416.93 cm^3 (Tamil Nadu III). Compared to the general mean, five seed sources, viz., Tamil Nadu III (416.93 cm^3), Kerala VII (408.57 cm^3), Karnataka (366.56 cm^3), Kerala VI (364.58 cm^3) and Andaman (335.22 cm^3) recorded significantly higher volume index (Table 3). The seed source from Madhya Pradesh showed significantly lower mean for volume index. Considering volume index at two growth stages, four seed sources, viz., Andaman, Tamil Nadu III, Kerala VI and VII proved superior and the seed source from Madhya Pradesh proved inferior to general mean consistently.

In teak, variations in several growth characters, stem and morphological characteristics were also reported to be due to provenances (Rawat *et al.*, 1998).

Table 3. Mean performance of seed sources – number of leaves and volume index

Sl.No.	Seed source	Number of leaves	Volume index17		
		3 MAP	6 MAP	3 MAP	6 MAP
1	Lao-PDR	17.71	18.65	42.15	189.69
2	Bangaladesh	18.88	19.50	29.91	174.53
3	Uttar Pradesh	14.03	15.25	20.52	120.32
4	Uttranchal	14.51	15.79	29.83	95.08
5	Madhya Pradesh	8.51	10.51	4.55	21.21
6	Assam	16.51	17.65	37.94	179.62
7	Meghalaya	15.80	15.50	44.18	175.82
8	Tripura	28.69*	30.74*	74.28*	311.36
9	Orissa	14.63	16.51	20.57	123.74
10	Maharashtra-I	12.19	13.60	10.91	67.16
11	Maharashtra-II	10.10	13.47	8.45	52.47
12	Maharashtra-III	10.73	14.13	11.83	66.34
13	Maharashtra-IV	11.17	15.28	14.99	91.41
14	Maharashtra-V	12.15	16.44	15.26	101.03
15	Maharashtra-VI	10.56	13.25	12.22	87.40
16	Andaman	22.10	21.30	76.71*	335.22*
17	Karnataka	21.37	24.03	47.29	366.56*
18	Tamil Nadu-I	20.79	25.07	36.51	197.69
19	Tamil Nadu-II	18.82	25.07	34.93	167.28
20	Tamil Nadu-III	26.60*	26.47*	68.77*	414.93*
21	Tamil Nadu-IV	22.11	27.93	52.07	234.35
22	Tamil Nadu-V	19.39	20.16	17.54	61.59
23	Kerala - I	24.29	26.39	54.57	221.09
24	Kerala – II	23.78*	24.92*	42.83	197.41
25	Kerala – III	18.34	19.21	43.56	187.23
26	Kerala – IV	24.43*	26.23	44.78	181.02
27	Kerala – V	27.36*	31.62*	74.19*	312.97
28	Kerala – VI	29.68*	29.55*	77.25*	364.58*
29	Kerala – VII	31.02*	35.58*	95.21*	408.57*
30	Kerala – VIII	24.04*	26.00	77.50*	272.12
	SEd	1.99	2.63	14.14	71.69
	CD	3.92	5.18	27.83	141.17

*Significant at 5% level

Significant variations have also been observed in respect of height, girth and number of internodes in 16 half-sib progenies of teak. Teak provenances differed significantly in terms of survival and other physical characteristics at field conditions (Rao *et al.*, 2001). This was probably due to minute microclimatic variation within the seed zones.

The provenance from Konni of Kerala had the best score for health, crown and branching habits, which was better than the local standard (Rao *et al.*, 2001). Jayasankar *et al.* (1999) reported that the provenances of Parambikulam, Nilambur and Malayattur consistently recorded better shoot and root growth, biomass production and relative growth rate. In the present investigation, two seed sources from Nilambur of Kerala (VI and VII) performed well under field conditions in addition to Tripura and Tamil Nadu III. These findings are also consistent with the observations of Grabe (1973) that seeds from different sources vary in their performance. The study thus attests to the need for determining best seed source for each planting area.

Variability and heritability parameters

The phenotypic and genotypic coefficients of variation for plant height were 39.72 and 25.04 per cent respectively. The plant height recorded moderate heritability of 0.4 and the genetic advance, as percentage of mean was 32.52 (Table 4). The collar diameter recorded phenotypic and genotypic coefficients of variation of 29.22 and 18.10 per cent respectively. Collar diameter also recorded a moderate heritability of 0.38 and the resultant genetic advance, as per cent of mean was 23.09. The phenotypic and genotypic coefficients of variation for this trait were 40.42 and 29.40 per cent respectively. Number of leaves recorded a maximum heritable value of 0.53. This trait also recorded a maximum of 44.05 per cent of genetic advance, as per of mean. Volume index recorded maximum phenotypic (97.98) and genotypic (51.77) coefficients of variation. This trait recorded lowest heritability value of 0.28. The genetic advance as per cent of mean recorded by this trait was 56.36 (Table 4).

The genetic variation, which is heritable, can be exploited for future use. In the present investigation, volume index recorded high PCV and GCV. Other parameters, viz., number of leaves recorded moderate PCV and GCV followed by plant height and collar diameter. Similar report on high GCV for volume index was also reported in teak (Arun Prasad, 1996). Higher GCV for number of branches in *Eucalyptus tereticornis* and low GCV for height in the same species have also been established (Surendran and Chandrasekharan, 1984). Low GCV for height in *E. tereticornis* (Venkataraman, 1996; Balaji, 1997) and low GCV and PCV for height and collar diameter in *Bambusa pallida* (Singh, 1993) have also been reported. The exhibition of low to moderate PCV and GCV for plant height and collar diameter in the present study is in conformity with the above assertions. Since the seed sources were at very early stage of growth phase when compared to its rotation age of 60, the present values are optimal and adequate and this may increase with age.

Heritability estimate has an important place in tree breeding as it provides an index of the relative strength of inheritance and environment. The best gains are made for characteristics that are strongly under genetic control and have wide range of variability (Zobel, 1971). In the present study, the number of leaves recorded the maximum heritability estimate of 0.53, which was of moderate in range followed by plant height (0.40) and collar diameter (0.38). Volume index registered low heritability (0.28), which might be due to the complexity of this

Table 4. Genetic estimates for biometric attributes of teak at 6 MAP

Sl. No.	Traits	PCV	GCV	Heritability	GA as % of Mean
1	Plant height	39.72	25.04	0.40	32.53
2	Collar diameter	29.22	18.10	0.38	23.09
3	Number of leaves	40.42	29.40	053	44.05
4	Volume index	97.98	51.77	0.28	56.36

quantitative trait prone to high environmental influences (Table 4). The heritability estimates for height both at individual and family level are low (Gogate *et al.*, 1997) which indicate considerable influence of environment on the development of this character. Panse (1957) reported that the heritability is mainly due to non-additive genetic effects. The genetic gain would be low while on the other hand, if the heritability is chiefly due to additive genetic effect, a high genetic advance is expected. In the present study, teak exhibited high heritability for number of leaves and moderate heritability for plant height and collar diameter, which were governed partly by additive gene actions. However, Rajesh Sharma *et al.* (1996) recorded low to very high heritability for height and low to moderate heritability for diameter and basal area. The genetic gain expected also followed a similar trend. Lower heritability estimates for various growth parameters has also observed in *Casuarina equisetifolia* (Kumaravelu, 1997; Mahadevan *et al.*, 1999; Paramathma and Surendran, 1997). Low heritable estimates for height, girth at breast height, crown and branching and health of trees was also established in teak (Rao *et al.*, 2001). The variations observed in heritability values for height and diameter corroborated the results of the present findings. However, high heritability values for height at individual and family level coupled with high genetic gain values are established in teak clones (Anmol kumar *et al.*, 1997), which indicate predominance of additive gene action.

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Clonal Propagation and Genetic Improvement

Teak Tissue Culture for Improved Productivity

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ABSTRACT

Tissue culture is an important branch of plant biotechnology, can be used for improved productivity through clonal multiplication of the superior plants. The possibility of plant production using the meristem tissue from 100 year old teak plant was demonstrated in 1980. This was the first report on teak tissue culture, indicating the possibility of application of tissue culture to forestry. The micropropagation technology was further refined and was used for scaling up of production of plants using elite / plus trees of teak and field planted at different locations in India. The work carried out in scaling up of technology was presented in last international workshop on teak held at Yogyakarta, Indonesia. The presentation in this meeting will include work carried on Improvement and upscaling of the micropropagation technology and field planting of the tissue culture raised propagules of teak. The major emphasis will be on the results obtained on the field performance of tissue culture raised plants of different clones of teak. The data obtained is from 5 to 8 years old plantations.

Keywords: Teak, micropropagation, scaling –up of micropropagation, field performance

INTRODUCTION

Plant Tissue Culture occupies a central position in plant biotechnology, whether it is micropropagation of superior mother clones, conservation of germplasm, genetic transformation or generation of novel plants through genetic engineering. It has long been realised that, tissue culture micropropagation of superior genotypes can result in capturing genetic gains, leading to increased productivity per unit area. Mass multiplication of the identified plus trees selected for higher growth, disease resistance and wood quality *in vitro* is known as micropropagation. This method is preferred over the conventional method of rooting of cuttings, grafting and propagation through seeds as the plants produced are true to type, disease free and can be produced round the year. Here the method of choice is meristem culture.

In case of woody perennials although extensive R and D has been carried out the success has been slow. In early eighties, only a few reports on mature tree tissue culture were available. The low rate of success in tree species was attributed to the inherent problems associated with the complex physiology of tree species. The major constraints faced in the propagation of tree species were contamination, phenolics and physiological status of the mother plant. However presently many tree species (both angiosperm and gymnosperm) have been successfully micropropagated, a few have been commercialization and outplanted.

TISSUE CULTURE STUDIES ON TEAK

Tissue culture studies on teak with an aim to develop a micropropagation protocol for rapid multiplication of mature identified mother clones were undertaken way back in late seventies. Extensive studies were conducted on right from germination of seeds in vitro, protocol for seedling multiplication and most importantly culture of meristems from mature trees (80-100 yr. old) growing in Allapally forest, Maharashtra, India. The constraints of control of phenolics, contamination faced during the initiation and establishment of cultures were combated, shoot cultures were established, further multiplied and rooted in vitro to obtain complete plantlets which were successfully transplanted to soil (Gupta *et. al.*, 1980) Tissue Culture raised plants were field planted at different places in Maharashtra and small scale field trials were conducted in collaboration with Maharashtra Forest Development Corporation, Maharashtra. The data received on the growth performance of these plants was inconsistent and could not be considered for the analysis of growth performance of tissue culture raised plants in the field. However during the same time a field trial in a randomized block design with seven replication was conducted at NCL, Pune to study the growth performance of tissue culture raised plantlets of seedlings (T2) and elite tree origin (T3) in comparison with seedlings raised from seeds (T1). The significant increases in height and girth were reported in T2 and T3 as compared to T1. T3 showed highest growth increment. Growth performance of these plants have been reported (Mascaranhas *et al.*, 1987,1993)

Considering the potential application of micropropagation technology for teak improvement programmes, extensive studies on tissue culture of teak were carried out at NCL, Pune.

The milestones of these activities are summarized below :

1. First report on clonal multiplication of teak by tissue culture from mature trees (over 80 yr.) (Gupta *et al.*, 1980) Method for clonal multiplication of teak using material both from seedlings and mature trees. Viable plants produced and successfully transplanted in field.
2. Extensive R and D to study factors affecting micropropagation of teak and refinement of protocol, development of simple method for control of phenolics, faster multiplication *in vitro*, minimal media and improvement of *in vitro* rooting percentage (Mascarenhas *et al.* 1987,1993 Kendurkar *et al.*, 1991)
3. Preliminary field trials at NCL in Randomized block design indicating higher biomass (height and girth) reported (Mascarenhas *et al.*, 1987,1993)
4. Extensive R and D for refinement and scaling up of protocol for large scale production mainly to extend it to different genotypes collected from dry, moist and semi moist regions of India. Development of an efficient method for *ex vitro* rooting of teak micro shoots. To assess technocommercial feasibility, large scale production of plants and field planting at locations in the states of Madhya Pradesh, Maharashtra, Tamil Nadu, Karnataka etc. (Nadgauda *et al.*, 1997,1998)
5. Preliminary studies on cryopreservation of teak meristems (Kendurkar *et al.*, 1999)
6. Analysis of growth performance data collected from clonal trials and provenance trials (Nadgauda *et al.*, 2001)
7. The technologies developed for micropropagation of teak transferred to one International company and two Indian companies.
8. DNA Marker studies to test the clonal homogeneity of the tissue culture raised plants.

Mass propagation of teak through tissue culture and assessment of technocommercial feasibility

In order to refine and scale up the protocol extensive R and D was carried out on following lines :-

- Reduction in number of steps.
- Optimization of chemical and physical parameters.
- Improvement of multiplication rate.
- Development of *ex vitro* rooting method and improvement in survival rates.
- Methods for successful transportation of plants to field.

Fresh green (apical and axillary) buds were collected from identified clones of teak from moist, semi moist and dry regions of India. Significant refinements in the protocol such as standardization of season of collection, type of explant, methods for proper transport to laboratory in healthy green condition, control of phenolics and contamination were achieved and cultures were established from more than 15 genotypes. Physical and chemical parameters were further tuned to favour the optimum growth, multiplication and plant production from different genotypes of teak. Thus the protocol was scaled up and more than half-a-million plants were produced. These plants have been out planted at different agroclimatic zones to assess not only the growth performances but also the site specificity of different clones. For easy transport of plants, stumps were prepared. These stumps included 2-4 cm of the stem portion above the first pair of buds with tap roort cut to a length of 20 to 25 cm. This resulted in the considerable reduction of the cost of transport of plants.

In earlier meeting held at Yogyakarta, in Indonesia, during year 2000 part of the work carried out on teak was presented, which included the technology development, setting of pilot plant, up-scaling of technology and out planting of plants at multilocations. This paper describes the further growth analysis of the field trials of teak.

Field trials on tissue culture raised plants of teak

Clonal trial on teak :

Among the teak clones numbered NC-21. NE, TD, KLS the clone NC-21 proved to be the best performer in Maharashtra and Gujarat. In one of the trials conducted at Gujarat, NC-21 and NE showed higher growth performance upto 3 yr; however from the data recorded at the age of 4 yr. clone NE exhibit highest increment.

Performance of clones NC-21 and NE at different locations:

The performance of tissue culture raised plants of teak planted in 1994 at Madhya Pradesh has indicated an average increment of 17.85% for height over control and 21.28% for girth over control within 6 years for clone NC-21. In one of the trials planted using tissue culture raised plants of clone NE in Chattisgarh, the height increment of tissue culture raised plants is 40.75% higher over control and girth increments 62.09% higher over control at the age of 3 yr.

The trial conducted at National Chemical Laboratory, Pune using tissue culture raised plants of clone NC-21 has shown higher growth as against seed raised controls (although it is conducted in loamy soil). The tissue culture raised plants show average height of 4.58 m after 10 yr as against controls 3.91 m. The average girth at breast height 23.70 cm which is more by 6.27 cm than seed raised controls (17.43 cm)

The trial conducted at Gujarat has shown the excellent growth performance of clone NC-21. The average height is 9.18 m and average girth at breast height is 0.635 m. (Table – I) The average wood volume / ha calculated based on these results is 74.34 m^3/ha at the age of 6 yr. (Table – II) These results are encouraging as the average wood volume of conventional plantation after 20 years is 139 m^3 / ha. (Ref. Manual of Indian Timber by Gamble)

Volume of tree = $[(G/4)^2]$ x height x 0.3
= $(0.635/4)^2$ x 9.18 x 0.3
= 0.0694 m^3

Total No. of trees / ha = **1100**
Approx. estimated wood volume / ha = 76.34 m^3 / ha
Av. Teak yield / ha after 20 yrs. = 139.00 m^3 / ha

Wood density analysis of teak :

Teak being a timber tree, physico-chemical properties of teakwood is important at the time of harvest.

Table 1. Growth perfomance of NC-21 clones from Gandhinagar, Gujarat (India)

Age (months)	Avg. Height (m)	Increse in height %	Avg. Girth (m)	% increase in Girth (%)
17	5.03	-	2.540	-
21	5.49	9.14	2.800	10.23
29	6.15	22.27	3.300	29.92
32	6.52	29.62	3.414	34.41
42	7.39	46.91	4.600	81.10
57	8.30	61.01	5.500	116.53
72	9.18	82.50	6.350	150.00

Table 2. Projected average wood volume of clone NC-21 from Gandhinagar, Gujarat (India)

Height (m)	GBH (m)	Wood volume / ha after 6 years	Wood volume conventional plantation after 20 years
9.18	0.635	76.34 m^3/ha	139 m^3 / ha

Wood density is one of the important measure to judge the wood quality. The wood density of the clonal plants was determined collecting wood samples from randomly selected plants. The basic wood density was calculated using formula

$$\textbf{Basic wood density} = \frac{\text{Oven dry weight (kg)}}{\text{Oven dry volume (m}^3\text{)}}$$

To calculate oven dry weight, wood was dried in oven at 80^0 C and weights were recorded after regular intervals, until two consecutive observations were equal. For estimation of volume, water displacement method was used.

Wood density analysis of the samples collected from field trial conducted at Chaudhary Plantation, Raipur, Chattisgarh indicate average dry basic density of 671.27 kg/m^3 of tissue culture raised plants as against average 620.51 kg/m^3 of seed raised control plants (Table 3).

Table 3. Wood Density analysis of clone NC-21 from Raipur, Chattisgarh

	Wet Density (Kg/m^3)	Dry Density (Kg/m^3)
Control	860.30	620.51
TC raised	975.88	671.27

Average of 10 samples each and 3 replications

Testing of Clonal homogeneity

With a view of assessing the clonal fidelity of tissue culture raised plants of teak molecular analysis of tissue culture raised plants was carried out. RAPD analysis of tissue cultured plants along with mother plants confirmed clonal homogeneity. (Dr.S.N. Raina, Pers.Comm., Delhi University)

Molecular analysis is being carried out at NCL,Pune using RAPD and ISSR primers. For RAPD analysis 253 primers have been tested. Out of a set of 100 ISSR primers used, 21 ISSR primers gave amplification. Based on further analysis, 4 ISSR primers which can be used to test fidelity in teak clones have been identified (Dr. V.S. Gupta, NCL,Pune Personal comm. unpublished) Further studies on the development of a protocol for quality testing of tissue culture raised plants using these molecular markers are in progress.

CONCLUSION

Tissue culture studies on teak were started with the following questions in mind –

a. Whether it is possible to propagate the mature trees *in vitro*.
b. Can the technology be applied to large scale propagation.
c. How tissue culture raised plants will behave in field.
d. Are there any advantages of this technology?

As an outcome of the extensive studies carried out at NCL,Pune the achievements are very significant.

- It has been demonstrated that large number of plants can be produced using meristems from identified superior clones growing at different forest regions.
- The technology can be successfully applied for large scale production of the plants.
- The most striking observations in the field are that tissue culture raised plants showed more than 90% survival, very high uniformity and accerlated growth, resulting into reduction in rotation time. The results of specific gravity analysis are encouraging suggesting that the technology has definite advantages and if exploited commercially, can lead to significant gains.

- The growth is accelerated after first thinning of plantation (data is being collected and will be presented during meeting)

Molecular marker studies for assessing the clonal homogeneity can assure the quality of tissue culture raised propagules. Extensive molecular biology studies are however necessary for early selection of superior genotypes.

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Selection and Propagation of Superior Teak for Quality Improvement in Plantations: case study of the ICSB/Cirad-Forêt joint project

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ABSTRACT

Innoprise Corporation Sdn Bhd (ICSB), an investment subsidiary of the Sabah Foundation, has embarked on an extensive Research and Development program for teak (*Tectona grandis*), a highly prized timber species. Through ICSB's joint collaboration with CIRAD-Forêt, a French R and D organization, a plant improvement program was initiated in the early 1990's. Special efforts have been devoted to vegetative propagation strategies based on the development of efficient techniques, both at the laboratory and at the nursery levels. Materials from mature selected plus trees (ortets) from a broad genetic base, and seeds of presumed high genetic value but in restricted number, were multiplied by using a well-developed tissue culture technique at the Plant Biotechnology Laboratory. Additionally, seed lots from natural forest stands, plantations and a multi-provenance clonal seed orchard (CSO) were obtained. These were germinated and used to establish two main provenance/ progeny trials in two different locations within ICSB concession in east Sabah, Malaysia, in addition to other numerous conservation and demonstration plots. Data of six-year old trees from these provenance/progeny trials illustrated the great potential of the CSO materials especially in terms of growth rate compared to the other origins under the prevailing conditions. Advanced selection of genotypes combining various traits of major economical value i.e. wood characteristics, is underway. These genotypes and their progenies will be further tested in different sites in the immediate future. The ownership of such a rich germplasm coupled to the efficiency of the developed techniques offers a tremendous potential for genetic improvement, selection and mass production for large-scale plantations of higher yield and superior quality. Commercial production of selected materials from this rich genetic base will then ensue as tissue culture-issued materials for overseas markets.

Keywords: clonal deployment, field trials, genetic resources, germplasm, provenance/progeny trial, superior planting stock production, vegetative propagation, tissue culture.

INTRODUCTION

Teak was first introduced in Kota Marudu in the state of Sabah, Malaysia, by the Dutch Tobacco Company in the 1920s', but did not become popular until the early 1990s (Lapongan, 1998). Since then, private plantation owners and oil palm companies have grown teak mainly by intercropping with oil palm or other cash crops, with particular mention for the mosaic 10x10m interplanted with 10x10m oil palm design experimented at Balung Plantation in Sabah (Salleh, 1995; White, 2002). However, the teak planting material used was not specifically selected for such plantation systems.

Over time, lack of information on the optimal density and spacing in an intercropping system and thereby, fear of potential losses to the yield of associated crops, resulted in the planting of teak mainly along borders of many oil palm plantations and to some extent, roadsides. Moreover, the reputation of long rotation species traditionally associated to teak began to slacken further in Sabah and Malaysia as a whole. As a result, investors nowadays are more eager to invest in the oil palm industry due to the more lucrative returns that can be obtained in a time period as short as three years. Planters were not even encouraged by the finding from a cost analysis of teak planting in Malaysia that estimated teak could be viable as a plantation crop even with an increase of 20% in the cost of planting and a drop in price on a 15-year rotation (Krishnapillay *et al.*, 1997). Nevertheless, while the interest in teak planting within Malaysia declines in the face of competition from other cash crops such as cocoa, rice, rubber and especially oil palm for which the country has for years gained the world production leadership, the scenario is just the opposite in other parts of the world.

Countries in the tropical and sub-tropical zones such as Central and South America, Africa, India, Australia, and other parts of South-east Asia begin embarking on large-scaled planting of teak, recognizing it as a prime candidate for forest plantation establishment in terms of value and world market demand. Accordingly, particular attention is being devoted to means for improving quantitatively and qualitatively the yields in shorter time frames than traditionally expected. Since the early 1990's, Innoprise Corporation, the investment subsidiary of the Sabah Foundation, a state-run organization, and CIRAD-Forêt, a French Research and Development Organization have been working together, aiming at this objective.

CONSTITUTING GENETICALLY-RICH BASE POPULATIONS

Securing the access to a genetically broad-based population is an asset of magnitude importance for developing simple or more sophisticated tree improvement strategies. This is particularly true for teak considering the noticeable differences among provenances, progenies and even half-sib (Bath, 2000). Relevantly, one of our priorities has been to gather as many teak origins as possible and to establish properly designed base population plots within ICSB's concessions.

The first batch of seeds originating from the Solomon island seed-source was introduced in 1989. As for many seed sources, information on the accurate natural origin of this plant material is lacking, although Tenasserim (Myanmar, ex Burma) seems to be the most likely provenance (Kevin White, personal communication). The resulting seedlings were planted by the Plant Improvement and Seed Production (PISP for short) unit as a demonstrational plot in the Luasong Forestry Center, located about two hour drive from Tawau, on the east coast of Sabah. This plant material has been thriving since then, showing remarkable performances under local conditions with average diameter and height of 2-3 cm and 4 m in the first 2-3 years respectively, followed by a gradual evening out in average height of 2 to 3 m in subsequent years. The trees give rise to long clear boles with delayed flowering, bearing in mind that in teak, the later the attainment of the flowering stage, the longer the bole and therefore, the higher the value.

The second introduction of seeds was made in 1995, this time collected from the teak seed stand belonging to the Forest Research Institute of Malaysia in Perlis, located in the north of Peninsular Malaysia close to the border with Thailand. There is still a basic need to document the accurate provenances of these seeds. The small amount of seeds from this batch was germinated under *in vitro* conditions at the Plant Biotechnology Laboratory (PBL) following the procedure described by Monteuuis *et al.* (1998), and then planted as yet another demonstrational plot in Luasong.

In 1996, in order to widen the existing genetic base of teak in our project, ICSB jointly with Cirad-Foret procured seeds from two extensive sources - from natural forest stands or plantations and from progenies produced from a multi-provenance clonal seed orchard in Ivory Coast. Altogether, there were 77 seedlots comprised of India, Thailand, Papua New Guinea, Tanzania, Ivory Coast, Solomon Island, Indonesia, Segama (Sabah) and Perlis (Peninsular Malaysia) (Tables 1 and 2). The seeds were germinated either at the PISP nursery in Luasong or at the PBL, particularly those with presumably low germination capacity. A detailed report on the seedling procedure at the PBL has been published (Monteuuis *et al.*, 1998).

However, in the same way as for many species introduced as exotics, tracing the accurate natural origins of every seed-source as well as the number

Table 1. List of the various seedlots obtained, germinated and planted within our project

Provenances:	* India Chandrapur Maharastra * India Sakrebail Karnataka – 2 batches * India Virnoli Vir. Karnatakan – 2 batches * India Karadibetta Karnataka * India Gilalegundi Karnataka * India Maukal Karnataka – 7 batches * Thailand Mae Huat Lampang (natural stand) * Thailand Mae Huat Lampang (planted stand)
Seed sources:	* Bulu Kumba, Indonesia * Papua New Guinea ex Brown River - presumably from Myanmar (Burma) (Cameron 1966, White, personal communication); * Solomon Island Arara - presumably introduced from Myanmar if not from India or Thailand, via Papua New Guinea (White, personal communication); * Solomon Island Viru–presumably introduced from Myanmar if not from India or Thailand, via Papua New Guinea (White, personal communication); * Perlis, Peninsular Malaysia – from Forest Research Institute Malaysia, presumably from Thailand * Kota Marudu, Sabah – introduced by the Dutch Tobacco Company, presumably from India
Total: 22 seedlots	

of progeny and provenances included, constitute a real problem; information, when reliable, is fragmentary and a lot of uncertainties remain. In this respect, we are placing strong hopes on the use of molecular markers for accessing the information that is lacking.

GERMPLASM CONSERVATION

The teak genetic resources gathered within the project can be conserved either as seeds, planted outdoors or in tissue culture conditions.

As seeds

Seed lots can be stored in a fridge or cold room, at 4°C for some time. However, loss of germination capacity over time must not be underestimated. Several months of storage under such environment may result in a dramatic decrease in germination rate, already known to be low and unpredictable under the best conditions for teak (White, 1991). Depending on the challenge, resorting to tissue culture for germinating recalcitrant seeds can be envisaged, as already successfully undertaken (Monteuuis *et al.*; 1998).

In vivo

Within our project, *in vivo* conservation plots consist mainly in the resources existing in the nursery or in the base and breeding populations, in other words, in demonstration plots, provenance-seed source/ progeny trials, clonal tests and seed stands. Practically, mainly genotypes exhibiting superior phenotypes will be preserved. In that sense, our concept of germplasm conservation, deliberately operation-oriented, might be too restrictive. Cost, however, remains for us a major concern. We cannot afford to set up and maintain ex-situ conservation plots for all the genotypes from as many different origins as we can get, owing to various factors such as availability of sites, costs in silvicultural practices and manpower for maintenance of the plots

In vitro

In vitro culture conditions can be a good option for germplasm conservation (Haines, 1994), in a more restricted environment than *in vivo* plots whereby proper maintenance remains a critical issue (Zobel and Talbert, 1984). The pathogen-free characteristics of tissue culture allow the international exchange of living plant

Table 2. List of Families obtained from the Ivory Coast Clonal Seed Orchard and planted within our project

Origin of seed lots	Number of seedlots
India Nellicutha	13
India Nilambur	10
India Vernolirge	3
India Va	2
India Purunakote	3
Ivory Coast Bamoro	2
Ivory Coast Kokondekro	1
Laos Paklay	2
Senegal Djibelor	1
Tanzania Kihuhwi	3
Tanzania Mt	3
Tanzania Bigwa	3
Thailand Huoi-Nam-Oon	3
Thailand Maasale Valley	2
Thailand Pong Salee	2
Thailand Ban Pha Lay	2
Thailand Ban Cham Pui	1
Total : 17 origins	**Total : 56 seedlots**

material without any sanitary or climatic constraints, contrary to *ex-vitro* plants or plant portions.

Currently, our *in vitro* gene pool is limited to the genotypes under micropropagation. The protocols developed have been conceived as very conservative for maintaining the various genotypes for several years under sustainable sub-culture regimes, while preventing somaclonal variation risks (Monteuuis *et al.*, 1998; Goh and Monteuuis, 2001).

Clonal or genotypic fidelity, which is a requisite for gene bank, remains a crucial concern for us. Another option under investigation currently is the resort to cryopreservation, the efficiency of which has been proven for other tree species (Ashmore, 1997). Developing protocols adapted to teak will be facilitated by the possibility to regenerate teak plant from *in vitro* meristem culture, contrary to many tree species (Monteuuis, unpublished results). The main advantage associated with cryopreservation is the possibility to store genotypes for unlimited periods of times in a very restricted environment and without maintenance requirements, while preserving their integrity, as detailed by Ashmore (1997).

STRATEGIES FOR SETTING-UP IMPROVED YIELD AND QUALITY PLANTATIONS.

From seeds

The traditional means of propagating teak is through seeds, as has been practiced for centuries, with the possibility of storing the seedlings in the form of "stumps" when necessary (Kaosa-ard, 1986; Tin Tun, 2000). Various seed-based strategies have been suggested by specialists for improving the genetic quality of teak seeds (Wellendorf and Kaosa-ard, 1988; Kaosa-ard, 1998, 1999; Kjaer *et al.*, 2000). The seed stand and the seed orchard options are worth considering in our context.

SEED STAND OPTION

The different origins listed (Tables 1 and 2) have been set up on easily accessible ICSB stands according to planting designs adapted to the conversion of the demonstration plots or provenances-seed source/ progeny trial into seed stands. The two provenance/ progeny trials were set up in a partially equilibrated incomplete block design and were comprised of 41 and 42 seedlots respectively, with 26 seedlots common to both trials (Williams and Matheson, 1996). The two sites were very dissimilar in terrain in that one is on a hilly area (Luasong Forestry Center) whereas the other is located on lowland (Taliwas, Lahad Datu). Data from these trials will thereby also allow us to assess the genetic origin x environment interaction. Further, as much as possible, close vicinity of genetically related individuals within each trial has been avoided. Each progeny elementary plot did not include more than 5 siblings in order to minimize the losses when selecting the best in the plot to be kept as seed producers, while felling the others in order to prevent risks of inbreeding depression.

Mass selection prevails at the first step of the selection process. Individual selection is mainly phenotypic, with special attention to traits of major economical importance for teak such as: growth rate, small nodes, bole straightness and basal circularity in absence of buttress or flutes. Wood quality assessment including both aesthetic (wood pattern, texture) and technological characteristics has also to be taken into consideration for phenotypic selection.

In this respect, we are placing a lot of emphasis on the utilization of non-destructive methods for wood quality analysis (Baillères and Durand, 2000).

Further to this selection of plus trees for clonal testing, inferior trees and half-sib in close vicinity are culled in order to favor the intermating of superior individual not genetically related. In the absence of sufficiently detailed records, resort to molecular biology techniques such as AFLP developed in Cirad-Forêt laboratory can help in the determination of the genetic relatedness among individuals within the same neighborhood. The further testing of the selected seed producers of the seed stand based on the performances of their progeny will indicate their combining ability which can be used for refined or more advanced selection and culling activities (Kjaer and Foster, 1996; Mandal and Chawhaan, 1999). A final density of 120 - 180 seed producers per hectare of seed stand is expected at the end of these selection and roguing activities (Figure 1).

SEED ORCHARD OPTION

The best combining genotypes or "combiners" can be asexually propagated or duplicated to be mixed according to a well-suited planting design within a vegetative seed orchard consisting clones from different families and provenances, as illustrated in Figure 1.

These clones will be produced on their own root system as either rooted cuttings, microcuttings or even layering (Lahiri, 1985; Monteuuis *et al.*, 1995; Monteuuis *et al.*, 1998) in order to prevent grafting incompatibility problems and the consequential production of "illegitimates". These are likely to depreciate the genetic quality of the seeds produced, firstly, when collected directly from such unexpected 'mothers' since illegitimates are most of the time hard to distinguish from the grafts as they look similar, and secondly, as these will pollute the genetic quality of the seeds produced by the "legitimates" around.

However, the numerous question marks and uncertainties associated with the real benefits that can be expected from such orchards have to be seriously pondered (Kjaer and Foster, 1996; Kasoa-ard *et al.*, 1998; Kjaer *et al.*, 2000; White and Gavinlertvatana, 1999). The implementation of this strategy is therefore only to be considered for the long term.

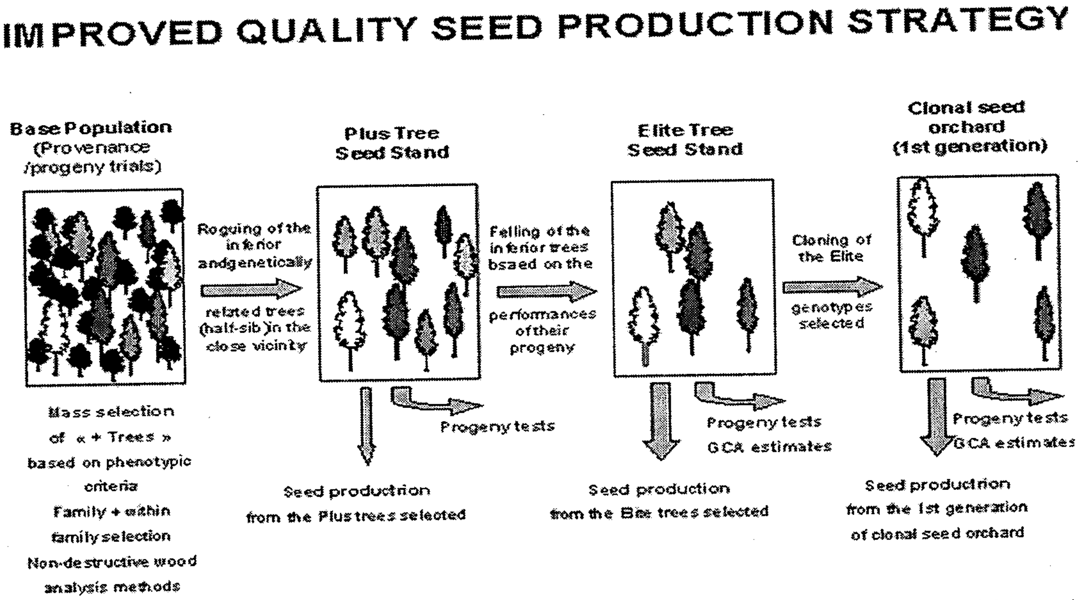

Figure 1: Illustration of the project strategy aiming at producing improved quality seeds in the shortest delay starting from genetically-rich base populations. Advanced generations of clonal seed orchards can be envisaged for the long term.

FROM CUTTINGS OR MICROCUTTINGS

Production of teak planting stock by seeds, although primarily employed, remains severely handicapped by the followings factors:

i. Quantitatively limited seed production (Wellendorf and Kaosa-ard, 1988, White, 1991).
ii. Late flowering. It is noteworthy that in teak, straight bole length, which affects directly its market value, is strictly dependent on the capacity of the terminal meristem to remain vegetative as long as possible (White, 1991). Its conversion into the flowering stage induces a fork formation, as the result of a true dichotomy process.
iii. Low germination rates (Kaosa-ard *et al.*, 1998; White, 1991). In Thailand, for example, only 5 plantable seedlings on average can be practically expected from 100 seeds in a large-scale nursery (Kjaer and Foster, 1996; Kaosa-ard, 1998).
iv. Substantial variability among individuals, even among half-sibs, within progenies, with regard to traits of major economical importance such as growth, form, technological and aesthetic characteristics (wood pattern) (Dupuy and Verhaegen, 1993; Kaosa-ard *et al.*, 1998; Bath, 2000);
v. Limited accurate genetic knowledge about the inheritance of such economically significant traits, and consequently, some uncertainty for the ultimate gain, notwithstanding the time constraints associated with sound breeding programs (Wellendorf and Kaosa-ard, 1988; Kjaer and Foster, 1996; Kaosa-ard, 1998).

The hindrances and uncertainties associated with long term breeding strategies for teak greatly penalized by low seedling productivity have been developed (Kjaer *et al.*, 2000; White and Gavinlertvatana, 1999). According to these authors, the magnitude of the real genetic gain associated with the seedling route has yet to be clearly defined, and the basic question to know whether all the efforts invested during the past decades are worthwhile remains. This is undoubtedly a major concern for potential investors, for which rapid pay-off is a decisive argument. From practical and theoretical information, it can be objectively assumed that for teak, greater genetic gain can be expected from the cutting forestry option, especially when clonal, than that from the seedling forestry (Zobel and Talbert, 1984; Ahuja and Libby, 1993a and b; Monteuuis and Goh, 1999).

Two different strategies can be considered for establishing wood production populations from vegetatively mass-produced teak planting stock, either in bulk form or by clonal propagation.

THE BULK OPTION

Bulk propagation consists in vegetatively propagating a group of mixed genotypes without maintaining any individual identification. This can be useful for increasing the number of a limited quantity of juvenile genotypes of presumably high and similar genetic value, derived for example, from controlled pollination.

The main advantage of the bulk propagation option lies in the absence of a need to strictly and clearly identify by proper labeling one genotype from another. This option will also maintain a certain degree of genetic variability depending on the number of genotypes involved at the beginning, and which in turn may induce an overall heterogeneity in the resulting wood production populations. This seems especially true for teak considering the variability among genotypes. However, successive generations of serial propagation may eventually result in a significant reduction of the original genetic base due to genotypic differences in the multiplication rates, i.e. in the number of shoots produced to be used as cuttings with sufficiently high ability for adventitious rooting.

Bulk propagation has been restricted in our project to superior quality, quantitatively limited or rare seed lots propagated under *in vitro* conditions. At this stage, the genotypes are too young to express any individual difference warranting a selection. The original genetic base in optimized micropropagation conditions, contrary to nursery environment, is thus maintained at least during the first several subculture cycles. However, over time, with little or no control on the genotype-dependent capacity for axillary shoot production, the risk of gradually losing clones with reduced capacity has to be acknowledged.

THE CLONAL OPTION

In clonal propagation, contrary to the bulk propagation strategy, the genotypic identity is rigorously and individually preserved through successive propagation cycles, which may last several centuries in certain cases. Each clone consists of asexually-derived offspring with virtually the same genetic make-up, regardless of the number of its representatives.

Clonal propagation involving scrupulous genotypic identification ensures a better control of the plant material propagated by cuttings than by the bulk option, in addition to a number of other advantages associated with cloning of forest trees (Zobel and Talbert, 1984; Ahuja and Libby, 1993a and b). The possibility to reproduce, theoretically in unlimited numbers, the best trees, from quality and yield standpoints, for large-scale plantation uses, offers tremendous prospects.

The basic requisite for successful teak propagation by rooted cuttings is the existence of a good capacity for adventitious rooting (Monteuuis *et al.*, 1995). From our first field observations, it appears that once rooted, teak cuttings develop "true-to-type", and a good within-clone uniformity can be ultimately expected. Increased yield, higher uniformity for economically important traits such as growth rate, trunk form, straight bole length, wood characteristics, and shorter rotations constitute strong incentives to develop teak clonal plantations (Wellendorf and Kaosa-ard, 1988; Bath, 2000). Such uniformity can not objectively be expected from plantations set up from seedlings, or even from cuttings issued from bulk propagation by virtue of

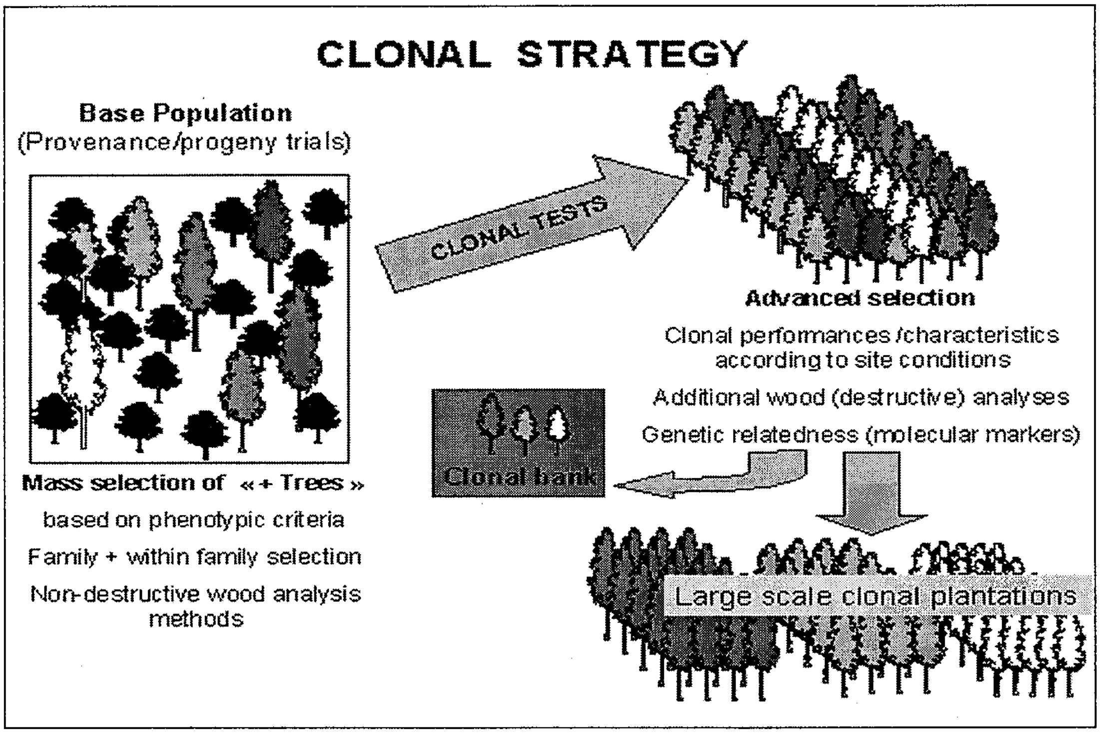

Figure 2: Illustration of the project strategy for large-scale clonal plantations of teak. Molecular markers can help with pedigree information, certification as well as for genetic relatedness between the clones used for clonal deployment.

the arguments developed previously. Properly selected and wisely deployed clones will thus maximize the short-term returns from suitable planting sites, which are dramatically reducing in surface area (Ball *et al.*, 2000).

Utilization of clones can be profitably adapted to intercropping after proper selection particularly, on crown form. Planting density and silviculture practices can be adapted to intensive management systems, with the possibility to harvest several times from the same stump, taking advantage of the excellent coppicing ability (Martin *et al.*, 2000). Such practices look very attractive for enhancing plantation yield while significantly reducing the planting and the (micro)cutting costs. With regard to these financial aspects, it has to be emphasized that clonal plantations generally require less planting stock than plantations established from seedlings, which compensate, to a certain extent, the higher cost of (micro)cuttings. Figure 2 summarizes the clonal strategy adopted for our project.

Efficient techniques for mass vegetative production of superior quality planting stock

Mass production of rooted cuttings in nursery

Mass propagation of teak of any age by rooted cuttings in nursery conditions has been developed and become fully operational within our project since 1992. The requisites, as well as the advantages and limits of this propagation option have been extensively presented and confirmed by a decade of experience (Monteuuis, 1995; Monteuuis *et al.*, 1995; Monteuuis, 2000). Average rooting rates of 80% are routinely obtained from mature genotypes intensively managed as container-grown stock plants once the mobilization phase has been successfully carried out. In such conditions, annual production of 600 rooted cuttings per square meter of stock plant area (15 stock plants per square meter) can be easily obtained (Monteuuis *et al.*, 1995).

In vitro mass propagation

The availability of a well-equipped laboratory within our joint project prompted us to explore the prospects of propagating teak in tissue culture conditions via microcuttings (Bon and Monteuuis, 1996). This successful application has already been reported (Monteuuis *et al.*, 1998; Goh and Monteuuis, 2001). The conceived tissue culture protocols were made as simple as possible in order to be easily applicable and to cope with the constraints of large-scale application in terms of cost efficiency and high productivity. Mass micropropagation of any genotype, either in bulk or clonally, through axillary-produced microshoots with an exponential multiplication rate of three to four at the end of every six week-duration sub-cultures is now possible. The rooting-acclimatization phase is advantageously achieved in nursery conditions under a mist-system with more than 90% success on average. After weaning and raising under the same intensive nursery conditions as for the cutting-derived plants, the tissue-culture plants develop into vigorous and true-to-type vegetative plants. More than 400,000 microcuttings have been produced up to now for local plantations as well as for oversea markets by applying this technique. The possibility to send the *in vitro* plants off to different destinations, regardless of distance, in the absence of phyto-sanitation restrictions, considerably expands the market prospects and constitutes an outstanding asset.

The *in vivo* rooted cutting and *in vitro* microcutting options for vegetatively mass propagating superior teak genotypes with the respective pros and cons have been extensively reviewed, leading to the conclusion that the best option, in many respects, consists in the combination of the two techniques (Monteuuis, 2000).

CONCLUSION AND PROSPECTS

The Research and Development collaborative project between ICSB and Cirad-Forêt was initially implemented to work primarily on rattan species. The shift and the emphasis given to teak started in the early 1990's as a result of the unexpected success obtained from the vegetative propagation techniques developed at the nursery and tissue culture levels. The possibility to mass produce clones by rooted cuttings or *in vitro* microcuttings in cost-effective conditions from any selected mature superior teak tree, as well as from good-performing teak trees introduced locally, prompted us to invest more on these activities. The rationale and the prospects of using clonal materials for teak have been indeed advocated for a long time. Being aware of our vegetative propagation assets, the next step has been to gather our own base populations with a genetic background as rich as possible. This aim has been attained to a large extent by our possession of a highly diverse teak genetic resource that covers the range of adaptability of the species. This noteworthy genetic richness combined to efficient propagation and diffusion techniques are likely to satisfy any plant material order, in the form of seeds, or clones in tissue culture conditions for oversea markets, with the possibility to certify the plant material by DNA fingerprinting.

Keeping up with the latest advances in technology which can further benefit the project remains a major concern. In this respect, we are placing emphasis on the application of molecular markers such as microsatellites and AFLP techniques currently employed for teak by Cirad-Forêt, as well as non-destructive wood analysis methods for moving one step forward in the selection of superior plant material and clonal deployment. Proper site x genotype matching indeed deserves particular attention with respect to pest and disease (defoliators and borers) aspects, as well as to heartwood formation, controlled by genetic and environmental parameters, and which determines log quality (Bailleres and Durand, 2000).

The need to intensify the production of premium quality high value timbers, teak being the most prized one, with a worldwide demand far greater than the supply available, is a strong incentive along this line.

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Tissue Culture Strategies for Quality Planting Stock Production of Teak

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ABSTRACT

Teak is the most preferred species in plantation forestry in India. The projected annual planting of teak in India is 240 million seedlings for over 1.2 million ha. A total of 800 hectares of clonal seed orchard (CSO) is established which can provide just 15-16 million seedlings of good planting stock. Therefore, micropropagation technique was established to quantitatively enhance production of genetically improved planting stock using the seeds of clonal seed orchards. Many micropropagation protocols for plantlet production of teak are known, yet few are practically applicable for mass production. Comprehensive method for good shoot multiplication, cost effective rooting and application to a wide range of genotypes was developed. Seedlings raised from seeds collected from different clones in clonal seed orchard were used for culture establishment. Nodal segments of *in vitro* germinated seedlings were placed for five days on MS (Murashige and Skoog) medium supplemented with 22.2 mM Benzyladenine (BA) and 11.62 mM Kinetin (K) for culture establishment. Rapid shoot proliferation was done in a 2-step culture method where cultures are maintained for two culture cycles in 2.22 mM BA, 1.16 mM K and 0.25% phytagel followed by a transfer to one cycle in 4.40 mM BA, 2.32 mM K and 0.25% phytagel. Healthy shoots of 4.0 cm and above were treated with 1000 ppm Indole-3-butyric acid (IBA) solution in *ex vitro* conditions and 80-100% rooting was achieved. Genetic uniformity of the tissue culture plants was tested using DNA markers. Through commercial micropropagation approach about 3000 plants were supplied Andhra Pradesh Forest Development Corporation. Effects of cytokinins, solidifying agents, method of subculturing on shoot proliferation of teak were also discussed.

Keywords: teak, micropropagation , CSO seeds, *ex vitro* rooting, DNA markers

INTRODUCTION

Tectona grandis is a valuable timber species grown on a large-scale by State forest departments, private companies and farmers in India. The annual planting target of teak in India is about 1.2 million hectares. Planting stock production is by seed, although there are many disadvantages, including poor fruit production, empty fruits and a low germination rate (Joshi and Kelker, 1971; Gupta and Kumar, 1976). Reliable seed sources are also limited. Various vegetative propagation methods like grafting, budding and rooting of cuttings are being practiced for teak multiplication (Rawat and Kedharnath, 1968; Nautiyal *et al.*, 1991, 1992; Nautiyal and Rawat, 1994; Goh and Monteuuis, 1997). However, the quantity of production is limited because of the poor rooting of cuttings collected directly from mature trees without any pretreatment for rejuvenation, limited availability of rootstocks and intensive maintenance of stock plants. Further, higher rooting percent is achieved with specific type of shoot cuttings only (Monteuuis, 1995). Micropropagation as a tool for clonal propagation of teak to overcome these problems has been advocated (Monteuuis *et al.*, 1998; Devi *et al.*, 1994; Mascarenhas *et al.*, 1987, 1993; Apavatjrut *et al.*, 1988; Tiwari *et al.*, 2002). Although commercial level production strategies are worked out for the mass micropropagation of teak (Monteuuis *et al.*, 1998), detailed methodologies have not been available. In the present study, we have developed a comprehensive method to amplify the genetically-improved seeds obtained from clonal seed orchard, which can be used on a commercial scale.

MATERIALS AND METHODS

Plant material

Fruits collected from clonal seed orchard (CSO) of Maharashtra were used in this study. Endocarps of the fruits were broken and seeds were removed for aseptic germination. Surface sterilisation of the seeds was done with aqueous solutions of 0.1% sodium hypochlorite for 5 minutes and 0.1% mercuric chloride for 5 minutes, followed by three rinses with sterile double distilled water. The surface-sterilised seeds were germinated individually on the medium containing agar (0.7%) and sucrose (3%) devoid of growth regulators.

Culture establishment

In optimisation experiments for culture establishment and shoot multiplication, individual identity of *in-vitro*-grown seedlings was not maintained. Nodal segments of 1-cm length were excised from 60-75 days old seedlings (6-8 cm in height) and placed on the following culture media.

a. MS 1- Murashige and Skoog's medium (1962) (MS) supplemented with 0.67 mM Benzyladenine (BA), 0.70 mM Kinetin (K), and 0.4% agar (Mascarenhas *et al.*, 1993).
b. MS 2- MS medium supplemented with 22.2 mM BA, 11.62 mM Kinetin and 0.7% agar (modified from Devi *et al.* 1994). After 5 days of inoculation, the explants were transferred to MS + 2.22 mM BA + 1.16 mM K + 0.7% agar.
c. SH- Schenk and Hilderbrandt (1972) Medium containing SH macronutrients, MS micronutrients and organic additives, 1.48mM Indole-3-butyric acid (IBA), 4.40mM BA, 3% sucrose and 0.7% agar (Apavatjrut *et al.*, 1988)

All the media ingredients used in this study were obtained from Hi-Media laboratories, India, except for the growth regulators and phytagel, which were obtained from Sigma Chemical Co., St. Louis, Mo.

Shoot multiplication

In the first experiment, the effect of MS medium containing different concentrations of BA (1.11, 2.22 and 4.44 mM) and Kinetin (0.58, 1.16, 2.32 and 4.6 mM) were tested to standardise the concentrations of the growth regulators for optimal growth. For each treatment, 10 nodal segments of *in-vitro*-developed shoots were used. All the nodal segments excluding the apical bud were used for the experiment. In the second experiment, MS medium with agar (0.7 and 0.8%), phytagel (0.2, 0.25 and 0.3%) and combinations of agar and phytagel (0.35 and 0.1%; 0.4 and 0.125% respectively) were tested to identify a suitable solidifying agent. Twenty culture flasks were used for each treatment, with a single cluster per flask having two to three shoots per cluster.

Multiplication of improved genotypes

Quality seeds obtained from the following CSO clones were germinated *in vitro* and fast growing seedlings were selected and used for large-scale multiplication.

Name of the clone	Origin of the clone	Source
MHAL A9	Maharastra	Maharashtra CSO
MHAL A3	Maharastra	Maharashtra CSO
TNT 10	Tamil Nadu	Maharashtra CSO
SBL 01	Andhra Pradesh	Maharashtra CSO

Individual seeds were treated as genotypes and germinated as described and maintained separately throughout the experiment. Fifty-five days after germination, seedlings were cut into single nodal segments and placed on culture initiation medium (MS 2) for five days then transferred to the shoot multiplication medium. Shoot multiplication was carried out in 2-step culture method as optimised in the previous experiments.

Subculture method

For continuous shoot production, the nodal segments of the *in-vitro*-formed shoots were used. The response diminished after 5-6 subcultures. The shoots were therefore subcultured by two different methods.

1. Node planting (single nodes derived from *in vitro* grown shoots),
2. Horizontal placement (placing the stem segments with at least 3 nodes horizontally on the culture medium after removing the leaves and apical bud)

Data on number of shoots produced and number of shoots suitable for rooting were recorded.

Rooting

Ex vitro rooting experiments were performed with the micro cuttings of various lengths (2-3, 3-4, 4-5 cm) obtained from the four genotypes. Twenty micro cuttings were used for each treatment. Bases of the cut ends were dipped in 1000 ppm IBA solution for 5 minutes and inserted directly into net pots (64 cc) containing vermiculite presoaked in water. Prior to auxin treatment, the lamina was clipped leaving the top pair of expanded leaves. The net pots were placed in polytents under shade, closed tightly on all sides to maintain high humidity (approximately 95%). After 20-25 days, the polytents were opened gradually. Data on rooting were recorded after 35 days of treatment.

Culture conditions

Cultures were maintained under 12-h photoperiod with the light intensity of 40 mmol $m^{-2}s^{-1}$ at $25 \pm 2\,^{0}C$. The media were supplemented with 20% sucrose, adjusted to the pH of 5.7 ± 0.1 prior to the addition of gelling agent and autoclaved at 121 ^{0}C and 108 kPa for 20 minutes.

Stomatal studies

Stomatal studies were conducted using the *in-vitro*-grown normal shoots, vitrified shoots, acclimatized plants (leaves formed in culture) and seedlings. Three leaves from three different shoots/plants were used. Lower epidermal peelings from each leaf were taken. Stomatal index (SI) was determined after examining 10 fields of view per epidermal strip. SI was calculated using the following formula.

$$SI = \frac{\text{No. of stomata}}{\text{No. of stomata + No. epidermal cells)}} \times 100$$

Diameter and length of the stoma and stomatal pore were determined after examining 100 fully opened stomata. Guard cell behaviour of the stomata was studied by incubating the leaves in dark for 10-15 minutes.

ISSR-PCR analysis

Leaf samples obtained from five ramets of one clone was used for DNA extraction. Genomic DNA was extracted using the Qiagen's Dneasy plant DNA extraction kit following the manufacturer's instructions. ISSR-PCR amplifications were carried out in the reaction mixtures of 10 ml containing 1x PCR buffer, 0.1mM each of dCTP, dGTP, dTTP and dATP, 2.5 mM MgC12, 0.8 mM primer, 1.0 unit of Taq DNA polymerase and 30 ng of template DNA. The following 6 primers were used to study the genetic uniformity of teak tissue culture plants.

Primer 1	GRT RCY GRT R (CA)7
Primer 2	CRT AY (GT)9
Primer 3	ARR TY (CAG)4
Primer 4	AGC RR (ATT) 4
Primer 5	AYA RA (GCT)6
Primer 6	YCY RRG (ATT)4

All the PCR reactions were carried out in PTC 100 Thermal Cycler (MJ Research Inc., USA) using the following reaction conditions: 94° C for 3 min. initial denaturation and 35 cycles of 94° C for 30 s, 50° C for 30 s and 72° C for 1 min. followed by final extension of 72° C for 10 min. The PCR products were analysed in 1.2 % agarose gel containing 0.5 mg/ml ethidium bromide in 0.5X TBE buffer and run in same buffer at 100V for 3 hrs. The gels were viewed and photographed over UV light in a BioRad Geldoc system.

Statistical analysis

The significance of differences among the treatments was established by one-way analysis of variance. Percentage data was subjected to arcsine transformation prior to analysis.

RESULTS AND DISCUSSION

The potential benefits of the use of clonal planting

Table 1. **Effect of media composition on culture establishment of teak**

Media Code	Media composition	Mean number of shoots ± S.E	Mean shoot height (cm) ± S.E	Culture response (%)	Culture morphology*
MS 1	MS + 0.70 mM K + 0.67 mM BA + 0.4% Agar (Mascarenhas *et al.*, 1993)	1.5± 0.4	4.2 ± 0. 7	62	Partially Vitrified shoots
MS 2	MS + 22.2 mM BA + 11.6 mM K + 0.7% agar** (Modified from Devi *et al.*, 1994)	2.8 ± 1.1	2.3 ± 0.4	55	Normal shoots
SH	SH macronutrients + MS micronutrients + 3% sucrose + 1.48 mM IBA + 4.40 mM BA + 0.7% Agar (Apavatjrut *et al.*,1988)	1.2 ± 0.5	4.5 ± 0.9	60	Callus formation at the base of the explant

* Recorded after 3 subcultures
** After 5 days the explants were transferred to MS + 2.22 mM BA + 1.16 mM K + 0.7% Agar

stock in reforestation programs have long been recognized. However, to achieve the maximum possible genetic gain for teak improvement, both sexual reproduction and vegetative multiplication must be followed (Kaosa-ard *et al.*, 1998). It can be accomplished through micropropagation using CSO seed grown aseptically.

Culture establishment

40 days of culture incubation in MS1 and SH medium provided good shoots (Figure 1) beyond which there was vitrification (MS1) or excessive callus formation at the base (SH) (Table 1). The protocol of Devi *et al.* (1994) (MS medium with 22.2 mM BA and 4.6 mM K) produced malformed and vitrified shoots when the explants were maintained on the same medium for more than 15 days. However, quality shoot production was obtained when the nodes were transferred to MS medium with 2.22 mM BA and 1.16 mM K after 5 days of culturing in MS2 medium (Table 1). Tiwari *et al.* (2002) also recommended the use of high concentration of BA (22.2 mM BA) during culture establishment of teak.

Shoot multiplication

After about four to five subcultures on the MS medium with 2.22 mM BA and 1.16 mM K the shoot growth and multiplication rate declined. Optimisation was achieved by transferring the shoots to various concentrations of BA and K with 0.7% agar (Table 2). High frequency shoot proliferation (Table 2) with good shoot production was achieved in the medium containing 4.40 mM BA and 2.32 mM K, and the mean height of shoots was 4.2 cm (Figure 2). Continuous subculturing (4-5 subcultures each with 40 days interval) on the same medium resulted in vitrification, which was overcome by varying the concentrations of agar or phytagel alone, or combinations were used with 4.40 mM BA and 2.32 mM K (Table 3).. Although phytagel improved shoot multiplication, some cultures still showed vitrification in 0.2% concentration. Increasing the

Table 2. Effect of cytokinins on shoot multiplication of teak (MS + 0.7% Agar)

Cytokinins	Mean no. of shoots ± S.E	Mean shoot height in cm ± S.E	Cultures vitrified (%)
1.11 mM BA0.58 mM K	0.6 ± 0.4	2.2 ± 0.9	10
2.22 mM BA1.16 mM K	1.8 ± 0.8	5.6 ± 2.2	10
4.40 mM BA1.16 mM K	1.8 ± 0.6	5.6 ± 1.9	25
4.40 mM BA2.32 mM K	2.5 ± 1.0	4.2 ± 1.2	15
4.40 mM BA4.60 mM K	1.5 ± 0.9	2.9 ± 0.8	40

Table 3. Effect of gelling agent on shoot multiplication of teak (MS + 4.40 mM BA + 2.32 mM K)

Gelling agent	Mean number of shoots ± S.E	Mean shoot height in cm ± S.E	Cultures vitrified (%)	Culture morphology
Agar				
0.7%	1.8 ± 0.9	5.0 ± 1.2	40	Normal shoots
0.8%	1.2 ± 0.6	3.2 ± 1.0	0	Shoots with very short inter nodes
Phytagel				
0.2%	3.9 ± 1.8	4.0 ± 1.5	30	Normal shoots
0.25%	3.5 ± 2.2	4.2±1.2	10	Normal shoots
0.3%	1.5 ± 0.8	2.2 ± 0.9	10	Part of the shoots dried
Agar + Phytagel				
0.35% + 0.1%	2.8 ± 0.5	3.1 ± 0.9	55	Normal shoots
0.4% + 0.125%	3.2 ± 0.7	2.8 ± 1.2	40	Normal shoots

concentration of phytagel to 0.25% produced normal cultures (90%) with more shoots, (average of 3.5), compared to agar medium. However, maintenance of cultures over four months in MS medium with 4.40 mM BA, 2.32 mM K and 0.25% phytagel again led to vitrification. Therefore, a 2-step culture method was developed with two culture cycles in 2.22 mM BA, 1.16 mM K and 0.25% phytagel followed by one cycle in 4.40 mM BA, 2.32 mM K and 0.25% phytagel.

Plant regeneration via shoot proliferation is aimed at the production of large number of normal regenerated plants. In the present study, the number of shoots produced, growth of shoots and culture morphology were greatly affected by the concentration of cytokinins and gelling agent's strength. Ziv (1991) reported that vitrification is associated with *in vitro* conditions favorable for optimised growth and proliferation. The decline in the response of cultured nodes observed in this study may be due to the changes in physiological factors under culture conditions. Cachita (1991) reported that explants of same origin and nature, or of the same type behave differently in the culture media because of their varying physiological and metabolic properties. The 2-step culture method maintained proliferation and normal shoot production for almost two and half years.

Shoot production of improved genotypes

To increase micropropagation efficiency, the stem segments were subcultured horizontally or as single nodes using 2-step culture method. The mean number of shoots produced from horizontally placed

Table 4. Subculturing method and multiple shoot production of teak

Clone	Subculture method	Mean no. of shoots ± S.E	Percent shoots > 4 cm
TNT 10	Horizontal shootNode	9.3 ± 1.01.8 ± 1.2	2740
SBL 01	Horizontal shootNode	6.2 ± 0.92.5 ± 1.8	3855
MHAL A9	Horizontal shootNode	6.0 ± 0.62.2 ± 1.0	835
MHAL A3	Horizontal shootNode	6.6 ± 1.32.5 ± 2.1	025

Table 5. Data on shoot cluster culture of teak

Clone	Mean no. of shoots ± S.E	Percent shoots > 4 cm
TNT 10	4.5 ± 0.5	45
SBL 01	4.5 ± 0.5	62
MHAL A9	5.3 ± 0.6	42
MHAL A3	5.6 ± 0.5	45

Table 6. Effect of shoot height on *ex vitro* rooting of micropropagated shoots of teak

Clone/Shoot height (cm)	No. of roots	Mean root length	Length of longest root	Increment in shoot height	Shoots rooted (%)
TNT 10					
2-3	2.5a	5.2a	6.6abc	0.8a	65
3-4	3.2a	6.1a	12.5cd	0.8a	100
4-5	3.8a	8.0a	14.8d	1.2a	100
SBL 01					
2-3	3.2a	3.0a	3.3a	0.7a	35
3-4	2.4a	5.1a	6.7abc	0.4a	50
4-5	3.2a	3.1a	5.0ab	0.7a	80
MHAL A9					
2-3	4.2a	4.0a	6.2abc	0.4a	40
3-4	3.0a	8.5a	12.3cd	0.4a	40
4-5	2.8a	10.0a	15.0d	0.8a	80
MHAL A3					
2-3	3.0a	8.4a	11.9bcd	0.4a	35
3-4	2.8a	9.0a	10.9bcd	0.6a	40
4-5	2.0a	8.4a	14.3d	0.6a	90

Means within a column followed by the same letter are not significantly different at the 5% level (Student Newman Keul's test)

stem ranged from 6.0 (MHAL A9) to 9.3 (TNT 10) (Table 4). Nodal segments of TNT 10 produced 1.8 shoots, while SBL 01 and MHAL A3 produced 2.5 shoots. The number of shoots suitable for rooting (> 4 cm length) was 0% in the case of MHAL A3 and 38% in SBL 01. Nodal cultures significantly influenced the production of shoots with length of >4 cm ($P< 0.005$), the percent of shoots with > 4 cm varied from 25 (MHAL A3) to 55 (SBL 01). The shoots produced from horizontally-placed stem segments were healthy. However, most of the micropropagation protocols of teak use nodal segments for multiplication (Apavatjrut *et al.*, 1988, Mascarenhas *et al.*, 1993, Tiwari *et al.*, 2002). The cultures, which show poor shoot elongation, may be subcultured as clusters to increase the production of rootable shoots. In this method 3-4 rootable shoots were produced per culture flask. Multiple shoots produced from the nodes or horizontal stem were cultured as clusters to increase the number of shoots suitable for rooting. The number of shoots collected for rooting increased up to 62 % (SBL 01) when the shoot clusters were maintained on the medium for one culture cycle (Table 5).

Ex vitro rooting

There was no significant difference ($P< 0.05$) within and between the genotypes for the root characters like number of roots and root length except for longest roots. Shoots of 4-5 cm length produced 80 – 100 percent rooting (Table 6). The length of the longest root was reached up to 15.0 cm. After 40-45 days, the rooted plants were moved to shade house (Figure 3). The survival rate of the *ex vitro* rooted plants was 85- 90% in net pots. When the hardened plants produced 2-3 pairs of new leaves, they were transferred to polybags (20 cm x 7.5 cm) with potting mixture containing sand, soil and composted coir pith (1:1:3 v/v) (Figure 4). However, Tiwari *et al.* (2002) reported the ex vitro rooting of *in* vitro raised micro shoots with 77.9% survival of the plantlets.

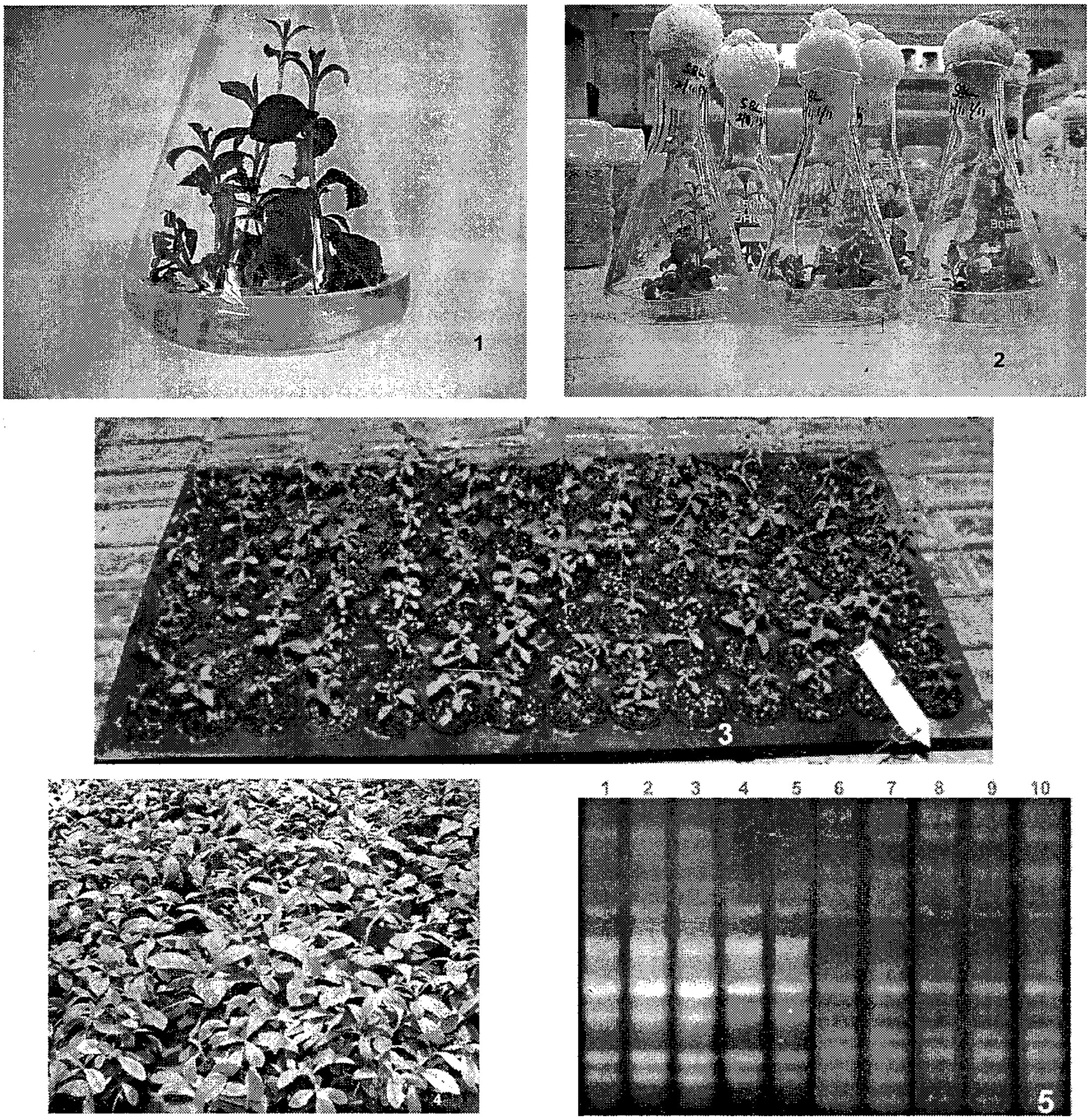
Stomatal studies

Stomatal nature and their behavior in tissue culture plants are useful in devising the strategy at various stages of acclimatization. *In-vitro*-developed leaves lacked cuticles but had unicellular and uniseriate trichomes scattered all over the leaf surface. Normal seedlings have branched multicellular trichomes covering the entire leaf surface. Stomatal structure of *in vitro* grown leaves differed markedly from that of normal seedlings. Stomata of leaves in culture were larger in size and circular in shape with a larger stomatal aperture (Table 7). These stomata did not

Table 7. Stomatal size and stomatal index (SI) of micropropagated and seedling leaves of Teak

Sample	Stomata (mm) Width	Pore (mm) Length	Width	Length	Stomatal Index
In vitro leaves	19.0b	19.4b	5.3b	9.3ab	26.3ab
Acclimatized leaves	14.2a	15.9a	2.8a	7.2a	26.8ab
Seedlings	13.8a	16.2a	2.1a	7.6a	27.2ab

Means within a column followed by the same letter are not significantly different at the 5% level (Student Newman Keul's test)



Various stages of micropropagation in Teak Figure 1: Shoot cultures inititated from nodal explants. **Figure 2:** Multiple shoot formation **Figure 3:** Rooted micro cutting **Figure 4:** Hardened plantlets ready for field planting. **Figure 5:** ISSR banding pattern obtain with five ramets of one genotype(Lanes 1-5 primer ARRTY (CAG)4) and Lanes 6-10 primer AVARA(GCT)6) close in the dark, whereas the normal stomata in the seedlings responded. When tissue-culture-raised plants were hardened, the lamina expanded and a thin layer of cuticle was formed and the stomata became functional. The phenology and stomata of new leaves formed was very similar to normal leaves. There was no significant difference in stomatal index between in *vitro* leaves, acclimatized leaves and seedling leaves (Table 7).

Genetic uniformity analysis

Reliable techniques to assess genetic uniformity of the tissue culture plants are highly desirable in clonal propagation of tree species. Inter-Simple Sequence Repeats (ISSRs) which does not require prior information on sequence and produces highly reproducible polymorphisms have been used to test the quality of tissue culture plants (Leroy *et al.*, 2001). Among the six ISSR primers used, two primers reproducible amplification pattern (Figure 5). All the five ramets of one clone similar banding pattern confirming no variation among the plantlets obtained from one genotype.

Commercial propagation strategy suggested for teak

Commercial micropropagation is already practiced world-wide for many ornamentals, horticultural crops and forestry species. Thorpe *et al.* (1991) suggested the importance of micropropagation for the commercial production of forest trees, as it is an integral part in any tree improvement program. Results reported here constitute a promising step towards large-scale *in vitro* propagation of a species in which conventional propagation has been very difficult. Thus, the present study used the seeds obtained from the clonal seed orchards. The protocol was also tested in a commercial tissue culture laboratory and about 5000 plants have been produced in a period of one year with 10 starter cultures. Compared to seed propagation of teak where one ha. of CSO produces planting stock for only 17.0 ha., micropropagation can increase the planting stock by 500 times.

At present Indian tissue culture units are mainly involved in propagation of crops and ornamentals for export markets. However, in recent years, production for the domestic market has increased from 10% to 40% (Kumar 1994). Also availability of labor at much cheaper rates encourages tissue culture propagation in India. Most of commercial propagation laboratories are situated in Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu and Kerala, where teak is grown extensively (Govil and Gupta, 1997). The capacity of these units could be utilized for multiplication of teak, to enhance the availability of improved planting stock.

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Quality Timber Products of Teak from Sustainable Forest Management pp 409-412

Clonal Propagation of Plus Trees of Teak and Field Performance of Ramets

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ABSTRACT

Plus Trees of teak (*Tectona grandis* L.f.), 40 to 50-years–old, were cloned through a unique technique standardised at Kerala Forest Research Institute, Peechi. The technique involves two major steps viz., production of juvenile epicormic shoots on branch cuttings obtained from Plus Trees and rooting of juvenile epicormic shoot cuttings. Sufficient number of juvenile epicormic shoots were produced on large branch cuttings (3 to 10 cm diameter) collected from the crown of the Plus Trees and planted in large poly bags filled with sand and soil, kept inside the mist propagation chamber. When the epicormic shoots, sprouted on the branch cuttings, attained 10-15 days' growth they were harvested and made into suitable shoot cuttings having two pairs of leaves and apical bud intact. Leaf area was reduced by trimming away the distal half of the lamina. For induction of rooting these cuttings were treated with 6000 ppm of a rooting hormone (indole butyric acid (IBA) prepared in talc) after subjecting them to prophylactic treatment with Bavistin (0.05 % a.i.) solution. The pre-treated cuttings were inserted into vermiculite filled root-trainers (cell volume = 300 cm^3) and kept inside the mist propagation chamber for rooting. Within a period of 30-45 days the epicormic shoot cuttings sprouted and rooted. The satisfactorily rooted and sprouted cuttings were hardened inside the hardening chamber to obtain rooted cuttings of desired plus trees suitable for field planting. Following this technique, 30 Plus Trees of teak were cloned successfully to get true to type rooted ramets in sufficient numbers, as and when required. Hardened ramets, 120-days-old, were field planted at different locations in Kerala during 2000-'02. These ramets showed 99 percent survival and very good growth in height and girth (maximum 8.5 meters height and 25 cms. gbh after 23 months of growth). Practical applications of this technique in tree improvement of teak will be discussed.

Keywords: Cloning, plus tree, epicormic shoots, hormone, rooting, ramets, field planting.

INTRODUCTION

Teak (*Tectona grandis* L.f.) is one of the most valued timber trees of India. The common practice of raising plantations of teak through seedlings or stumps existed since eighteen forties. The conventional method of producing planting material of teak for raising plantations is by sowing seeds in the nursery beds and subsequently making use of stumps (root/ shoot cuttings) prepared from these seedlings. Successfull attempts to propagate teak through vegetative means started at the beginning of the twentieth century (Fergusen, 1938), by establishing teak seed orchards using bud-grafts and this gained importance as it was aiming at the genetic improvement of teak. It is well established that a quicker and direct method for tree improvement is clonal propagation of plus trees by rooting shoot cuttings for immediate genetic gain and increasing the productivity of the species. Vegetative propagation of teak has been attempted earlier by several workers (Mahtolia, *et al.*, 1995; Uniyal and Rawat; 1995; Monteuuis, 1994; Thida Mundt, 1997; Nautiyal *et al.*, 1991; Nautiyal *et al.*, 1992) with limited success. A truly successful method for clonal propagation of plus trees of teak has not been reported so far.

One of the main requirements for clonal propagation

Table.1. Number and locations of Plus Trees used for clonal propagation.

Location (Kerala, India)	Total No. of Plus trees identified	Plus trees cloned
Nilambur	13	10
Konni, Thenmala, Achencoil areas	25	19
Wyanad	2	1
Total	40	30

of teak is the availability or production of sufficient number of juvenile shoot cuttings for propagation since branch cuttings of mature teak trees gave only moderate or poor rooting success (Bhatnagar and Joshi, 1978; Nautiyal *et al.*,1991;1992). Rooting of coppice shoot cuttings of mature trees of teak has been reported (Palanisamy and Subramanian, 2001) but this involves felling of mother trees and is therefore not suitable for a long rotation tree species like teak.. The present paper describes a technique for clonal propagation of plus trees of teak through production of juvenile epicormic shoots on large branch cuttings, and rooting them under mist. The field performance of rooted ramets of plus trees of teak is also presented.

MATERIALS AND METHODS

Branch cuttings having diameter 3 to 10 cm were collected from the middle and lower parts of the crowns of plus trees (age >40 years) growing in different forest divisions of Kerala State. These were brought to the propagation complex as quickly as possible, without causing any damage to the bark or dormant buds on them. The branch cuttings were further sized and cuttings having a length of 50 cm were made out of these branch pieces. The side branches, if any, were carefully removed and these cuttings were immediately inserted into large polythene bags (size 30 cm X 8 cm and 250 guage) filled with soil and sand in equal proportion (1:1). These were kept inside the mist propagation unit and intermittent misting (15 seconds misting in every 30 minutes) was provided until they sprouted and produced juvenile epicormic shoots on them.

When the juvenile epicormic shoots produced on the branch cuttings attained growth of about 10 to 15 days and height of about 8-10 cm, having at least two or three pairs of leaves developed on them, they were harvested and made into shoot cuttings, after trimming away the distal 2/3 portion of the leaves, and retaining the apical bud intact. Immediately after harvesting they were subjected to hormone treatment using indole butyric acid (IBA) having a concentration of 6000 ppm prepared in talc. As a prophylactic measure, the cuttings were soaked in a solution of Bavistin w/v (0.05 percent) for about 30 minutes, before being treated with hormone powder.

The treated cuttings were inserted into the rooting medium (vermiculite) filled in root trainers having a volume of 300 cm^3 and were kept under intermittent misting inside the mist propagation unit. The temperature was regulated at 30±2 °C and humidity to 85-90 percent. The misting frequency was controlled, so that the misting was on for 15 seconds at an interval of 30 minutes. The cuttings were kept on the mist bench for a period of 45 days, in order to allow them to sprout and root properly, after which the cuttings were removed and observations recorded. Using this technique a total of 30 plus trees located in different Forest Divisions of Kerala were successfully cloned (Table 1).

The rooted ramets were removed to the hardening chamber and were kept there for about 45 days in order to allow them to harden properly. The cuttings were also hardened in the open nursery for few days before being taken to the field for planting out. The rooted ramets were field planted at different locations in Kerala following a linear design and at a spacing of 2.5m X 2.5m.Regular observations were recorded on their growth, survival and field performance.

RESULTS AND DISCUSSION

Production of juvenile epicormic shoots

The branch cuttings sprouted and juvenile epicormic shoots started growing with in 10-15 days. The conditions provided inside the mist chamber is conducive to sprouting of dormant buds present on the branch cuttings and formation of juvenile shoots. With in a period of 20-30 days almost all buds present on the cuttings grew and produced juvenile shoots. In general, on an average 8-12 juvenile shoots were produced on a single branch cuttings.

There are reports on the use of juvenile coppice shoots produced on stumps of felled trees for propagation in eucalypts (Zobel and Ikemori,1983; Lal *et al.*,1993) and in teak(Palanisamy and Subramanian, 2001). However, there are no reports of production of juvenile shoots of teak inside the mist chamber for propagation. In the present method described, when large branch cuttings are planted vertically, the chances of sprouting and production of epicormic shoots were maximum and moreover, the shoots obtained grew upwards showing orthotropic growth habit which is desired in the propagation programme of plantation tree species like teak. Sufficient number of juvenile shoot cuttings could be produced on the branch cuttings of plus trees by this method. Since the branch cuttings spouted and produced shoots, in all months, the method is suitable to produce juvenile shoots, whenever needed.

Rooting of juvenile shoot cuttings

With in a period of 10-15 days, the planted juvenile shoot cuttings started developing roots on them. The sprouting and rooting of the cuttings were completed with in a period of 30-45 days, after which the rooted ramets were removed to the hardening chamber. During rooting, the apical buds of the cuttings started growing, indicating the rooting process. The mean percentage of rooting varied from 20 to 90, between the plus trees (see Fig.1). Maximum percentage of rooting (90) was obtained with plus trees of Thenmala (T46) followed by Nilambur (T10) while it was minimum (20 percent) in some plus trees (T34, T16)(see Fig 1).

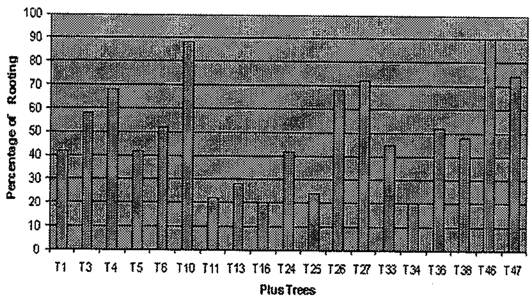

Figure 1. Percentage of rooting success of plus trees of teak (T1;T3;T4 *etc.* are numbers of Plus trees)

Figure 2. View of the clonal garden of teak at Chettikulam a, 11 months after planting ; b, 23 months after planting

Rooting of coppice shoot cuttings and of juvenile cuttings of seedlings, within a period of 20-25 days were reported by Palanisamy and Subramanian (2001) and Kaosa-ard *et al.* (1998) and the maximum percentage reported was 72-91 percent. In the present study, the initiation of rooting was observed within 15 days after planting which is shorter than the earlier reported time. The age of the mother tree appears to be important factor in influencing rootability of the cuttings. Monteuuis (1994) obtained 40-60 percent rooting in cuttings of young (5-15-year- old) trees while Nautiyal *et al.* (1991) reported 60 percent rooting in cuttings collected from 16-year-old trees and only 10 percent rooting in cuttings collected from 62-year-old trees. Since the juvenile shoots are used for rooting in the present study there was no decrease in percentage of rooting observed, in relation to age, or any delay in initiation of rooting on the cuttings. The method described has very high potential for production of true to type propagules of desired plus trees.

Field performance of rooted ramets

The growth and survival of rooted juvenile shoot cuttings during hardening was >90 percent in all the

Table 2. Field performance of (Mean height and girth (GBH)) of rooted ramets planted at Chettikkulam, Kerala, India, 23 months after planting

Sl. No.	Clone No	Mean Ht. (m)	Mean GBH (cm)
1	T1	5.32	15.5
2	T4	6.40	17.8
3	T5	7.07	22.0
4	T6	4.48	16.5
5	T10	6.72	19.0
6	T11	6.13	21.8
7	T13	6.27	17.25
9	T24	6.36	17.3
10	T26	6.24	19.2
11	T27	6.86	22.5
12	T34	5.79	17.3
13	T36	7.76	23.5
14	T38	6.30	19.5
15	T44	6.44	20.2
16	T46	8.50	25.0

plus trees. The rooted ramets were field planted in different locations of Kerala during the year 2000-'02. Their field survival observed in the initial year was 99 percent. The height growth of ramets were 4.5 meters in some of the clones (eg. T10 , T46, T47) after 11 months growth in the field at Chettikkulam and almost similar rate was maintained in the second year of planting (Fig.2). At the end of the 23 months' growth in the field, the maximum height growth recorded was 8.5 m and gbh 25 cm. (Table 2).

In general, the productivity of teak in Kerala is 2.85 $m^{-3}ha^{-1}$year in a 53- year rotation period which is very low as compared to the national standard (10 $m^{-3}ha^{1}$year) (Subramanian, *et al.*,1999). One of the reasons for low productivity appears to be the genetically inferior planting stock used for raising plantations. Clonal propagation of plus trees and using genetically improved planting stock for raising plantations, appears to be an immediate step to increase the productivity of teak as in the case reported for eucalypts (Zobel and Ikemori, 1983; Lal *et al.*, 1993). So far the technology for large-scale clonal propagation was not standardised. The technique described has great potential and offers the possibility not only to propagate large plus trees aged 40 years or more with out felling them, but also to clone the superior trees on a large-scale and to raise plantations using the improved planting stock.

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Clonal Propagation Technology for Teak for Production of Improved Planting Stock

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ABSTRACT

Clonal propagation technology for mature teak trees (>50 year-old) and quality seedlings has been standardized. Indole butyric acid (IBA) was found to be the most effective auxin for adventitious rhizogenesis in teak. Cuttings from coppice shoots of mature trees rooted between 72 to 91% in different seasons, while the cuttings from 1 to 2 year-old stumps gave 79 to 100% rooting throughout the year. Mature coppice shoots showed high rooting potential probably due to high carbohydrate and nutrient contents in the mature shoots. Adventitious root formation and root system of cuttings collected from coppice shoots of mature trees (>50 years) were similar to those of 1 to 2 year-old stump cuttings suggesting the juvenility of coppice shoots for rooting. In teak, rhizogenesis depends upon the physiological status of the cutting and season is no longer a major barrier. The clonal technology will be helpful for production of genetically superior planting stock of teak for raising clonal plantation and afforestation programme and thereby augment productivity.Teak trials have been established with improved planting stock raised vegetatively from mature trees and quality seedlings. The early evaluation showed that the growth performance of coppice shoot cuttings from mature trees was similar to those of seedlings. Superior trees of teak have been selected in different locations in Kerala and multiplied clonally.

Keywords: clonal propagation, teak, adventive rhizogenesis, rooted cuttings

INTRODUCTION

Teak (*Tectona grandis* L.) is one of the most important high quality timber yielding species in the world. The global teak plantations are estimated to be 3 million ha, and 94% is located in tropical Asia with major share in India (44%) followed by Indonesia (33%) contributing maximum resources. In India natural teak forest and plantations covered about 8.9 million ha and 1.5million ha respectively (Tewari, 1992; Subramanian *et al.*, 2000), and it is planted in large scale (50,000 ha approximately) every year. About 1200 ha clonal seed orchards (CSO) and 5000 ha of seed production areas (SPA) of teak have been established in different teak growing states (Emmanuel, 2000; Anon., 2002) to obtain superior seeds to raise teak plantations. The area of teak plantations established in India through quality seeds of SPA and CSO origins are less, and most of the teak plantations are raised from seeds of unselected sources resulting low productivity. The average productivity of teak in Kerala is 2.85m^3/ ha/ year in 53 years rotation period. Further the seed production in CSO is very low and it showed poor germination indicating that the existing CSO can not meet the demand of required quality planting stock. Therefore clonal propagation is the only alternative method for production of improved planting stock of teak in large scale to enhance productivity. It is well established that clonal plantations of *Eucalyptus* enhanced the productivity significantly compared to plantations of unimproved seed origins (Zobel and Ikemori, 1983; Lal *et al.*, 1993). However clonal propagation technology for teak is not standardized so far and hence clonal plantation of teak is not available.It has been reported that branch cuttings of mature trees of teak gave moderate rooting

Table 1. Rooting performance of coppice shoot cuttings of mature trees (>50 years old) and stump cuttings of 1 to 2 year old seedlings in different months. Results are the mean values of three replicates.

Months	Coppice shoot cuttings of mature tree	Seedling/Stump cuttings
January	91	87
February	77	85
March	72	100
April	76	97
May	NC*	NC
June	75	NC
July	81	95
August	NC	98
September	NC	86
October	37	89
November	79	79
December	NC	86

* Experiment not conducted

in a particular season (Bhatnagar and Joshi, 1978; Nautiyal *et al.*, 1991, 1992 ; Palanisamy *et al.*,1995) and this technique is not suitable for mass multiplication. Palanisamy and Subramanian (2001) reported that coppice shoot cuttings of mature trees of teak gave good rooting. In the present study attempt has been made on selection and clonal propagation of mature teak trees and quality seedlings of CSO origin for the production of genetically improved planting stock.

MATERIALS AND METHODS

The superior trees of teak (>50 years) were selected from teak plantations at Nilambur and Trichur, Kerala by check tree method. The trees were felled at 20 to 30 cm (approximately) above the ground level and the coppice shoots emerged 2 to 3 weeks after felling. Mature coppice shoots were collected at regular intervals and rooting was carried out following the method of Palanisamy and Subramanian (2001). The cuttings were treated with 2000ppm IBA and planted in root trainers filled with composted coir fibre as rooting media and kept in polytunnels at 80 to 90% RH under shade house conditions for rooting. The cuttings were misted with distilled water 4 times daily.

For the multiplication of quality seedlings, seeds were collected from CSO Maharashtra and plus trees from Topslip Tamil Nadu and the seedlings were raised in a nursery bed . The 1 to 2 year-old seedlings were uprooted and stumps(6 cm shoot and 16 cm tap root) were prepared, and planted in polythene bags containing sand, soil, farmyard manure and coir fibre in the ratio of 1:1:1:1 and kept in a mist chamber or polytunnels with intermittent misting. New sprouts emerged from the stumps within a week and it was collected at regular intervals for propagation. The cuttings were sterilized with 0.1% Bavistin (fungicide) for 3 minutes followed by distilled water rinses, treated with 1000 ppm IBA and planted in root trainers filled with coir fibre and kept in polytunnels for rooting (80 to 90 % RH) as the coppice cuttings of mature trees. The experiment was conducted in different seasons.

Rooting data was recorded 25 to 30 days after planting in both coppice shoot cuttings of superior trees and stump cuttings of seedlings . The rooted cuttings were transplanted to polythene bags containing sand, soil, farmyard manure and coir fibre (1:1:1:1) and hardened in the low radiation followed by open condition and used for planting. To study the growth performance of the propagules raised from mature tree and quality seedlings, field trials have been established in different locations in Tamil Nadu (Tirunelveli and Sadivayal) and Kerala (Panampally). Drip irrigation was also given to the field trial raised in farm land at Tirunelveli. The trials were evaluated one year after planting.

RESULTS AND DISCUSSION

The coppice shoot cuttings of mature tree and cuttings

Table 2 . Rooting response of different clones from Nilambur and Trichur, Kerala during the period November 2002 to April 2003. Results are the mean values of three replicates.

Clone No.	Source	% of Rooting
NPT 7	Old Amarambalam, Nilambur	63
NPT 10	Padukka, Nilambur	84
NPT 11	Padukka, Nilambur	72
NPT 12	Padukka, Nilambur	54
NPT 16	Padukka, Nilambur	75
NPT 18	Padukka, Nilambur	78
NPT 19	Padukka, Nilambur	88
NPT 22	Padukka, Nilambur	69
NPT 26	Emangadu,Nilambur	86
NPT 27	Emangadu,Nilambur	78
NPT 29	Emangadu,Nilambur	60
T 302	Elanad, Trichur	65
T 306	Elanad, Trichur	60
T 308	Elanad, Trichur	75
T 309	Elanad, Trichur	56
T 311	Elanad, Trichur	51

from 1 to 2 year-old stumps of teak showed good rooting in IBA treatment (Table 1), and adventitious root formation occurred within 20 to 25 days after planting in both the cases. The coppice shoot cuttings gave 72 to 91% rooting in different seasons except in October where the rooting was 37%, while the cuttings from seedling stumps showed 79 to 100% rooting in most of the months (Table 1). The rooting performance in stump cuttings of seedlings is higher when compared to those of coppice shoot cuttings of mature trees. Kaosa-ard *et al.* (1998) reported 90% of rooting in stem cuttings of juvenile seedlings of teak. Earlier findings stated that rooting of branch cuttings of mature trees of teak is season specific, gave moderate rooting and also take 2 to 3 months for adventitious root formation (Bhatnagar and Joshi, 1978; Nautiyal *et al.*, 1992; Palanisamy *et al.*, 1995). Monteuuis *et al.* (1995) observed 40 to 60% rooting in young teak trees (5 to 15 years old), while Nautiyal *et al.* (1991) reported 60% rooting in 16 year-old trees in a particular season and very poor rooting (10%) in 62 year-old trees. Isikawa (1968) and Libby and Hood (1976) suggested that as the donor plant matures, the rooting rate decreases and the length of the time required for root formation increases. The branch cuttings from mature teak trees are physiologically mature and the propagules raised through branch cuttings show slow growth and it can not be used for planting programme. On the other hand the coppice shoots of mature tree are juvenile, and the rooting response, period of rhizogenesis and the root system morphology of coppice shoot cuttings were similar to those of cuttings from seedling stumps (Palanisamy and Subramanian, 2001). This is further confirmed in the field trials that the growth performance of coppice shoot plant of mature tree was similar to those of seedlings. In teak adventitious rhizogenesis is highly dependent upon the physiological maturity and nutritional status of the cuttings and season is not playing any major role (Palanisamy and Subramanian, 2001), which is contradictory to the earlier findings (Bhatnagar and Joshi, 1978; Nautiyal *et al.*, 1992; Palanisamy *et al.*, 1995). The survival rate of vegetative propagules of coppice shoot cuttings of mature trees and quality seedlings after hardening was >90%. It has been worked out that approximately 65,000 plants may be raised from 1000 quality seedlings in a year at the rate of 90% rooting. Though the seed production is very less in the CSO of teak in the entire country it can be mass multiplied through this technique, and improved planting stock of teak can be raised. Kaosa-ard *et al.* (1998) estimated a possible genetic gain of 17% from the seedlings of selected clones of clonal seed orchard.

About 100 superior trees of teak have been selected in Nilambur and Trichur, Kerala and being multiplied clonally. The rooting of the clones at Old Amarambalam, Padukka and Emangadu of Nilambur region varies between 54 to 88% and those of Elanad, Trichur region shows 51 to 75% (Table 2). The Nilambur clones showed better performance on rooting compared to those of Trichur probably due to high precipitation at Nilambur. Teak trials with improved planting stock raised vegetatively from mature trees and quality seedlings have been established in different locations. The early evaluation (2 years) revealed that there is no significant difference on growth performance of coppice shoot plant of mature tree and seedlings. The trial provided with drip irrigation at Tirunelveli, Tamil Nadu showed promising growth with 10 to 14 feet height and 18 to 20 cm girth one year after planting.

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Quality Timber Products of Teak from Sustainable Forest Management pp 417-422

Implications of Clonal Variation in Reproductive Traits for the improvement of Teak (*Tectona grandis* L. f.)

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ABSTRACT

Although seed orchards represent a vital link between commercial plantations and the ongoing tree improvement programme in teak, understanding the variation and genetic control of reproductive traits in seed orchards has been consistently ignored. We estimated inter and intra clonal variation for reproductive traits in a Twenty-year old clonal seed orchard in Karnataka, South India. Inter clonal variation was significant for majority of fecundity and phenological traits suggesting a strong genetic control. Strong provenance effect on phenology was observed. Clones from central and southern provenances were early in initiating flower buds, flowers and peak flowering than those from northern, thus resulting in asynchronous flowering among clones. Hence, selecting clones based on proximity of clonal origin could be used as a thumb rule. In general, clones from southern provenance had larger flowers and produced larger pollen grains compared to clones of northern provenance. Further, clones from southern provenance tend to produce more number of flowers and fruits per inflorescence than those from northern provenance. Interestingly clones for northern provenance showed higher pollen viability, higher fruit set and seed set percent and hence more Pre Emergent Reproductive Success (PERS). However, PERS was on lower side (0.172-0.645), but significantly differed among the representative clones studied. Clones that initiated leaf flushing early and possessed longer duration of peak flowering tend to produce higher number of fruits per inflorescence. Hence these two traits should be considered while selecting trees for CSO in order to increase the fruit yield. However, clones that coincide flowering with peak rainy days recorded lower fruit set and hence should be avoided.

Keywords: Teak, *Tectona grandis*, Clonal Seed Orchard, Reproductive traits, Provenance, Phenology, Pre-Emergent Reproductive Success

INTRODUCTION

Teak (*Tectona grandis*) is an important plantation tree species of the tropics. It is estimated that in India, the annual teak planting area has increased enormously from 15,000 ha during eighties (Neelay *et al.*, 1983) to 1,00,000 ha in recent years (Pandey and Brown, 2000). Hence there is huge demand for quality seeds. In India there are over 55 teak seed orchards (Kumaravelu, 1993) and many are being planned and /or in the initial stages of their establishment to cope with the increased demand for seeds. Unfortunately, in many breeding populations of teak low fruit yield has been reported (Bedell and Vijayachandran, 1994), although about 5 kg of seeds are expected, on an average, to be produced per tree from tenth year onwards. (Kumar, 1992).

Generally, CSO is a plantation of vegetatively propagated genotypes, which are previously selected for their superiority from wide geographical areas. Obviously these genotypes have evolved to diverse selection pressures of different climatic situations. The basic assumption made while establishing a seed orchard is that the diverse clones used are highly compatible with each other and flower synchronously. However, these basic assumptions have not been thoroughly evaluated among the teak CSOs in India. In fact reproductive characters are never considered as criteria while selecting the plus trees (Tewari, 1992). Inter and intra clonal variations in floral traits and their associations if any, utilizing a large-scale clonal orchard have not been properly attempted (but see Nagarajan *et al.*, 1996). Since variations among clones for reproductive traits can potentially affect the fruit production, it is imperative to assess and quantify the clonal variations for reproductive traits. With this background, we studied reproductive phenology and variation in the reproductive traits in a twenty-year old seed orchard.

MATERIAL AND METHODS

Weekly observations on phenological events were done from January 1999 to February 2000 in a teak Clonal Seed Orchard (CSO) established at Manchikere (Karnataka, South India). This CSO consists of 24 clones of previously selected superior trees. In all, there were thirteen clones derived from Northern zone, four from Central and seven from Southern zones of Karnataka (Table 1). Totally 407 ramets were scored every week for flowering phenology using standard formats (Gunaga *et al.*, 2000). The time taken for commencement of flower buds, flowering and peak flowering were calculated as the number of days from 1st January to the date of their first appearance on every tree. Peak flowering was defined as the period during which, more than 75 per cent of the flowers in a tree are in bloom. Other floral and fecundity traits were estimated for a subset of eight clones considering three ramets each. Minimum of twenty inflorescences per tree were collected at the end of the fruiting season and number of fruits were counted; the scars on these inflorescence were taken as an indication of number of flowers. An artificial pollen grain germination medium was standardized (Hanumantha, 2000) and fresh pollen grains from all the ramets were sprinkled on to the medium in a petri-plate to test their germination during peak blooming. At least one hundred pollen grains per ramet were scored while assessing viability.

Statistical Analyses

The data on each phenological phase were analysed

Table 1. Clone I.D., origin of clones and their broad provenance in Karnataka considered for the study, in the Clonal Seed Orchard (CSO).

Sl.No	Clone I.D.	CloneNumber	Origin of the Clone Range (Division)	Provenance
1	MYHD1	1	Barchi (Haliyal)	North
2	MYHD2	2	Barchi (Haliyal)	North
3	MYHD3	3	Barchi (Haliyal)	North
4	MYHD4	4	Barchi (Haliyal)	North
5	MYHV1	5	Gundvamoli (Haliyal)	North
6	MYHV3	7	Gundvamoli (Haliyal)	North
7	MYHV4	8	Gundvamoli (Haliyal)	North
8	MYHV5	9	Virnoli (Haliyal)	North
9	MYHV6	10	Virnoli (Haliyal)	North
10	MYHV7	11	Virnoli (Haliyal)	North
11	MyHaK1	32	Kulagi (Haliyal)	North
12	MyHaK2	33	Kulagi (Haliyal)	North
13	MyHaK3	34	Kulagi (Haliyal)	North
14	MYSA1	13	Arasake (Shimoga)	Central
15	MYSA2	14	Arasake (Shimoga)	Central
16	MYSS2	16	Sacrebyle (Shimoga)	Central
17	MyBL1	31	Bhadravati(Shimoga)	Central
18	MYHuT1	17	Thithimati (Hunsur)	South
19	MYHuT2	18	Thithimati (Hunsur)	South
20	MYHuT3	19	Thithimati (Hunsur)	South
21	MYHuT6	22	Thithimati (Hunsur)	South
22	MYHuT7	23	Thithimati (Hunsur)	South
23	MYHuT8	24	Thithimati (Hunsur)	South
24	MyMK3	37	Kakanakote (Mysore)	South

Table 2 Clonal variation for a few phenological events in a teak CSO.

Phenophases	Range		F-ratio	P-level	C.V. (%)
	Min	Max			
Time flower bud initiation*	128.00	235.00	47.36	<0.01	8.21
Time of flowering initiation*	135.00	243.00	46.13	<0.01	8.11
Time of peak flowering initiation*	150.00	264.00	41.91	<0.01	6.84
Duration of flowering (days)	07.00	90.00	1.30	NS	27.80
Duration of peak flowering (days)	07.00	45.00	1.07	NS	50.49

*expressed as number of days from 1st January., C.V. = Co-efficient of Variation

as one way analysis of variance by using MSTATC programme on a PC and the variability was decomposed into genetic and environmental components (Matziris, 1994). Provenance mean values for fecundity traits were tested by constructing a contrast. Contrast is the statistical device, which allows testing of specific groups of means within an experiment with out resorting to a separate analysis of variance (Sundararaj and Nagaraju, 1968). The magnitude of difference between two groups of means is also shown as the effect (Table 4). In the present study, while constructing the contrast all the clonal mean values from northern provenances were given co-efficient of +1 and those from southern provenances were given co-efficient of –1. For this reason positive value in the effect indicates the superiority of mean of northern clones over that of southern clones and vice-versa.

RESULTS AND DISCUSSION

Clonal variation for reproductive phenology

Significant inter clonal differences in time of initiation of flower bud, flowering and peak flowering were observed suggesting a strong genetic base. The intra-clonal variation was however, not statistically significant (Table 2). The co-efficient of variation for time of flower initiation was 8.11 per cent. Average number of days to initiate flowering as computed from 1st January 1999 ranged from 143.46 days (MyBL1) to 203.10 (MyHaD2) days. In general, flowering initiation ranged from May to September, while peak flowering from May to August. These two events were coincided with the rainy months of the study site. The observed variation among clones in flowering phenology events may reflect an adaptive behaviour to the local conditions in which their mother trees were grown.

Season of flowering for the entire CSO was between May to September month. The duration of flowering ranged between 59.80 (MyMK3) and 42.05 days (MyHaD2). Peak flowering duration was always lesser than the total flowering duration. There were no statistically significant differences among the clones for duration of flowering and peak flowering (Table 2).

Strong provenance effect on flowering phenology was observed in the present study (Table 3). Clones from Central and Southern provenances of Karnataka were early in initiating flower buds (by 30 days), flowering (by 30-40 days) and peak flowering (by 25-30 days) compared to those from northern provenance. The Fig.1 depicting the distribution of ramets in each provenance clearly shows the differences in initiation time of flowering. Considering the overall CSO, there

Table 3. Provenance variation for initiation events in teak CSO (expressed as number of days from 1st January)

PROVENANCE	Time flower bud initiation (Mean± SD)	Time of flowering initiation (Mean± SD)	Time of peak flowering initiation (Mean± SD)
Northern Provenance	173.57±23.19	184.78±24.04	207.11±21.78
Central Provenance	138.65±10.16	147.50±10.15	174.78±13.55
Southern Provenance	141.47±12.70	152.18±15.05	178.27±18.29
F-ratio	116.01	114.85	97.30
P-level	<0.001	<0.001	<0.01
C.V. (%)	12.48	12.25	10.26

C.V. = Co-efficient of Variation

Table 4 Variation for fecundity traits (Mean ± SD) in a few clones of teak CSO.

Clone. No	Pollen germination[1] (%)	No. of. Flowers	No. of fruits	Fruit set (%)	PERS[2]
2	62.00 ± 7.21	4879 ± 376.2	58.33 ± 2.08	1.199 ± 0.08	0.527±0.068
7	74.67 ± 5.03	5622 ±1201	51.33 ± 2.31	0.946 ±0.024	0.352±0.086
9	90.00 ± 4.00	4175 ± 302.6	47.67 ± 1.15	1.145 ± 0.08	0.454±0.099
13	78.67 ±16.29	5069 ± 402.8	60.00 ± 2.64	1.187 ± 0.07	0.363±0.051
19	67.33 ±10.26	4398 ± 239.5	41.00 ± 2.00	0.934 ± 0.07	0.368±0.029
24	58.67 ±23.09	5621 ± 104.8	70.00 ± 2.64	1.245 ± 0.05	0.445±0.038
32	83.33 ± 5.03	1917 ± 405.8	28.33 ± 0.58	1.529 ± 0.37	0.645±0.110
37	77.33 ± 8.08	5834 ±1243	24.00 ±1.73	0.429 ± 0.13	0.172±0.05
F. ratio	4.95	10.25	186.25	11.98	10.20
P.Level	<0.01	<0.01	<0.01	<0.01	<0.01
C.V. (%)	11.24	14.63	4.22	14.92	18.13
CONTRAST ANALYSIS					
Effect[3]	3.50	-541.04	-1.167	0.128	0.078
F-ratio	4.248	14.91	8.082	15.23	25.88
P-level	0.036	<0.01	0.013	25.88	<0.01

[1] Per cent germination in a standardized pollen germination medium., [2] PERS= Pre Emergent Reproductive Success (expressed as per cent fruit set X proportion of ovules set into seeds)., CV = Co-efficient of variation., CD = Critical difference., SD = Standard deviation., [3] The positive values in the effect column indicate the superiority of means of northern clones over that of southern clones and vice versa.

were two distinct peaks of flower initiation (Fig 1). In general, clones from northern provenances flowered during July to September, while those of central and southern provenance bloomed between June to August. However, these duration events did not show any provenance variation. It has been documented in several tree species that initiation of a phenological event was genetically influenced, while duration of an event was more often determined by the local environmental conditions.

Clearly, a significant proportion of ramets of clones from Southern and Central region escaped early showers in the orchard compared to those from northern region (Fig 1). Perhaps, this is first empirical evidence among the CSOs of teak in India, where asynchrony has been documented and quantified through meticulous observations.

Clonal variation for fecundity traits

Inter clonal variations for all fecundity traits (except seed to ovule ratio) among eight representative clones were found to be statistically significant (Table 4). However, intra clonal variation was negligible suggesting a strong genetic control of these traits. The variation in reproductive success of different clones was assessed by calculating Pre Emergent Reproductive Success (PERS), which is a product of proportion of flowers set multiplied with fruits and proportion of ovules set as seeds (Palupi and Owens, 1998). Though the values of PERS were very low (0.172-0.645) for the clones studied, there was significant inter clonal variation (Table 4).

In order to bring about the patterns of variation among southern and northern clones, a simple contrast analysis was worked out (Table 4). In general, clones from southern provenance had larger flowers and produced larger pollen grains compared to those of northern provenance. Further, clones from southern provenance tend to produce more number of flowers and fruits per inflorescence than those from northern provenance.

Interestingly clones of northern provenance had higher pollen viability, higher fruit set and seed set per cent and consequently more PERS. This may be because of the fact that the clonal seed orchard, Manchikere, Karnataka is situated in the northern provenance and clones native to the region may be more adaptive to the local conditions (such as vagaries in rainfall) than southern clones. This North-south pattern was also found in fruit traits. Among the boreal forests of America, broad geographic trends, predominantly clinal in nature, correlated strongly with latitude have been described. For instance, Southern provenances tend to grow three to four times faster than northern provenances in white spruce. Such differentiation among growth rate obviously has an adaptive value (Wright, 1976).

Association among phenological events and fruit set

Positive and significant correlation, both at clonal mean basis and individual tree basis, among time and duration of phenophases suggested that phenological events can potentially affect fruit production (Table 5). Clones that flush their leaves early tend to initiate flower bud, flowering and peak flowering earlier. Interestingly clones that initiated leaf flushing early and possessed longer peak flowering duration (r= 0.104) tend to produce higher number of fruits (r= 0.099). Though the value of the Pearson's correlation co-efficient were low, they were statistically significant.

In order to elucidate the influence of rain on fecundity traits, we computed correlation coefficient between number of fruits per inflorescence (of every tree irrespective of clonal identity) with period of flowering or peak flowering, which were affected by rain. The number of fruits per inflorescence in a tree was significantly and negatively influenced by proportion of rain affected days of flowering (r= -0.155, P< 0.05) and peak flowering (r= -0.116, P <

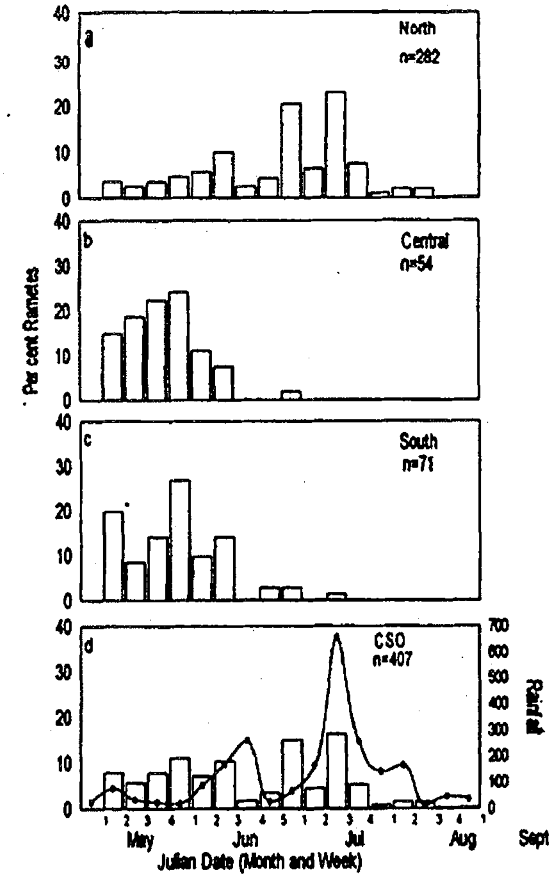

Figure 1 Distribution of teak clone rametes form different provencess (a-c) and from overall CSO with respect to intiation of flowering across time

Table 5. Association among a few initiation and duration events of phenology in a teak CSO. Co-efficient of correlation on clonal mean basis (below diagonal) and on individual tree basis (above diagonal) are shown.

Traits	Leaf flushing initiation	Flower bud initiation	Flowering initiation	Peak flowering initiation	Duration of flowering	Duration of Peak flowering	No. of fruits/ inflorescence
Leaf flushing initiation	-	0.794**	0.770**	0.765**	-0.118*	-0.013	0.099*
Flower bud initiation	0.971**	-	0.895**	0.889**	-0.340**	-0.079	0.064
Flowering initiation	0.976**	0.995**	-	0.846**	-0.296**	-0.073	0.062
Peak flowering initiation	0.944**	0.977*	0.982**	-	-0.201**	-0.124	0.042
Duration of flowering	-0.357*	-0.398**	-0.367*	-0.330*	-	0.217**	0.013
Duration of Peak flowering	-0.125	-0.205	-0.205	-0.201	0.253	-	0.104*
No. of fruits/ inflorescence	0.113	0.199	0.177	0.141	-0.241	0.026	-

Critical r value for clonal mean basis (below diagonal) = 0.396 at P0.05 level; 0.505 at P-0.01 level
Critical r value for individual tree basis (above diagonal) = 0.098 at P0.05 level; 0.128 at P-0.01 level
* Significant at 0.05 P-level; ** Significant at 0.01 P-level

0.05). It clearly indicated that ramets that coincide flowering with peak rainy days tend to show lower fruit set and hence should be avoided. PERS was significant and positively associated only with fruit set per cent (r= 0.90; P-< 0.01 and d.f.= 22) and negatively associated only with number of flowers per inflorescence (r= -0.74; P-< 0.01 and d.f.= 22); however none of the other fecundity traits showed statistically discernable association with PERS.

Implications for improvement of teak

One of the most important aspects in a seed orchard is the synchrony among the clones for flowering phenology, which decides the extent of random mating among the constituent clones and hence the genetic gain in the resultant progeny (Vasudeva *et. al.*, 1999). Results clearly suggest that the clones of diverse origin do not synchronize flowering and hence do not contribute equally to the resultant seed crop. Further the differences in pollen viability among clones may also contribute to non-random mating in the seed orchard. Clones with higher pollen viability and vigour can potentially sire disproportionately higher number of ovules than those with lower levels of pollen viability and vigour. Differential fruit production among clones can potentially alter the parental balance in the seed crop. As a consequence, the resultant progeny may have very narrow genetic base.

While selecting clones for future seed orchards, it may be important to select clones within a broad provenance region such that their flowering time could be nicely matched. Further, the results also hint that duration of flowering is more amenable for modification through silvicultural practices to suit to the needs of the orchard manager. Phenological data are also important in planning controlled crosses for breeding programmes using clones of different provenance. Specific combining ability effects could also be captured by carefully selecting the parents for supplemental pollinators. While establishing a clonal seed orchard, one should avoid the clones that coincide flowering with peak rainy days that tend to produce lower fruit production.

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Early Detection of Mislabelled Teak Clones Using *Glutamate Oxaloacetate Transaminase* (GOT) Marker

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ABSTRACT

Glutamate Oxalacetate Transaminase (GOT) was performed in teak using vegetative tissues to genotype 50 ramets of ten clones in hedge orcahard (clonal archive). Two polymorphic loci (GOT-B, GOT-C) were used to estimate the level of mislabelling in ramets and subsequently in clones. Genotype analysis revealed that GOT-B and GOT-C were effective to identify the errors. Relatively high levels of errors were observed showing that 16 per cent of ramets and 40 per cent of clones analysed were mislabelled. The gentic consequence of the teak improvement programmes is discussed in the paper in relation to the necessary measures to be taken in that context.

Keywords: Tectona grandis, GOT, isozymes, teak clones, mislabelling, hedge orchard

INTRODUCTION

Continued progress in teak improvement program is directly linked to breeding, testing and selection. In the past, it was assumed that the identity of clones or pedigree was without errors despite the occurrence of errors. Such errors can arise from a variety of sources, ranging from simple labelling and data entry mistakes to pollen contamination during controlled breeding, and even vandalism. Error rates of 10% are not unusual in breeding programs and will have impact on calculation of breeding value and genetic gain (Butcher, 2002). In addition, errors on identity are especially damaging for clonal programs. In Indonesia, programs of genetic improvement of teak have an emphasis on breeding for growth based on among other clonally untested trees (Rimbawanto *et al.*, 2002). Nowadays, focus of research on clonal propagation is on using techniques of cutting and tissue culture followed by clonal tests. The development of biochemical or molecular genetic markers for teak has provided a useful tool for monitoring breeding programs; validating crosses, detecting errors, clonal identification etc. An error made in the labelling of a clone during propagation will be carried over years and quite often left undetected. Therefore, early detection is important as an early warning system to correct the practices in the programs. In this regard, genetic markers can be used as a tool to certify the clones. It is known that isozymes have been successfully used on numerous occasions to identify mislabelled clones. Most of this work has dealt with problems in seed orchards and clone gardens.

The glutamate oxaloacetate transaminase (GOT) which is identical to aspartate amino transferase (AAT, E.C. 2.6.1.1) is one of the enzyme systems often used in isozyme studies on plant and animal genetics. In surveys of higher plant isozymes, three to four electrophoretic GOT zones have been reported (for review, see Gottlieb 1982). In teak, GOT is encoded by three gene loci, two of which (GOT-B or GOT-2 and GOT-C or GOT-3) are polymorphic (Sulistyono, 2002). Since it's controlling gene loci were found to be largely polymorphic, GOT can be used for clonal identification. This paper will discuss the effectiveness of GOT markers for early detection of mislabelled clones in a hedge orchard serving as clonal archive.

MATERIALS AND METHODS

Plant tissue

One enzyme system, *glutamate oxaloacetate transaminase* ((GOT, E.C. 2.6.1.1), was used to identify ten clones in hedge orchard of Perum Perhutani, Cepu, Central Java. This orchard, which is also known as stool bed, serves as clonal archive from where clonal materials are taken for cuttings and bud-graftings of teak. The identities of sample clones have been changed for this paper to be as follows: P-A, P-B, P-C, P-D, P-E, P-F, P-G, P-H, P-I and P-J. Five putative ramets of each clone were taken for isozyme analysis making up a total number of 50 samples. Small cuts of young leaves were ground in three drops of homogenising buffer (Sulistyono, 2002).

Electrophoresis

The crude homogenates were then subjected to horizontal starch gel electrophoresis, using the buffer system of Ashton and Bradon, pH 8.7. Further details of electrophoretic and staining procedures were given by Liengsiri *et al.* (1991).

Data analysis

Isozyme variants were confirmed through analysis of GOT banding patterns following the procedure of Finkeldey (1999). Two locus genotypes of five ramets for 10 clones were scored. Mislabelled ramets were then determined according to the consensus genotype, which is found in at least three ramets.

RESULTS

GOT banding patterns

Gels stained for GOT had three loci. The GOT-A was invariant in the material used and supposed to be controlled by a single gene locus, while the other two were polimorphic. Mislabelled ramets were detected in clone P-B, P-C and P-D that can be easily distinguished from the most frequent genotype which is assumed as a consensus genotype (Figure 1). On the other hand, non-mislabelled clones were not detected in clone P-E, P-F and P-J (Fig. 2). However, no degree of mislabelling in this case is an underestimated figure. The use of more loci of other various markers may detect additional number of mislabelled ramets.

Genotypes and mislabelling

Calculations made from individual genotypes in Table 1 show that degree of mislabelling on ramet basis was 16%, while on clone basis was 40%. The use of GOT loci was proven to be very effective for early detection of mislabelling.

DISCUSSION

GOT catalyses the reversible reaction of glutamate and oxaloacetate to 2-oxoglutarate and aspartate, thus having an important role in nitrogen metabolism by distributing this nutrient originally assimilated into glutamate to other compounds (Ireland and Joy, 1985). In genetic studies on forest tree species, apart from clone identification, GOT has frequently been assayed to determine genetic diversity and differentiation.

One source of genetic identity questions is mislabeling. The clonal identification demonstrates that errors had been taken place during the propaga-

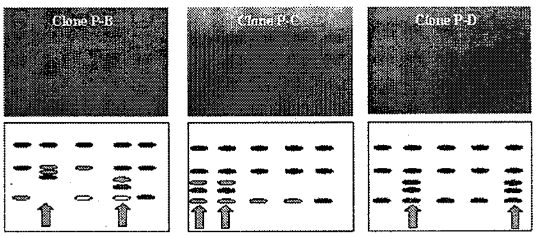

Figure 1. GOT banding patterns of three clones showing mislabelled ramets (marked with red arrow). The schematic pattern refers to the photograph above.

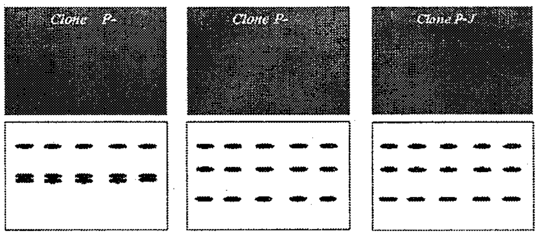

Figure 2. GOT banding patterns of three clones showing no detection of mislabelled ramets. The schematic pattern refers to the photograph above.

Table 1. Genotypes of individual ramet at two GOT loci and the calculation of mislabelling based on the number of ramet and clone

Clone	Ramet	Locus		% Mislabelled	
		GOT-B	GOT-C	Ramets	Clone
P-A	12345	1111111111	2222221212	40	100
P-B	12345	1112111111	2211221222	40	100
P-C	12345	1111111111	1212222222	40	100
P-D	12345	1111111111	2212222212	40	
P-E	12345	2222222222	1111111111	0	0
P-F	12345	1111111111	2222222222	0	0
P-G	12345	1111111111	1212121212	0	0
P-H	12345	2222222222	2222222222	0	0
P-I	12345	2222222222	1111111111	0	0
P-J	12345	1111111111	2222222222	0	0
Average				**16**	**40**

tion or establishment stage of teak hedge orchard. Such errors are likely to be part of most, if not all programs, and should not be taken as harsh criticism of the tree improvement program. Rather, identity screening and other appropriate measures should be taken from now on to rectify identity errors.

There are numerous ways that errors can enter the teak improvement program. This clone garden represent a unique situation in that clones developed for these applications are grafts, which are genetic mosaics. That is, the root stock is genetically different than the scion. The ramets which differed from the concensus genotype (Cheliak and Pitel, 1984) originated either from mislabeled scion or, perhaps more likely in the second case, from the roorstock overtaking the grafted scion. Unfortunately, it is almost impossible to determine the exact cause of error after the fact.

Almost similar results was observed in perhaps different clonal materials from the same clone garden using SCAR markers (Rimbawanto *et al.*, 2002). It is essential that clear study objectives are determined to ensure that appropriate genetic tool is utilized or considering "which marker for which purpose". Characters used in identification must be quantifiable and be under genetic control. These two key factors must be considered regardless of whether the objective is to certify clones, varieties, or families.

With regards to isozyme methods, one important advantages in this case is that large number of individuals (ramets and clones) can be surveyed in relatively short amount of time at a reasonable cost. A disadvantage with isozymes is the limited number of genes to survey which is approximately 30 loci.

CONCLUSIONS

Enzyme system of GOT was found to be very effective for early detection of mislabeling in teak hedge orcahard at a reasonable cost. The degree of mislabeling observed in this clonal archive was relatively high suggesting identity screening of clones and other appropriate measures should be taken to rectify the errors.

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Clonal propagation of *Tectona grandis* L. f. by Leafy Stem Cuttings: Effects of Branch Position and Auxin Treatment on Rooting Ability

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ABSTRACT

Investigation was carried out on adventitious root formation in cuttings of coppiced shoots of teak to examine the effect of position of branch and auxin treatment on root formation. Both leafy and softwood shoot cuttings of 3-year-old teak stock plants grown in hedge gardens were used for the experiment. The rooting parameters, viz., per cent callusing, per cent rooting and per cent sprouting, mean number of leaves, shoots and their length, and mean number of roots and their length per cutting were significantly influenced by the position of branch and the auxin treatment. Application of 4000 ppm IBA increased per cent rooting and per cent sprouting whereas NAA suppressed it. Treatment of 4000 ppm IBA also increased mean number of leaves, shoots and their length and mean number of roots per cutting. Maximum mean number of roots and their length were recorded from cuttings taken from the branch emerging at the upper position followed by branch of middle and lower positions. But cuttings of branches at middle position gave the highest values of per cent rooting and per cent sprouting, mean number of leaves and shoots and the mean shoot length per cutting. The interactive effect of position of branch and auxin treatment on rooting and sprouting response was also significant.

Keywords: Branch position, hedge garden, stem cuttings, auxin treatment, rooting, teak

INTRODUCTION

Teak (*Tectona grandis* L. f.) is the principal timber tree of peninsular India and is one of the most important timbers of the world. It occurs naturally in India, Myanmar, the Lao People's Democratic Republic and Thailand, and it is naturalized in Java and Indonesia, where it was probably introduced some 400 to 600 years ago. In addition to it, the tree has been introduced to the other parts of the worlds also (Pandey and Brown, 2000). Teak is the tropical hardwood most in demand for 'luxury' applications including quality furniture, shipbuilding and decorative building components, and its demand in the tropical timber market is increasing. Teak timber supplies from natural forest have dwindled during the last 2-3 decades. This has led to an increase in investments on raising teak plantations, causing massive demands of superior quality planting stock of preferably known teak clones, and search for suitable technologies for mass production of clonal planting material (Husen and Pal, 2003a & b). Several methods of teak cloning, which include techniques of macro-propagation (Husen and Pal, 2000 & 2001; Planisamy and Subramaniam, 2001; Husen and Pal, 2003 a & b) and micro-propagation (Gupta *et al.*,1980; Mascarenhas *et al.*, 1993) have been developed. Of these, rooting juvenile cuttings which are obtained from teak clonal hedge gardens is the most promising terms of economics, ease and simplicity of the method for mass production of quality planting stock. However, there is a need to standardize the method of propagation by cuttings as it is well known that rooting behaviour of teak cuttings is strongly influenced by a number of factors (Planisamy and

Subramaniam, 2001; Husen, 2002; Husen and Pal, 2003a & b). Of these factors position of branch in the crown of mature trees is an important determinant of rooting behaviour of cuttings Nautiyal *et al.*, 1991; Husen and Pal, 2000). However, there is no published information available on the effect of position of branch on rooting behaviour of coppiced shoot cuttings taken from hedged stock plants of teak, and hence the present investigation was taken up.

MATERIAL AND METHODS

Three-year-old stock plants, which were raised using seed of teak clone FG11, were coppiced in the first week of May by severing the main stem at 30.0 cm distance from the ground level. Shoots began to grow on the stumps within 7-10 days of coppicing. About 1-2 shoots emerged from each node. The coppiced shoots were collected in the first week of June. The shoots emerging from different positions (i.e. basal, middle and upper) were kept separately. The terminal node of the shoots was excised. Each shoot was made into mono-nodal leafy soft-wood cuttings as described earlier (Husen, 2002).

a-Naphthalene acetic acid (NAA) and indole-3-butyric acid (IBA), at 2000 and 4000 part per million (ppm) concentration were applied in their powder formulation, which also contained 0.05 per cent Bavistin (BASF India Ltd. Mumbai). The control cuttings were treated with talcum powder (this powder was used for 1000 and 2000 ppm IBA preparation) containing Bavistin only. After treatment the cuttings were planted into plastic trays, which were filled with sterilized vermiculite (pH 7.0). The vermiculite was presoaked in tap water for 24 hours before filling it up in the trays. The cuttings were planted immediately after the treatment with auxins and these were kept inside a mist chamber where the relative humidity was maintained at 85±2 per cent and maximum and minimum day-night temperature at 32 ± 1°C to 26 ± 1°C respectively. After 45 days, the cuttings were carefully removed from the rooting medium and observations were recorded on callus formation, sprouting, rooting, number of sprouts per cutting and their length (cm), number of leaves per cuttings, number of roots per cutting and their length (cm).

Statistical analyses were carried out with SPSS (Statistical Package for Social Sciences). A factorial completely randomized design was used with 5 replications (5 cuttings per replicate) and two factors, position of branch (basal, middle and apical) and auxins treatment (0, 2000 and 4000 ppm of NAA and IBA). Because the percentage data are based upon a binomial response and some mean percentage lie outside the stable variance range of 30 to 70 per cent, all percentage data were transformed to arcsine "p is the callusing or rooting or sprouting percentage (Anderson and Mc Lean, 1974). All other analyses were performed on untransformed data. The analysis of variance (ANOVA) procedures were used to test for significant effect of the treatments for the response variables measured. The ANOVA for all rooting parameters, the value for each replication was estimated based on all available cuttings. For the comparison of different means of different treatments, the critical differences (CD) were calculated based on the student t-test at 5 per cent probability.

RESULTS

Effect of position of branch

Position of branch significantly ($P<0.01$ level) influenced the callusing, rooting and sprouting behaviour of the cuttings (Fig.1 and Table 1).

Maximum per cent callusing was observed on basal followed by apical while, minimum was observed in middle branches from position (Fig. 1). The middle position of branch revealed maximum

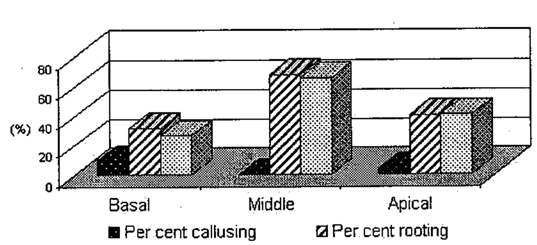

Figure 1. Effect of position of branch on per cent callusing {CD: 0.30}, rooting {CD: 0.27} and sprouting {CD: 1.05}

(68.21%) rooting percentage followed by apical (40.60%) and basal (32.38%) position (Fig. 1). Cuttings from branches on middle position exhibited maximum (66.05%) sprouting percentage followed by those from apical position (41.15%) and minimum sprouting was on cuttings from basal position (26.78%) (Fig. 1). The highest value of mean number of shoots per cutting, mean length of shoot per cutting and mean number of leaves per cutting were shown by cuttings of branches on the middle position, followed from the apical and basal positions (Table 1). But the cuttings of the branches taken from the apical position showed higher values of mean number of roots per cutting and mean length of root than in cuttings of branches taken from the other two position (Table 1).

Effect of auxins treatment

Except for mean number of shoots per cutting ($P<0.05$ level) all other rooting parameters viz., per cent callusing, rooting, sprouting (Fig. 2), mean length of shoot per cutting, mean number of leaves per cutting, mean number of roots per cutting and their length exhibited significant variation at $P<0.01$ level (Table 1).

Auxin treatment promoted callus formation at the basal cut end of the cuttings; NAA causing more callusing than IBA. Treatment with IBA increased per cent rooting and per cent sprouting while NAA suppressed it; the effect of each case was stronger when the higher concentration of each auxin was used (Fig. 2). Both IBA and NAA increased the values of mean shoot length per cutting and mean number of leaves per cutting, but more increase was caused by IBA than NAA. IBA and NAA treatments increased the mean root length per cutting and in number of roots per cutting; which 4000 ppm IBA was the most effective treatment in causing root elongation, NAA was the more effective auxin for increasing the number of roots (Table 1).

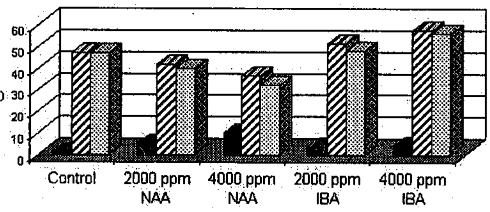

Figure 2. Effect of auxin treatment of cuttings on per cent callusing {CD: 0.23}, rooting {CD: 0.21} and sprouting {CD: 0.84}

Interactive effect of position of branch and auxins treatment

The interactive effect of branch position and auxin treatment on all rooting parameters of rooting and sprouting was significant (Figs. 3a, b & c and Table 1). Maximum callus formation was recorded on cuttings prepared from branches at basal position and treated with 4000 ppm NAA, while cuttings of branches from middle position generally did not produce callus irrespective of auxin treatment (Fig. 3a). A combination of 4000 ppm IBA and middle position of the branches exhibited the highest values of per cent rooting, per cent sprouting and mean number of roots per cutting while the combined effect of 4000 ppm NAA and basal position of

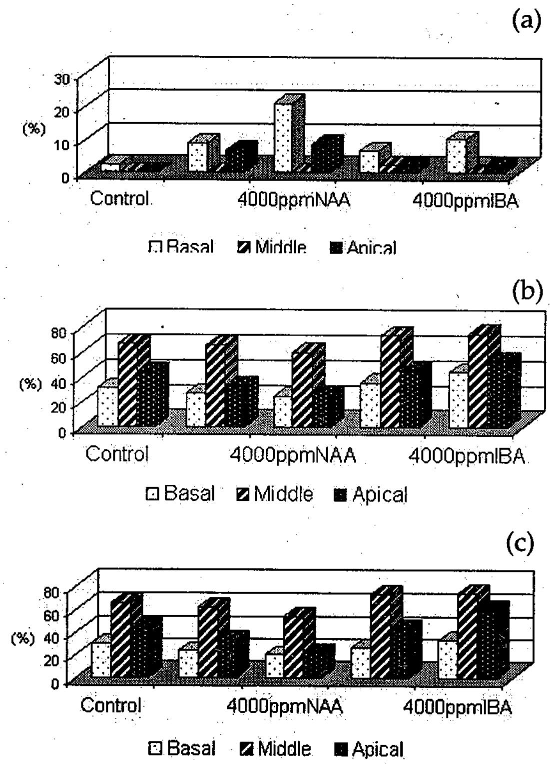

Figure 3. Interactive effect of auxins and position of branch on (a) per cent callusing {CD: 0.52} (b) rooting {CD: 0.47} and (c) per cent sprouting {CD: 1.88}

Table 1. Effects of position of branch, auxins treatment and their interaction on rooting response of coppice shoot cuttings

Parameters	**Position of branch**	**Treatment of auxins (in ppm)** Control	2000NAA	4000NAA	2000IBA	4000IBA	**Mean**
Mean number of shoots per cutting	Basal	0.81	0.62	0.44	0.49	0.66	0.60
	Middle	1.00	1.00	1.00	1.00	1.50	1.10
	Apical	0.85	0.65	0.48	1.17	1.16	0.86
Mean		0.89	0.76	0.64	0.89	1.11	
Source of variation		Treatment- *		Position of branch - **		Position of branch x Treatment-*	
CD $_{(0.05)}$		0.12		0.09		1.27	
Mean length of shoot per cutting (cm)	Basal	2.22	3.13	3.18	3.25	3.40	3.04
	Middle	3.05	3.23	3.48	3.52	4.10	3.48
	Apical	2.29	3.33	3.41	3.68	3.75	3.29
Mean		2.52	3.23	3.36	3.48	3.75	
Source of variation		Treatment- **		Position of branch - **		Position of branch x Treatment-*	
CD $_{(0.05)}$		0.12		0.09		0.20	
Mean number of leaves per cutting	Basal	3.14	3.79	3.95	3.63	3.87	3.68
	Middle	3.81	4.15	4.05	4.53	4.78	4.26
	Apical	3.29	3.26	3.21	3.74	3.66	3.43
Mean		3.41	3.74	3.74	3.97	4.10	
Source of variation		Treatment- **		Position of branch - **		Position of branch x Treatment-**	
CD $_{(0.05)}$		0.11		0.08		0.19	
Mean number of roots per cutting	Basal	3.10	3.81	4.56	3.60	3.78	3.77
	Middle	2.89	3.87	4.80	3.81	3.82	3.84
	Apical	2.56	3.88	5.19	4.30	4.28	4.04
Mean		2.85	3.85	4.85	3.90	3.96	
Source of variation		Treatment- **		Position of branch - **		Position of branch x Treatment-*	
CD $_{(0.05)}$		0.09		0.07		0.16	
Mean length of root per cutting (cm)	Basal	2.27	3.09	4.56	4.45	5.24	3.92
	Middle	2.90	4.95	5.32	4.72	5.84	4.75
	Apical	2.96	6.28	5.54	4.79	6.18	5.15
Mean		2.71	4.77	5.14	4.65	5.75	
Source of variation		Treatment- **		Position of branch - **		Position of branch x Treatment-*	
CD $_{(0.05)}$		0.14		0.11		0.24	

* Significant at P<0.05 level; ** Significant at P<0.01 level.

branch produced the minimum values for these parameters (Figs. 3b & c and Table 1). Further, IBA and middle position of branch showed maximum whereas that 4000 ppm NAA and basal position of branch minimum mean number of shoots per cutting (Table 1). The combined effect of 4000 ppm IBA treatment and middle position of branch exhibited maximum whereas, that of untreated control cuttings and basal branch position minimum mean length of shoot per cutting (Table 1). A combination of 4000 ppm IBA and middle position of branch produced maximum mean number of leaves per cutting, whereas combined effect of control treatment and basal position showed minimum mean number of leaves per cutting (Table 1). A combined effect of 4000 ppm NAA treatment and apical position of branch exhibited maximum whereas, that of untreated control cuttings and apical position of branch revealed minimum mean number of roots per cutting (Table 1). A combined effect of 2000 ppm NAA treatment and apical position of branch exhibited the highest whereas, that of untreated control cuttings and basal position of branch revealed the lowest value on mean length of root per cutting (Table 1).

DISCUSSION

The results clearly show that the position of branch even on a hedged donor plants has a significant effect on callusing, rooting and sprouting behaviour of the cuttings. Maximum rooting was observed in the cuttings taken from the middle position followed by those taken from apical position and the minimum in cuttings taken from the basal position. The mean number of roots per cutting and their length were higher in the cuttings taken from the apical position, which was followed in order, by the cuttings taken from the middle and lower position, respectively. Although, in most of tree species rooting ability of cuttings has been reported to increased from apical to basal part of the crown and of the shoots which has been attributed to accumulation of carbohydrates at the base of shoot (Hartmann *et al.*, 1997), there are many deviation from this general trend. For example, in *Triplochiton scleroxylon*, rooting percentage of cuttings form different node positions was found to decline basipetally (Leakey and Mohammed, 1985). Further, cuttings originating from the apical position of shoot of *Milicia excelsa* (Ofori *et al.*, 1997) *T. scleroxylon* (Leakey, 1983) and *Nauclea diderrichii* (Matin, 1989) displayed higher rooting percentages than those taken from the basal portions. But the, results of this study indicate that cuttings of branches originating from the middle position of teak displayed higher rooting percentage. It is evident from these findings that optimal branch position for the best rooting response varies with the plant species, and the position effect on rooting may be caused by variation in the physiological status of shoot tissues with the position of branch on stock plant resulting in occurrence of gradients along the stem axis in the cellular activity, in the level of assimilates and growth regulators, and in the level of lignification, etc.

Effect of auxin on callusing, rooting and sprouting behaviour of cuttings also varied with position of the branch and the nature and concentration of auxin. Generally, IBA treatment promoted rooting and sprouting of cuttings, which, were taken from the middle position while it was comparatively less effective in cuttings taken from the other position. NAA treatment was generally inhibitory for per cent rooting and per cent sprouting and its effect was lesser in cuttings taken from the middle position. However, NAA treatment increased per cent callus formation at the base of cuttings. Although, the effect of auxins in promoting rooting of cuttings is well known (Nanda, 1970; Hartmann *et al.*, 1997; Husen and Mishra, 2001; Husen, 2003) very little information is available on the effectiveness of auxins in relation to the branch position, especially when the cuttings were taken from the hedged garden.

CONCLUSIONS

The position of branch on stock plants of teak growing in hedge garden also has a significant effect on the rooting behaviour of stem cuttings. More profuse rooting was observed in cuttings taken from branches at middle position than those from branches at apical and basal position. Even the effect of auxin promoting rooting varied with position of branch. Thus, treatment with IBA promoted rooting more strongly when the cutting were taken from branches at the middle position and lesser when these were taken from branches at the apical and basal position.

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Improved Techniques for Raising Nursery Stock in Teak

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ABSTRACT

A nursery experiment was conducted in the Silviculture Nursery, College of Forestry, Sirsi, Karnataka, during 2000 and 2001 in order to study the effect of stump size on growth and seedling biomass of teak. Stumps having collar diameter of 1 - 2 cm and root length of 15 cm performed better, as compared to the rest. However, shoot length exhibited no effect on the growth parameters except on collar diameter, number of coppices and dry weight of root. Interaction of collar diameter, shoot length and root length had positive bearing only on the biomass attributes. Hence the use of stumps having collar diameter of 1 - 2 cm, shoot length of 2 -4 cm and root length of 15 cm is recommended for raising teak plantations.

Keywords: Nursery experiment, teak stumps, growth parameters, survival per cent, planting stock.

INTRODUCTION

Teak (*Tectona grandis* Linn. f.) enjoys worldwide reputation as a quality timber on account of its remarkable physical and mechanical properties, particularly elasticity, strength and durability. Teak has a great demand in trade and hence it is imperative to develop its effective management strategies for obtaining good quality seedlings through silvicultural techniques. Advantages of use of the stump as a planting material include the reduction or immunity to damage in transit, ease of handling and planting, regeneration of roots at a depth below the surface fluctuations in moisture and uniformity of stocking which are rarely attainable by any other method (Tewari, 1992). In view of this, an investigation was undertaken to screen suitable size of the stump for production of healthy planting stock for plantation purposes.

MATERIAL AND METHODS

The study was conducted at the Silviculture Nursery, College of Forestry, Sirsi, Karnataka, during 2000-2001. Stumps were prepared from eight-month-old seedlings raised in nursery beds. There were 18 treatments in total, consisting of stumps having two levels of diameter classes, three classes of shoot length and three classes of root length as given in the Table 1. The experiment was laid out in completely randomized design. Each treatment was replicated twice and each replicate consisted of 20 stumps. Stumps were planted in slanting position in polythene bags of 25 x 15 cm size. Medium consisting of red soil, sand and FYM in a ratio of 2:1:1 was used. Watering was carried out daily. Necessary plant protection measures were adopted. Removal of excess coppices was done after 30 days of planting leaving one healthy shoot. Number of coppices in each seedling was counted after 30 days of planting and average was recorded as coppices per seedling. After six months of planting of the stumps, measurement of height, collar diameter, number of leaves, root length, number of lateral roots, fresh weight of shoot and root was done on randomly selected six seedlings. Leaf area was assessed using Leaf Area Meter. For fresh weight of shoot and root, only newly sprouted shoot and all lateral roots from the stumps were considered for weight measurement leaving original stump. After taking fresh weight, same samples were dried in hot air oven at 60±1°C for 12 hours for the record of the dry weight.

RESULTS AND DISCUSSION

Performance of the teak seedlings grown from different stumps is presented in Tables 2-5.

Effect on growth attributes

Collar diameter of the stump had a significant influence on all growth attributes except number of lateral roots and of coppices. Among collar diameter classes, stumps having collar diameter of 1–2 cm recorded highest height (45.96 cm), collar diameter (0.97 cm), number of leaves (7.70 / seedling), leaf area (319.25 cm^2), root length (35.35 cm), shoot fresh weight (75.16 g), shoot dry weight (32.23 g), root fresh weight (32.43 g), root dry weight (12.41 g), total fresh weight (107.59 g) and total dry weight of the seedling (44.64 g), which was significantly superior to the stumps having less than 1 cm collar diameter. The thick and stout stumps possessing more reserved carbohydrates might be the reason for the better growth of seedlings as compared to thinner ones (Davis *et al.*, 1990 and Lebot, 1996). These results are on par with the findings of Annon (1945) in *Tectona grandis*, Wilson (1987) in *Gmelina arborea* and *Tectona grandis*.

Table 1. Details of the treatments

Treatment	Collar diameter class (cm)	Shoot length (cm)	Root length (cm)
T1	<1	2	5
T2	<1	2	10
T3	<1	2	15
T4	<1	4	5
T5	<1	4	10
T6	<1	4	15
T7	<1	6	5
T8	<1	6	10
T9	<1	6	15
T10	1 – 2	2	5
T11	1 – 2	2	10
T12	1 – 2	2	15
T13	1 – 2	4	5
T14	1 – 2	4	10
T15	1 – 2	4	15
T16	1 – 2	6	5
T17	1 – 2	6	10
T18	1 – 2	6	15

Stumps having varying lengths of shoot portion did not show significant effect on all growth parameters except collar diameter, number of coppices and dry weight of root. Stumps having 4 cm shoot performed well by producing maximum collar diameter (0.96 cm) and dry weight of root (12.00 g). This may due to production of less number of coppices and concentration of growth in the single shoot. Stumps having 6 cm shoot length produced more number of coppices (1.80 / seedling), which was significantly higher than 2 cm shoot length. This may be due to

Table 2. Influence of stump size on the seedling growth of teak

Particulars	Height (cm)	Collar diameter (cm)	Number of leaves	Leaf area (cm^2)
Collar diameter (cm)				
C1 <1.0	38.23	0.91	7.19	302.73
C2 1.0-2.0	45.96	0.97	7.70	319.25
Shoot length (cm)				
S1 2.0	41.73	0.94	7.48	309.27
S2 4.0	43.30	0.96	7.50	314.55
S3 6.0	41.25	0.92	7.36	309.15
Root length (cm)				
R1 5.0	37.54	0.89	7.10	294.98
R2 10.0	42.40	0.92	7.40	308.05
R3 15.0	46.35	1.00	7.84	329.94

	SEm±	CD 5%	CD 1%	SEm±	CD 5%	CD 1%	SEm±	CD 5%	CD 1%	SEm±	CD 5%	CD 1%
Collar diameter (C)	0.76	2.25	3.08	0.01	0.03	0.03	0.06	0.17	0.23	4.53	13.45	NS
Shoot length (S)	0.93	NS	NS	0.01	0.03	0.04	0.07	NS	NS	5.55	NS	NS
Root length (R)	0.93	2.75	3.77	0.01	0.03	0.04	0.07	0.21	0.28	5.55	16.48	22.57
Interaction of C x S x R	2.27	NS	NS	0.03	NS	NS	0.17	NS	NS	13.58	NS	NS

NS indicates non-significant

Table 3. Influence of stump size on the seedling growth and survival of teak

Treatment	Survival per cent	Root length (cm)	No. of lateral roots	No. of coppices
Collar diameter (cm)				
C1 <1.0	93.06 (76.87)	34.34	30.17	1.68
C2 1.0 - 2.0	95.83 (80.94)	35.35	31.50	1.66
Shoot length (cm)				
S1 2.0	92.50 (75.90)	34.71	31.75	1.53
S2 4.0	95.00 (79.74)	34.91	31.42	1.68
S3 6.0	95.83 (81.09)	34.91	30.00	1.80
Root length (cm)				
R1 5.0	90.00 (72.00)	33.51	18.83	1.68
R2 10.0	95.83 (79.85)	34.50	30.50	1.66
R3 15.0	97.50 (84.87)	36.53	43.17	1.66

	SEm±	CD 5%	CD 1%	SEm±	CD 5%	CD 1%	SEm±	CD 5%	CD 1%	SEm±	CD 5%	CD 1%
Collar diameter (C)	1.70	NS	NS	0.18	0.53	0.73	0.76	NS	NS	0.06	NS	NS
Shoot length (S)	2.08	NS	NS	0.22	NS	NS	0.93	NS	NS	0.07	0.20	0.21
Root length (R)	2.08	6.19	NS	0.22	0.65	0.89	0.93	2.76	3.96	0.07	NS	NS
Interaction of C x S X R	5.10	NS	NS	0.54	NS	NS	2.27	NS	NS	0.17	NS	NS

NS indicates non-significant ; Figures in the parenthesis are arc sine transformed values

Table- 4. Influence of stump size on the seedling biomass of teak.

Particulars	Fresh weight of shoot (g)	Fresh weight of root (g)	Total fresh weight (g)	Dry weight of shoot(g)	Dry weight of root (g)	Total dry weight (g)
Collar diameter (cm)						
C1 <1.0	60.95	27.44	88.39	24.71	10.19	34.90
C2 1.0 - 2.0	75.16	32.43	107.59	32.23	12.41	44.64
Shoot length (cm)						
S1 2.0	67.49	29.24	96.73	27.75	11.12	38.87
S2 4.0	69.90	30.83	100.73	29.11	12.00	41.11
S3 6.0	66.77	29.73	96.50	28.55	10.78	39.33
Root length (cm)						
R1 5.0	59.44	22.91	82.15	23.54	8.65	32.19
R2 10.0	68.59	29.34	97.93	28.50	10.77	39.27
R3 15.0	76.12	37.55	113.67	33.37	14.48	47.85

	SEm±	CD 5%	CD 1%	SEm±	CD 5%	CD 1%	Sem±	CD 5%	CD 1%	SEm±	CD 5%	CD 1%	SEm±	CD 5%	CD 1%	SEm±	CD	CD
Collar diameter (C)	1.08	3.21	4.40	0.79	2.36	3.23	1.49	4.43	6.06	0.55	1.63	2.23	0.20	0.60	0.82	0.64	1.90	2.61
Shoot length (S)	1.32	NS	NS	0.97	NS	NS	1.82	NS	NS	0.67	NS	NS	0.25	0.75	1.01	0.78	NS	NS
Root length (R)	1.32	3.62	5.37	0.97	2.89	3.96	1.82	5.41	7.41	0.67	1.99	2.73	0.25	0.75	1.01	0.78	2.32	3.18

NS indicates non-significant

presence of more number of dormant buds on lengthy shoot, which inturn produced more number of coppices. Very low number of coppice was produced by 2 cm shoot length (1.53 / seedling) because of presence of low number of dormant buds. Hence, to reduce the cost of thinning of excessive shoots, 2 to 4 cm of shoot length was found to be more desirable in teak.

Among three levels of root lengths of the stumps, stumps having 15 cm root length recorded maximum height (46.35 cm), collar diameter (1.00 cm), number of leaves (7.84 / seedling), leaf area (329.94 cm^2), root length (36.53 cm), lateral roots (43.17), fresh weight of shoot (76.12 g), dry weight of shoot (33.37 g), fresh weight of root (37.55 g), dry weight of root (14.48 g), total fresh weight (113.67

Table 5. Influence of interaction of collar diameter, shoot length and root lengths of the stump on the seedling biomass in teak

Treatment	Fresh weight of shoot (g)	Fresh weight of root(g)	Total fresh weight (g)	Dry weight of shoot (g)	Dry weight of root(g)	Total dry weight (g)
T1 (C1 x S1 x R1)	56.20	23.35	79.55	20.91	9.48	30.39
T2 (C1 x S1 x R2)	58.76	26.15	84.91	22.57	7.89	30.46
T3 (C1 x S1 x R3)	60.14	30.88	91.02	24.27	10.96	35.23
T4 (C1 x S2 x R1)	60.29	22.91	83.20	23.10	9.14	32.24
T5 (C1 x S2 x R2)	60.30	27.01	87.31	23.75	9.27	33.02
T6 (C1 x S2 x R3)	61.24	32.33	93.57	25.80	11.48	37.28
T7 (C1 x S3 x R1)	52.80	21.47	74.27	21.50	7.73	29.23
T8 (C1 x S3 x R2)	69.22	27.32	96.54	29.92	11.58	41.50
T9 (C1 x S3 x R3)	69.58	35.62	105.20	30.56	14.18	44.74
T10 (C2 x S1 x R1)	56.76	21.54	78.30	22.28	7.97	30.25
T11 (C2 x S1 x R2)	74.21	28.62	102.83	30.76	11.71	42.47
T12 (C2 x S1 x R3)	98.86	44.94	143.80	45.75	18.73	64.48
T13 (C2 x S2 x R1)	72.18	25.02	97.20	29.53	10.01	39.54
T14 (C2 x S2 x R2)	74.86	35.61	110.47	32.29	13.18	45.47
T15 (C2 x S2 x R3)	90.55	42.15	132.70	40.16	18.93	59.09
T16 (C2 x S3 x R1)	58.42	23.22	81.64	23.91	7.59	31.50
T17 (C2 x S3 x R2)	74.21	31.36	105.57	31.73	10.99	42.72
T18 (C2 x S3 x R3)	76.38	39.42	115.80	33.68	12.61	46.29
SEm±	3.24	2.38	4.46	1.66	0.61	1.91
C. D. at 5%	9.62	NS	13.25	4.93	1.80	5.67
C. D. at 1%	13.19	NS	18.15	6.76	2.47	7.77

NS indicates non significant

g) and total dry weight of the seedling (47.85 g), which was significantly better than stumps having 5 cm and 10 cm root length. It may be due to more surface area of root leading to the production of more number of lateral roots thereby increasing efficiency in drawing the nutrients. The least performance in all growth parameters was recorded by the stumps having 5 cm root length.

Among the interaction of collar diameter, shoot length and root length of the stumps, stumps having collar diameter of 1-2 cm, 2 cm of shoot length and 15 cm of root length recorded the highest accumulation of fresh weight of shoot (98.86 g), dry weight of shoot (45.75 g), total fresh weight (143.80 g) and total dry weight of seedlings (64.48 g) whereas maximum accumulation of dry matter of root (18.93 g) was recorded by the stumps having collar diameter of 1-2 cm, 4 cm of shoot length and 15 cm of root length. This might be attributed to the thickness of the collar diameter, less number of coppices by the shoot and long root helps in keeping good growth. The poor accumulation of the fresh weight of shoot, total fresh weight and total dry weight of seedling was found in stumps having collar diameter of less than 1 cm, 6 cm of shoot and 5 cm of root whereas stumps having less than 1 cm of collar diameter, 2 cm of shoot and 5 cm of root resulted in the lowest accumulation of dry weight of shoot. The lowest dry weight of root was noticed in stumps having collar diameter of 1-2 cm, 6 cm of shoot length and 5 cm of root length.

SURVIVAL PER CENT

Among different parameters of stumps, root length exhibited positive and significant effect on the survival per cent of the seedlings compared to the shoot length and collar diameter. Stumps having 15 cm of root length showed highest survival rate (97.50 %) compared to the rest of the root sizes. The higher surface area of the root leading to the production of more number of lateral roots there by increasing the surface area for absorption of nutrients might be the reason for the good establishment of seedlings in stumps having bigger root portion. The interaction of root length with either collar diameter or shoot length or in combination had no significant effect on the survival per cent of the seedlings.

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Quality Timber Products of Teak from Sustainable Forest Management pp 438-444

Teak Biotechnology: Development and Prospects

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ABSTRACT

During the past two decades, a major shift in emphasis has taken place in teak improvement towards teak biotechnology, away from traditional breeding programmes. Use of micropropagation as an integral component of tree improvement programmes has been initiated for teak. The micropropagation via meristem (axillary/apical) proliferation, shoot tip culture, clonal propagation, etc. has significant potential to overcome the handicaps associated with teak. Therefore, the technologies recently developed for propagation may indeed be useful for increased production per unit area per unit time.Genetic marker technology is proving to be very valuable for genotyping, analysis of genetic structure and for understanding the basis of genetic control of commercial traits. Marker- aided selection (MAS) and susceptibility tests of different strains of *Bacillus thuringiensis* (*Bt* gene) against the lepidopteran pest, *Palga damastesalis* are also being carried out. Gene construct, which contain *Bt* gene and suitable promoter, can be constructed for the genetic transformation to produce transgenic insect resistant teak. Research programmes for isolation of floral regulatory genes (which are part of the MADS box gene family) from inflorescence and floral tissue-cDNA library using DNA probes from Arabidopsis and Antirrhinum and also by PCR amplification of mRNAs, extracted from young flowering tissues using MADS box primers are under progress. The selected floral regulatory genes and promoters can be used for making gene constructs for genetic transformation to produce transgenic sterile teak. Molecular markers like Restriction Fragment Length Polymorphism (RFLP), Random Amplified Polymorphic DNAs (RAPDs), isozymes and allozymes have been used in teak improvement and also for the estimation of genetic diversity, genetic fidelity and clonal homogeneity.

Keywords: Tectona grandis, micro -propagation, molecular markers, MAS, RFLP, RAPD

INTRODUCTION

Biotechnology is neither a science nor a discipline (Cheliak and Rogers, 1990). Rather, it is a collection of techniques that include *in vitro* culture and selection, molecular mapping and genetic engineering. This collection of techniques is highly dynamic one as the new biotechnological approaches are continually being developed. During the past two decades, a major shift in emphasis occurred in forest tree improvement away from traditional breeding programmes towards forest biotechnology.

Biotechnology provides powerful tools to the forest scientists working to increase productivity (Farnum *et al.*, 1983) and quality of tree crops and / or reduced the cost and risk associated with long rotations in uncertain environments (Griffin, 1996). Teak (*Tectona grandis* L.f.) is one of the most valuable and prized timbers. Teak wood is considered as the best timber due to its strength, durability, termite resistance, easy workability, moderate weight, beauty, dimensional stability and teak is easily established in plantation regimes, which allows introduction of improved genetic material. However, there are also obstacles such as quantitatively limited and late seed production, low germination rates, substantial variability in growth and wood quality among individuals within progenies and lack of accurate knowledge about the inheritance of economically significant traits (White, 1991).

Incorporating biotechnology into the forest industry has tremendous potential for long-term economic impact in addition to preserving both the environment and forest health. The ability to genetically engineer into trees, novel traits ranging from insect and pathogen resistance to increase in growth rate and wood quality, will have an unprecedented impact on wood fibre production. When combined with tissue culture technologies (e.g., shoot-tip culture, meristem culture), integrating transgenic technologies into teak improvement programmes will dramatically accelerate the development of high-value teak genotypes, whose long rotation period has been a major limitation for traditional breeding strategies. Biotechnology provides immense prospects in teak improvement programme, mainly in the fields of micropropagation, genetic engineering of reproductive sterility in teak, genetic engineering for wood quality, teak improvement for stress environments, genetic engineering for insect resistance and many more areas.

Biotechnology now provides the necessary tool to solve many of the problems faced in conventional teak breeding programmes and offers prospects for teak improvement at an accelerated rate. This review deals with some of the important aspects in the genetic modification of forest trees to meet the demands of the growing forest industry. It is considered that teak biotechnology should be well placed over the coming decades to benefit from the opportunities offered by genetic modification.

TEAK TISSUE CULTURE TECHNOLOGY

The increasing demand on limited fibre resources by wood-based industries and the decline of world's forests has been the impetus for forestry operations to raise forest productivity. Natural forestry plantations are hindered by their high genetic diversity and the lack of phenotypic uniformity, which has a negative impact on end product quality and processing efficiencies. The use of clonally propagated plantings in reforestation has offered plantation management the advantages of phenotypic uniformity, high productivity, increased yields and rapid multiplication of trees resistant to disease and pests.

Vegetative propagation in teak by means of cuttings from juvenile seedlings and tissue-culture technique has been developed on a commercial scale (Kaosa-ard, 1990; 1993; Kaosa-ard *et al.*, 1987) and teak-planting stock based on this technique is being produced on a commercial basis. The price for this planting stock is approximately two to three times higher than that for traditional seedlings and/or stumps. Different clones require slightly different culture media, and it is therefore difficult to handle a large number of clones in commercial tissue-culture programmes. Tissue culture, for these reasons, is used only on a small scale at present. However, the combination of tissue culture and subsequent cutting of tissue-culture plantlets has proved to be both technically and economically feasible for large-scale production of clonal planting material. All successful large-scale micropropagation programmes are currently limited to propagation of material from juvenile tissues via adventitious and axillary bud production.

For increasing biomass yield, one alternative is to exploit the existing variability and multiply trees with desirable traits such as straight bole, disease resistance or fast growth. Conventionally, to maintain unique and desirable characters of the marked trees one can proceed through the conventional methods of rooting of cuttings. Cuttings can be taken only from the terminal portions during a particular season and the age of the mother trees is also crucial.

Most trees of teak, however, can be evaluated for desirable traits only at the stage of half rotation. But, by this time the tree quite often has lost its ability to form roots. Thus it is desirable to have a tissue culture method for mass cloning of hardwood species (Monteuuis, 1995). The micro propagation of teak has three diverse roles to play; augmenting quantity of planting material, cloning superior/elite trees and retention of most of the genetic potential of selected individual. Several problems are associated with commercial exploitation of tree tissue culture. India has been a pioneering country in the field of tree tissue culture. The first report of hardwood propagation from mature tissue came from the National Chemical Laboratory; Pune on *Tectona grandis* (Gupta *et al.*, 1980) and the list is expanding fast (Mascarenhas *et al.*, 1982).

GENETIC ENGINEERING FOR REPRODUCTIVE STERILITY IN TEAK

Containment of transgenes inserted into genetically engineered forest trees will probably be necessary before most commercial uses are possible. This is a consequence of high rate of gene dispersal by pollen and seed, proximity of engineered trees in plantations to natural or feral stands of inter fertile species and, potentially undesirable ecological effects if certain transgenes become widely dispersed.

In addition to gene containment, engineering of complete or male sterility may stimulate faster wood production, reduce production of allergenic pollen and facilitate hybrid breeding. Faster growth could also be achieved by averting energy consumed by flower production. There are several options available for generating sterile plants: chief among these are genetic ablation and inhibition of expression of genes essential for reproductive development. In genetic ablation, a cytotoxic gene is expressed under the control of a reproductive-specific promoter, killing all cells that follow that developmental pathway. Antisense RNA, sense suppression, can accomplish inhibition of gene expression or promoter-based suppression.

APETALA1 (*AP1*) gene of *Arabidopsis* and SQUAMOSA (*SQUA*) gene of *Antirrhinum* help to regulate the transition from an inflorescence meristem to a floral meristem. Mutants in SQUA develop additional inflorescence shoots instead of flowers, resulting in a multi-stemmed structure. These genes are homologues from the MADS box family of regulatory genes (Huijser *et al.* 1992; Mandel *et al.* 1992). The homologs of LEAFY (*LFY*) from *Arabidopsis* and FLORICAULA (*FLO*) from *Antirrhinum* also regulate the transition from inflorescence to floral meristem but they do not contain MADS-boxes. Mutations cause multiple branched stems in place of flowers (Huijser *et al.*, 1992).

AGAMOUS (*AG*) gene of *Arabidopsis* and PLENA (*PLE*) gene of *Antirrhinum* has role in differentiation of both male and female floral tissues. Mutation of AG results in stamens being transformed to petals and carpels developing as new flowers in a repetitive fashion (Okamuro *et al.*, 1993). Research programmes for isolation of floral regulatory genes (which are part of the MADS box gene family) from inflorescence and floral tissue-cDNA library using DNA probes from *Arabidopsis* and *Antirrhinum* and also by PCR amplification of mRNAs, extracted from young flowering tissues using MADS box primers are under progress. The selected floral regulatory genes and promoters can be used for making gene constructs for genetic transformation to produce transgenic sterile teak (Norwati *et al.*, 1997).

Although many challenges remain, the first significant steps towards engineering sterility in conifers have now been completed. Thus, imparting sterility by genetic engineering not only will be a large step towards the safe use of transgenic forest trees; it also will generate mutant phenotypes likely to yield fresh insights into the molecular diversity of floral development (Strauss *et al.*, 1991; 1992; 1995).

GENETIC ENGINEERING OF WOOD

Wood is the major component of the terrestrial biomass. Wood is a leading industrial raw material and an important component of the global economy. The widespread use of genetic engineering to modify commercially important properties of wood awaits two developments. One is a feasible method of gene transfer for teak, and the second is a fundamental understanding of wood development (Whettan and Sederoff, 1991) Genetic engineering is based on an approach historically derived from studies of single genes with qualitative effects, whereas quantitative genetics used for traditional breeding analysis has improved many important properties of plants by selecting for larger numbers of loci exerting small quantitative effects. If discrete loci affecting wood structure and composition could be identified, such loci would be useful both for traditional breeding and for molecular genetics of forest trees. Some properties of wood appear to be regulated in a major way by specific genes and enzymes, particularly in the lignin biosynthetic pathways.

GENETIC ENGINEERING OF INSECT RESISTANCE

Insect pests reduce forest productivity by destroying tree crops, increasing woody debris (with consequent fire damage), destroying wildlife habitat, impairing water quality, and diminishing recreation and amenity values. Gene transfer and recombinant DNA methods provide opportunities for enhancing insect resistance of forest trees by importing genes from other species and by manipulating native genes to create novel forms of resistance. Current opportunities for enhancing insect resistance include insertion of the toxin gene from the bacterium *Bacillus thuringiensis* and transfer of proteinase inhibitor genes from other plant species. Other strategies, such as manipulation and transfer of chitinase genes, lectin genes, baculovirus genes, and genes encoding enzymes involved in the production of novel secondary compounds, also hold promise but require more information before their likelihood of success can be judged. Use of genetically engineered, resistant trees should be environmentally safer than controlling insect pests with insecticides. The main environmental risk associated with the use of engineered trees is that insect may counter-evolve to overcome their resistance. The risks of serious counter-evolution can be reduced to an acceptable level by maintaining genetic diversity in the forest, using multiple genes for resistance, and employing forest management practices that mitigate the potential for counter evolution (Raffa, 1989; Tiedje *et al.*, 1989).

Examples that are currently amenable to genetic engineering include protein toxins such as that from *Bacillus thuringiensis* (*Bt*). Susceptibility tests of different strains of *Bacillus thuringiensis* against lepidopteran pest *Palga damastesalis* are also being carried out. Geneconstruct which contains *Bt* gene and suitable promoter will be constructed for the genetic transformation to produce transgenic insect resistant teak. Almost all of the formulations used in forestry contain isolates from the *kurstaki* subspecies of *Bt*, which is toxic to lepidopteran insects (West *et al.*, 1987). There are opportunities now for developing multiple *Bt* toxin gene resistance (Feitelson *et al.*, 1992) and there are possibilities of combining the *Bt* toxin gene with other types of insect resistance. The combining of pest resistant genes to inducible, site-specific promoters is also a research need in genetic engineering of teak. There is also room for considerable innovation in the tactical deployment of genetically engineered trees to minimize the likelihood of ecological problems in the future (Libby, 1988).

Plant secondary compounds constitute a major means by which trees and other plants protect themselves against insects, and should be a major object of future work on genetic engineering of insect resistance. An exemplary source of genes is found in the subtropical neem tree (*Azadirachta indica* A. Juss.), a member of the Meliaceae, which is known for its potent yet safe pesticidal properties (Jacobson, 1989). Insect pheromones from conifer-feeding bark beetles are often simple derivatives of tree terpenoids (Wood, 1982); thus, insertion of one or a few genes from insects or insect symbionts (Byers and Wood, 1981) might allow trees to produce pheromones or related compounds themselves, potentially disrupting insect mating and colonization behaviour. Antisense (van der Krol *et al.*, 1988) and Ribozyme technology (Walbot and Bruening, 1988) have been used for impairing insect metabolism. These genetic engineering technologies should be explored in future against the teak defoliators like *Hyblooea puera* and *Hapalia machaeralis*.

MOLECULAR MARKER TECHNOLOGY

Incorporation of genetic marker technology in teak breeding offers significant potential to accelerate tree improvement by providing: 1) a precise means to identify, combine and predict the performance of complementary genes with high breeding value, and 2) a predictive tool for within family selection of genetically superior individuals whose value of operational deployment may be captured by clonal propagation. Despite the potential value of molecular breeding to forest tree improvement, its application is not yet widespread (Dale and Chaparro, 1996).

Marker assisted selection (MAS) in particular has important applications in forest tree improvement programmes, providing the means to define accurately different alleles controlling traits (Plomion *et al.*, 1996). Molecular marker technologies currently employed to construct detailed genetic linkage maps are designed to exploit genetic variation among individuals at the sequence level. Techniques such as Restriction Fragment Length Polymorphism (RFLP) and Random Amplified Polymorphic DNA (RAPD) may be used in combination with conventional breeding programmes to accelerate the process and to reduce the size of population required. The potential usefulness of RFLP markers for tree improvement has been reviewed by Beckman and Soller (1983), and Tanksley *et al.*,(1989).

Teak species is being investigated to identify suitable molecular markers for clone identification, early screening of nursery material for some economic traits (e.g. wood quality and wood volume), hybridity and early detection of diseases in the nursery stage. Genetic variability studies have been carried out and the genetic fidelity was confirmed by RAPD/RFLP (Norwati *et al.*, 1997). Isozymes (Wickneswari *et al.*, 1996) and allozymes (Kjaer and Siegismund, 1996) markers have been successfully used for the estimation of genetic diversity in teak.

CONCLUSIONS AND FUTURE CHALLENGES

Milestone expectations in genomics are passed and reset with increasing frequency as technology, theory, and instrumentation progress. Though forest biotechnology is a young sector, its considerable achievements over past few decades are due to a tradition of cooperative research. The tradition of cooperative research must be extended to genomic mapping. Tree genomes are considerably larger and even a pine tree with a mega genome 200 times larger than *Arabidopsis* would take 22 years to sequence. The two main commercial forestry species (eucalypts and poplars) have relatively smaller genomes than pine, and angiosperms are likely to have considerable conservation of gene order with *Arabidopsis*-facilitating identification of candidate genes for key commercial QTLs. Teak is very important from the genome-mapping point of view. Although they are therefore better potential tree genome project candidates whether or not a dedicated "tree genome project" is needed at all may depend on how good a model *Arabidopsis* turns out to be-perhaps most of all, how the genetics of wood synthesis relates to cell wall synthesis. Potential targets for tree improvement identified 15 years ago are still relevant: apical dominance, nutrient use, wood quality, disease, pest and herbicide resistance and lignocellulose degradation. Herbicide, or insect-resistant crops are now second generation but, for most traits, the genes have yet to be characterized. The focus is on functional genomics, using microarray technology to define differentially expressed genes. Complex traits of teak need not be genetically complex; a prime example of this is fusiform rust disease in pine, where the use of marker analysis pinned it down to an easily managed, simple gene-for-gene system. Marker aided selection (MAS) of desirable clones or breeding stock is made much less efficient by problems of recombination shrinkage and linkage drag. MAS has not been demonstrated to be economically feasible in teak, and probably has little to offer. Clonal propagation is considerably cheaper than extracting DNA! Map based (positional) cloning will be the only route to QTL isolation, as there will be few clues to the identity of the genes responsible, and this approach will only be workable for trees of small genome size such as eucalypts and poplars. However, map based cloning will be hampered by the difficulty of mendelizing traits in trees through breeding near-isogenic lines (NILs).

Increased yield is a target all forestry sectors can agree upon. Improved growth potential of teak to give shorter rotation would have a major impact not only on productivity, but on the nature of the industry too. Prevention of reproduction through flowering control could increase yield by redirecting resource allocation into wood production. A better understanding of stress responses, particularly with regard to their impact on growth characteristics, might also allow increased productivity, either through expansion of the climatic range over which species can be grown or by increasing the number of species that can be commercialized as plantation trees. Reducing teak processing costs through biotechnological modification of the raw material would certainly have wide appeal, but as the structure function relationships of most wood polymers are not well known, it is difficult to predict the effects of changing either polymer structure or quantity.

Thus the improved biotechnological techniques have been developed for evaluating forest genetic resources and for selection, testing, manipulating and propagating improved genotypes of teak. The teak biotechnology objectives have progressed from quantities through qualities of industrial wood to the multiple products and services required for nation development.

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Health of Cultivated Teak

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Pest Factor in the Intensification of Teak Cultivation: A Global Assessment

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ABSTRACT

Intensification of teak cultivation, in terms of intensive management of plantations with irrigation, high nutrients input and genetic selection for faster growth rate, on the one hand, and large-scale expansion of plantations into exotic locations, on the other, are both recent developments. Limited empirical data as well as theoretical considerations show that both generate the risk of new pest problems. Pest problems arising from intensive plantation management are not judged to be serious, but expansion of exotic plantations could lead to serious outbreaks of the defoliator, *Hyblaea puera*, which is a well-known pest of native teak plantations in Asia. Although known to occur both in Africa and Latin America on other host plants, *H. puera* had not become a pest of teak in these regions until its outbreaks appeared all of a sudden in teak plantations in Costa Rica in 1995 and Brazil in 1996. Theoretical considerations suggest that the extent of plantation area is one of the main factors that determine the risk of pest outbreaks in exotics. Regular outbreaks of *H. puera* in teak plantations in Latin America appear imminent and their occurrence in Africa in the future cannot be ruled out. As in indigenous plantations, defoliation will not kill teak trees, but will cause loss of over 40% of the annual volume increment of the plantations. Research is needed to elucidate the conditions which lead to development of outbreaks of this serious pest.

Keywords: Teak plantations, teak defoliator, *Hyblaea puera*, pest outbreaks, exotics

INTRODUCTION

The teak tree, *Tectona grandis* L.f., whose natural distribution was limited originally to some parts of south and southeast Asia, is now one of the most widespread tropical tree species, thanks to plantation silviculture and the unique quality of teak timber. Over the years, it has been planted, as an exotic, in over 66 countries spread across the tropical and subtropical regions in the Asian, African and American continents as well as many islands in the Pacific and Atlantic oceans. In 1995, the global area under teak plantations was estimated at 2.25 million ha, most of it (94%) in the Asian tropics (Ball *et al.*, 1999). But since the past decade, there has been an unprecedented intensification of teak cultivation, particularly in Latin America, largely promoted by commercial enterprises. This intensification of teak cultivation has two dimensions – intensive management of the plantations and expansion of area under plantations. Intensive management includes irrigation, high input of nutrients and genetic selection of planting stock for faster growth rate. Generally, the success of exotic plantations is attributed to their freedom from insect pests present in their native habitats although there is the lingering fear that the native pests will catch up with exotic plantations sometime or other and when they do, they can be more devastating, in the absence of their natural enemies. Unfortunately, the pest factor is often ignored in plantation planning and management. Plantation managers have a tendency to ignore specialists other than economists and silviculturists, and specialists themselves have a tendency to ignore disciplines other than theirs. Even the International Teak Provenance Trial organized by DANIDA, with 64 provenances planted at 50 sites in 16 countries (Keiding *et al.*, 1986) did not pay sufficient attention to the pest factor. Although tree health was one of the eight characters assessed in this trial, the method suffered from lack of insight into the geographical spread and seasonal dynamics of the pests. The implications of the ongoing intensification of teak cultivation on the threat of pest outbreaks is examined in this paper, in the light of theory and indications from limited data. A broader study on pest outbreaks in exotic tree plantations of the tropics, including teak and other tree species, has been published elsewhere (Nair, 2001a) and some repetition of data and conclusions is unavoidable.

THE NATURAL AND PLANTED DISTRIBUTION OF TEAK

The natural distribution of teak is limited to approximately 25° to 9° North latitudes and 73° to 104° East longitudes, in two discontinuous patches, one in peninsular India and the other covering most of Myanmar, northern Thailand and a small part of northwest Laos (Kaosa-Ard, 1995; Guy and Tint, 1998). In terms of countries, it is indigenous to India, Myanmar, Thailand and Laos, and the total geographical coverage is about 28 million ha (Teaknet, 1995). Within Asia, there are two other regions where teak has become naturalized, presumably after early introduction from elsewhere. These are the Indonesian island of Java (together with some smaller islands east of Java) and the western part of the Yunnan Province of China. The planted distribution of teak covers at least 66 countries in the tropical and subtropical belt across the world as listed in Table 1. In 1995, 94% of the 2.25 million ha of planted teak were still within Asia, with at least 145,000 ha in Africa and 65,000 ha in Latin America. It may be seen that the planted area is highest in Asia-Pacific, followed by Africa and then Latin America.

Table 1. Exotic teak plantations across the world and distribution of *Hyblaea puera*[1]

Asia-Pacific		Africa		Latin America	
Country /Territory	**Area**	**Country /Territory**	**Area**	**Country /Territory**	**Area**
Australia*		Benin	15,000	Argentina	
Bangladesh*	165,000	Congo (Dem. Rep.)		Belize	
Bhutan		Congo		Brazil*	1,500
Cambodia*		Cote d' Ivoire	26,000	Chile	
China*	9,000	Gabon		Colombia	
Fiji*		Ghana	25,000	Costa Rica*	
Indonesia*	1,066,530	Guinea		Cuba*	
Japan*		Kenya		Dominican Republic*	
Korea (North & South)		Liberia	1,500	El Salvador	20,000
Malaysia*	4,328	Madagascar		Ecuador	
Nepal*		Malawi*		Honduras*	400
Oman		Mozambique		Jamaica*	250
Pakistan		Namibia		Mexico	
Papua New Guinea*	4,000	Nigeria	40,000	Nicaragua	10,000
Philippines*	21,550	Senegal	8,000	Panama	300
Ryukyu Islands[2]*		Sierra Leone		Peru	
Samoa*		Somalia		Puerto Rico	
Solomon Islands*	1,000	South Africa*		Suriname	
Sri Lanka*	72,000	Sudan	15,000	Trinidad and Tobago*	9000
Taiwan*		Tanzania	3,000	Uruguay	
Turkey		Togo	11,000	Venezuela	3,000
Vanuatu		Uganda*			
Vietnam*	2,037	Zambia			
		Zimbabwe			
All	**<1,345,445**	**All**	**> 144,500**	**All**	**>64,540**

[1] Planted area is given where fairly recent information is available. Countries in which *Hyblaea puera* has been recorded (on any host plant, not necessarily on teak) are marked with an asterisk. For primary data source see Nair (2001b).
[2] Whether teak occurs in Ryukyu Islands is not known.

CURRENT PEST PROBLEMS IN NATIVE PLANTATIONS

'Native plantations' refer to plantations raised in countries where teak is indigenous, i.e., India, Myanmar, Thailand and Laos. In these countries, monoculture teak plantations have been in existence for 100 to 150 years. A large number of insects have been found feeding on the living teak tree in these countries – 187 species in India (most of these also occur in Myanmar) and 72, in Thailand (Mathur and Singh, 1960; Hutacharern and Tubtim, 1995). The majority of these insects are leaf feeders, with a smaller number of sap feeders, stem borers, inflorescence and fruit feeders and root feeders. Most of these species occur in small numbers and cause only minor damage. Minor pests are not discussed here; for details on them see Mathur (1960) and Nair (2001a). A few insect species which have become serious pests are listed in Table 2. They can be categorized into two groups – defoliators and trunk borers.

Defoliators

The teak defoliator, *Hyblaea puera* is the most widespread and serious pest of teak. Outbreaks occur almost every year in India, over extensive areas. During these outbreaks which occur mainly during the early flushing period of teak, trees usually suffer total defoliation, sometimes repeatedly, and usually there is partial defoliation later in the growth season (Beeson, 1941; Nair 1988). Annual outbreaks are also known to occur in Myanmar and Thailand. Studies in young teak plantations at Nilambur in southern India showed that defoliation by *H. puera* caused loss of 44% of the potential wood volume increment (Nair *et al.*, 1996).

Another defoliator, known as teak skeletonizer, is also common in native teak plantations. Skeletonizer outbreaks occur in most years during the later part of the growth season, with exceptionally heavy outbreaks in some years. The insect is prevalent in India, Myanmar and Thailand and the species in all the three countries was known as *Eutectona machaeralis* (syn: *Pyrausta machaeralis*, *Hapalia machaeralis*). Recently, Intachat (1998) showed that the teak skeletonizer in Thailand is probably not *E. machaeralis* but a closely related species, *Paliga damastesalis*. The impact of this late-season defoliation on growth of the tree has not been critically investigated.

Trunk borers

Second in importance, in terms of damage caused, is the trunk borer, *Xyleutes ceramicus*, known as beehole borer. It occurs in Myanmar and northern Thailand. In some plantations in northern Thailand, 87 to 100 per cent of the trees are infested, the proportion of infested trees increasing with age (Chaiglom, 1990; Hutacharern, 2001). Heavily attacked trees die in course of time. *X. ceramicus* does not occur in India, but another cossid, *Alcterogystia cadambae*, of similar habits, is present in southern India where it causes similar damage

Table 2. Major pests of teak in native plantations

Pest category	Species	Countries of occurrence	Common name/Remarks
Defoliators	*Hyblaea puera* (Lepidoptera, Hyblaeidae)	Myanmar, India, Thailand, Laos	Teak defoliator
	Eutectona machaeralis (Lepidoptera, Pyralidae)	Myanmar, India	Teak skeletonizer
	Paliga damastesalis (Lepidoptera, Pyralidae)	Thailand	Earlier identified as *E. machaeralis*
Trunk borers	*Xyleutes ceramicus* (Lepidoptera, Cossidae)	Myanmar, Thailand	Beehole borer
	Alcterogystia cadambae (Lepidoptera, Cossidae)	India	Similar in habits to beehole borer

in endemic patches (Mathew and Rugmini, 1996).

CURRENT PEST PROBLEMS IN EXOTIC PLANTATIONS

'Exotic plantations' refer to plantations raised in countries where teak does not occur naturally. Exotic teak plantations have a history of 60 to 100 years. Their pest problems are best examined separately for the three major regions.

Asia-Pacific

Exotic teak plantations occupy about 1.35 million ha in the Asia-Pacific, of which about a million ha are in Indonesia (Table 1). In these exotic teak plantations, the major pests are the teak defoliator, *H. puera,* the skeletonizer, *E. machaeralis* or *P. damastesalis,* and a wood-dwelling termite, *Neotermes tectonae* (Isoptera, Kalotermitidae). *N. tectonae,* recorded only from Indonesia, hollows out portions of stem and branches and the infestation shows up as swelling of trunk and branches. It is recognized as a serious problem in Central and East Java.

Pests of lesser importance are an ambrosia beetle, *Xyleborus destruens* (Coleoptera, Scolytidae) which attacks the trunk of the living tree, making tunnels that extend into the heartwood (in Indonesia), the beehole borer, *X. ceramicus* (in Indonesia and Malaysia), the sapling borer, *Endoclita gmelina* (in Malaysia), the sapling borer, *Zeuzera coffeae* (in Indonesia and many other countries), the teak canker grub, *Acalolepta cervina* (in Bangladesh) and whitegrubs in nurseries (in Sri Lanka and many other countries). It may be noted that all except the wood-dwelling termite are present in native plantations also.

Africa

Teak plantations occupy at least 145,000 ha in Africa (Table 1). No major pest problem has so far been reported in spite of the long history of planting. Two small beetle borers, *Apate monachus* and *A. terebrans* (Coleoptera, Bostrychidae) were recorded from live trees in Ghana, but the infestation is believed to have originated from cut sticks of some windbreak species stored at site (Atuahene, 1976). Another small beetle borer, *Hypothenemus pusillus* (Coleoptera, Scolytidae) was also recorded on the shoot of *T. grandis* in Ghana (Cobbinah, 1972).

Latin America

Teak plantations in Latin America occupy at least 45,000 ha (Table 1). Although teak was introduced into Trinidad in 1913 and commercial plantings were raised in Brazil in 1971, there has been no major pest damage until 1995. In Costa Rica, outbreak of the teak defoliator, *H. puera* first appeared in 1995 in a commercial plantation and has progressively intensified, with about 600 ha infested in 1998, with some patches suffering total defoliation, necessitating helicopter application of insecticide (Camacho, 1998). In Brazil, the first attack was reported in 1996, in a commercial plantation, in a small area within 16 to17-year old teak plantations. In 1997, the outbreak spread to almost the entire 309 ha plantation, 16 to 24 years old. In 1998, the attack reached a small area of another plantation, located 150 km from the first one. No attack occurred in 1999 (Torres, 2000).

Minor pests of teak in Latin America include leaf cutting ants, *Atta* spp., in nursery and older plants, two cerambycid borers, *Neoclytus cacicus* and *Plagiohammus spinipennis* on young plants (CATIE, 1992) and whitegrubs in nursery. In addition, the small beetle borer, *Xyleborus morigerus* (Coleoptera, Scolytidae) has been reported on young plantations in Mexico (Vazquez, 1980). The damage caused by these insects is negligible.

PREDICTING FUTURE PEST PROBLEMS

Given the historical development of pest problems in teak plantations, their present status and recent trends, the direction in which teak cultivation is progressing, and the basic understanding of the principles governing the development of forest pest problems, it is possible to anticipate the future pest problems. Undoubtedly, there is an element of risk in such predictions. But as someone said, the best predictions are those that never come true because they are acted upon in time. That is sufficient justification for attempting the prediction, however crude it might be.

Factors controlling the development of pest problems in tropical forest plantations were discussed fully elsewhere (Nair, 2001a), based on the theory of insect population dynamics and available empirical data. Eight factors were identified to influence the risk of pest outbreaks in exotic forest plantations. These are (1) presence in the location of introduction, of other tree species closely related to the introduced exotic; (2) extent of area occupied by the exotic species; (3) genetic base of the planted stock; (4) distance from the native habitat of the exotic; (5) existence of serious pests in the native habitat of the exotic; (6) time elapsed since introduction; (7) chemical profile of the exotic species; and (8) innate biological attributes of the insects associated with the tree species. These considerations form the theoretical basis for the following discussion and conclusions.

Effect of intensive plantation management

Intensive management of plantations leads to better growth of the trees, with almost continuous flushing throughout the year and succulent shoots. New pest problems can arise as a result of this. Greater incidence of the sapling borer, *Z. coffeae* was noticed in young intensively managed plantations in agroforestry plantings in Kerala, India (unpublished pers. obs.), in agroforestry plantings in Central Java, Indonesia (Nair, 2001a) and in commercial plantations of Sterling Tree Magnum Ltd. (STM) in Tamil Nadu, India (Varma *et al.*, 2001). This borer prefers tender succulent stems of teak. The skeletonizer, *E. machaeralis* is prevalent only during the later part of the growth season in unirrigated plantations, but in irrigated STM plantations in Tamil Nadu and Andhra Pradesh in India, it was prevalent throughout the year (Varma *et al.* 2001; Loganathan *et al.*, 2001). A new pest, *Helicoverpa armigera* (Lepidoptera, Noctuidae), feeding on the terminal shoot of teak saplings has recently been recorded from intensively managed STM plantations in India (Varma *et al.*, 2001).

These preliminary observations indicate that new pest problems are likely to arise in intensively managed teak plantations. Continuous flushing of the normally deciduous teak is one major change brought about by irrigation. This can favour better survival of leaf-feeding insects such as *H. puera, E. machaeralis,* and others, but its effect on pest population dynamics is uncertain because of a large number of interacting factors like natural enemy effects and interspecies competition. Although some of the existing phytophagous insects may become more prevalent as a result of improved food availability, it seems unlikely that any new major pest problem will arise because of intensive management. The effect will be the same in both native and exotic plantations. However, to be on the safer side, it seems best to allow the trees to retain its natural deciduous habit, by withdrawing irrigation for a short period. If substantial gain in growth is obtainable through uninterrupted irrigation, large-scale field trials may be run to investigate its effect on pest incidence, before it is practised routinely.

Effect of expansion of planted area

Native plantations

Plantations already occupy substantial area in the countries where teak is indigenous, except in Laos. The defoliator, *H. puera;* the skeletonizer, *E. machaeralis* or *P. damastesalis;* and the trunk borer *X. ceramicus* or *A. cadambae* will continue to be the major pests wherever they are now prevalent in these countries. No major change in pest situation is expected due to further expansion of the planted area.

EXOTIC PLANTATIONS

Asia-Pacific

The three serious pests of native plantations are already present in some of the countries, as discussed earlier, obviously because within the Asia-Pacific region, the distance between the location of introduction of teak and its native habitat is short. No change is anticipated with further expansion of planted area. The wood-dwelling termite, *N. tectonae,* an indigenous pest observed in Indonesia, appears to be endemic to some parts of Java and is unlikely to spread to other areas.

AFRICA AND LATIN AMERICA

In Africa and Latin America, as discussed earlier, currently there is no serious pest problem for teak.

However, the threat of the defoliator, *H. puera* is very real, particularly for Latin America. The beginnings of the outbreak have already been witnessed in Costa Rica and Brazil. The spread of *H. puera* on teak in Latin America does not appear to be due to its accidental introduction from the Asia-Pacific, but to development of pest status by populations of *H. puera* already present in the region, on other hosts. The natural distribution *H. puera* covers not only Asia-Pacific but also Africa and Latin America (Table 1), although until recently its outbreak on teak had occurred only in some countries in the Asia-Pacific. Fig. 1 shows the world distribution of *H. puera* along with the natural and planted distribution of teak. In Africa, it is known to occur in Uganda, Malawi and South Africa (CIE, 1982) and in Latin America, in Honduras, Cuba, Dominican Republic, Jamaica, Trinidad and Tobago (CIE, 1982), Costa Rica (Camacho, 1998) and Brazil (Torres, 2000). It may be more widespread in both the regions but we are limited by the availability of published information. *H. puera* can thrive on at least 30 host plants (Nair, 1988), mostly belonging to the families Verbenaceae and Bignonaceae and at least one each in the families, Araliaceae, Avicennaceae, Juglandaceae and Oleaceae. In Latin America, it has been recorded on *Vitex parviflora*, *Tabebuia pentaphylla* and *Catalpa longisiliqua*. According to Torres (2000), it has been present in Brazil for a long time, causing damage to native vegetation. It is intriguing that although commercial plantations of teak have been raised in Brazil since 1971, the first *H. puera* outbreak on teak occurred only in 1996. Similarly, although teak was introduced into Trinidad as early as in 1913 (Keogh, 1996), with at least 9,000 ha of plantations existing now, no outbreak of *H. puera* on teak has been recorded in that country so far. These observations suggest that the recent outbreak is the result of expansion of area under teak cultivation. There is only circumstantial evidence to support this view but it is logical to expect that unlimited availability of the host plant over contiguous areas can promote the survival and multiplication of the insect in various ways. Greater effort is needed to understand the dynamics of the teak defoliator outbreaks and its relationship with weather factors, alternative hosts and extent of area under teak. Although there are indications that the monsoon system may play a role by signalling outbreak initiation, concentrating the air-borne moths and transporting them over long distance along the wind front (Nair, 1998), the circumstances leading to outbreak development are still not fully understood.

Outbreaks of *H. puera* have not so far been recorded on teak plantations in Africa (Cobbinah, 1997), but

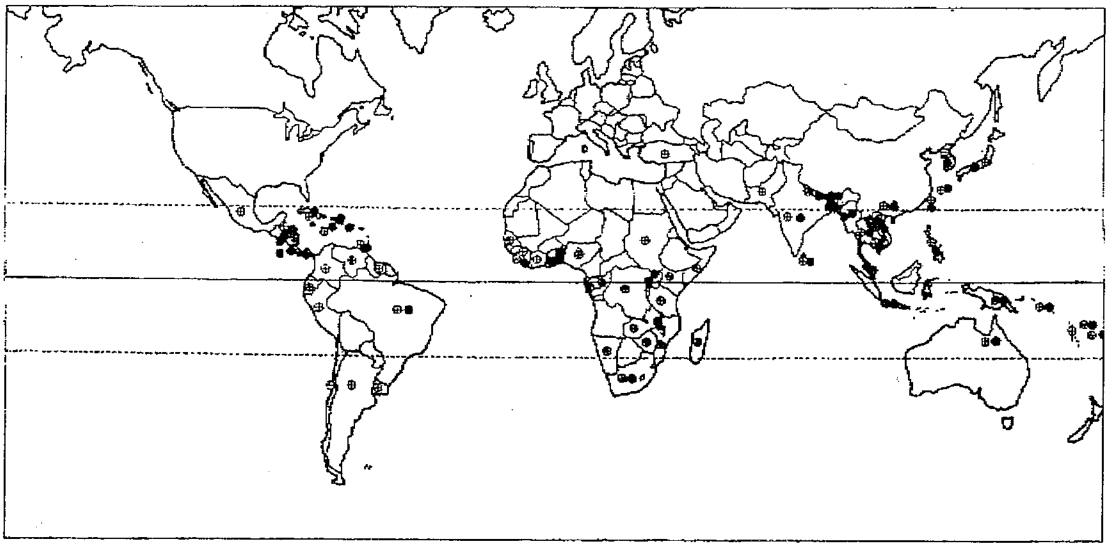

Figure 1. World distribution of teak (natural and planted) and the insect, *Hyblaea puera*. Circles with cross lines indicate teak and closed circles, *H. puera*.

this is no guarantee that it will not occur in the future. The pest and the host are already present in Uganda, Malawi and South Africa. No information could be obtained on the extent of area under teak in these countries. It is not unlikely that with expansion of area under teak, outbreaks of *H. puera* may also develop in Africa. Rain- and wind-aided migration and outbreaks of the armyworm, *Spodoptera exempta* (Lepidoptera, Noctuidae) is known to occur in East Africa (Rose *et al.*, 1987) and it has many similarities to *H. puera* outbreaks. It is clear that the mere co-occurrence of the pest and the host is not sufficient condition for development of pest outbreaks. Even within the Asia-Pacific, outbreak of *H. puera* has not been reported in a few private plantings and trial plots of teak in Australia, although the insect is known to occur on *Vitex trifolia* (Verbenaceae), a common straggling shrub in coastal Queensland and the Northern Territory (Wylie, 2000).

In conclusion, regular outbreaks of *H. puera* in teak plantations in Latin America appear imminent and their occurrence in Africa in the future cannot be ruled out. Further research is needed to elucidate the conditions which lead to development of outbreaks of this serious pest. As in indigenous plantations, defoliation will not kill teak trees, but will cause loss of over 40% of the annual volume increment of the plantations.

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Tree Health of Teak in Central Part of India

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ABSTRACT

Tectona grandis (Teak) is one of the important tree crops of central India. Its large scale plantations are raised by the state forest departments even by the some of the progressive tree planters. In order to have the faster growth of teak high input in the form of chemical fertilizers, organic compost, biofertilizers and irrigation are used. Though it is a very hardy species but it is prone to be damaged by the number of fungal pathogen started from seeds. Seed borne *Fusarium pallidoroseum* caused heavy mortality in nursery bed. A number of pathogens are responsible for damaging the teak plants by causing root diseases, stem and branch canker and die back, collar rot, heart rot in dry coppice teak and mortality in natural teak forests. *Amylosporus campbellii* root rots and as well as *Fusarium pallidoroseum* canker and *F. oxysporum* root rot in high input plantations are newly reported. Two bacterial diseases in nursery and plantations also caused considerable losses. Some of the established control / managements tactics were also described.

Keywords: Teak, *Tectona grandis*, Central India, pathogens

INTRODUCTION

Teak (*Tectona grandis* L.f.) is one of the most important and valuable timber species of India and, therefore, due importance has been given to raise its plantations by forest departments. Of late, many private companies also have started rising teak plantations through investment from public with a promise of higher returns. For the success of teak plantations, losses due to various abiotic and biotic factors such as failure in establishment, vagaries of weather, natural calamities, fire, insect pests and diseases must not cross the acceptable limits. Of these, diseases are known to be the most destructive agents adversely affecting the planting stock in nurseries and consequently the plantation yield and thus, directly affecting the overall productivity targets. Diseases of teak are mostly those described from India. Large-scale mortality in teak has been reported from various part of India. The mortality is recorded in natural teak forest and also in coppice teak forest.

SEED DISEASES

Seeds of teak are required in large quantities every year to raise planting stock. To meet the plantation targets, seed storage is an essential requirement and seed should be free from pathogens. Fungi, belonging to various groups, cause seed diseases and significantly affect seed development and germination. Jamaluddin (1999) has given a comprehensive account of forest seed pathology in India. Studies on teak seeds have been conducted by many other workers also and fungi have been found responsible for causing diseases. Sharma and Mohanan (1980) noticed 24 genera of fungi from teak seeds, out of which *Alternaria, Curvularia* and *Fusarium* were found to cause mortality in seedlings. *Fusarium pallidorosum* (Cooke) Sacc is the most common seed rot pathogen of teak, which causes root rot of seedlings (Jamaluddin *et al.*, 1997). Harsh *et al.* (1994) have isolated eighteen species of fungi, of which fifteen were found associated with pollen grains, ten species with fruits, nine species were ectophytic and twelve were endophytic on teak seeds. They concluded that fungi infect the seeds through pollen grains and some fungi are responsible for killing the developing ovules and, therefore, for emptiness of the locules in teak fruit. Weathering of teak fruit was done by using cellulolytic fungi like *Scytalidium, Trichoderma,* etc. (Dadwal and Jamaluddin, 1988).

BACTERIAL DISEASE IN NURSERY

This disease has a wide distribution in the tropics and warmer parts of the temperate zone. The wilt pathogen *Pseudomonas solanacearum* (Smith) Smith has a wide host range of which solanaceous plants are more susceptible (Bakshi, 1976). Bacterial collar rot, earlier described as a wilt of teak seedlings, is now recognized as collar rot due to primary bacterial colonization in the collar region. *P. solanacearum,* a soil bacterium enters through the collar tissues and colonizes the entire collar region. Later on the bacterial population builds up and blocks the conducting tissues. In advance stages of infection, top leaves become flaccid and drop. Infected collar region starts shrinking and turns brownish black. Affected seedlings develop typical wilt symptoms and several patches of blackish brown dead seedlings can be noticed in nursery beds (Table 1).

Soni and Jamaluddin (1998) have recorded patches of 1 meter diameter in 10 x 1 m sized beds when infection was severe. This disease was caused by *Pseudomonas tectonae.* The affected tissues become flaccid and ultimately wilt symptoms developed and the seedlings died.

Incidence of bacterial collar rot in teak nurseries is generally recorded in beds that are water logged or with high soil moisture content. Saprophytic colonization of bacteria in dead root due to water logged condition is also examined.

BACTERIAL COLLAR ROT IN PLANTATIONS

Bacterial collar rot occurs in plantations where water accumulation is common. In this disease, the collar region becomes soft and rot develops in the bark very fast. The rot penetrates in wood too and the affected plants develop the sign of wilt (Table 2). "High-tech" plantations are more prone to this disease due to their fast growth, softening of tissues and lower lignification. The causal organism of this disease was identified as *Pseudomonas tectonae.*

PREVENTATIVE MEASURES

1. Since the disease is manifested mainly under water logged condition or high soil moisture regime the seed beds should be properly raised and levelled. Soil mix of seed beds should be loose and well drained. Clayey soil should be avoided in soil mix of teak beds.
2. Soil drenching with 1000 ppm plantamycin or oxytetracycline at 20 days interval (two treatments) is recommended in high rainfall areas or nursery sites near canal banks and

Table 1. Bacterial wilt

Bacterial Wilt	Damage	Symptoms	Control
Nursery	Lohara, Chandrapur – 50-60 % Raipur – 30 % Belkund, Jabalpur 25 % Kanchangaon, Mandla – 40-50 %	Wilt and root rot	Proper drainage in nursery beds and spray with 1000 ppm plantamycin / oxytetra cycline.

Table 2. Bacterial rot

Collar rot	Damage	Symptoms	Control
Plantations	Hoshangabad – 30 % Raipur – 25 % Sagar – 20 %	Collar rot	Proper drainage in plantation. Drenching with 1000 ppm plantamycim / oxytetracycline.

disease prone nursery sites where water logging is common.

3. The shoots of wilted plant should be removed and stumps dipped in 1000 ppm oxytetracycline solution and planted in polypot. They start sprouting after 20-30 days.

BACTERIAL LEAF CURL

In this disease, leaf become short, flaccid and crinkled. The growing apical part of the plants is seriously affected. The internodal distance becomes smaller, interveinal chlorosis is developed, the bacteria produces numerous water soaked specks, which later become brown surrounded by a halo and bacterial ooze is accumulated. The midribs and veins of leaves also become flaccid. There may be splitting of bark in the main stem of the plant and bacterial canker is developed. The disease is highly damaging in teak nurseries, high tech plantations and in plantations with water logging as is found in teak plantations and nurseries in north Bilaspur Division. The infection also developed during of heavy rains. Here, *Xanthomonas* species (*Xanthamonas melhusi* and *X. erythrinae*) were identified from the diseased leaves. Earlier this disease was reported by Patel *et al.* (1952). The disease can be controlled by spraying 1000 ppm plantamycin or tetracycline. The proper drainage should be maintained in the sites both teak nurseries and plantations.

LEAF SPOT DISEASES

Leaf spot of teak caused by *Phomopsis tectonae* is a common nursery problem. Initially, it appears as a minute scattered necrotic spot, which later on coalesces to form circular to irregular lesions. In the advanced stages of infection 50 per cent leaves get rotted due to this disease. This has been found to result in premature defoliation in 3 to 6 month old seedlings. Serious disease condition develops during warm and humid months specially in August and September. The diseases is also spread in tender shoots. Severity of disease causes considerable damage to the seedlings with reduction in photosynthetic area and premature fall of infected foliage (Dadwal and Jamaluddin, 1989). Disease can be minimized by applying Dithane M-45 0.2 per cent as monthly foliar spray from July to September in teak beds and one spray during July in plantations.

Among other foliar diseases powder mildew by *Uncinula tectonae*, leaf spots by *Cercospora tectonae, Dothiorella* sp., *Leptosphaerulina trifolii, Macrophomina phaseolina, Phoma exigua, Phyllosticta tectonae, Phomopsis variosporum, Colletotrichum* state of *Glomerella cingulata* and *Sclerotium rolfsii* are some important diseases of nursery seedlings and young plantations. The leaf spot diseases were controlled by spraying dithane M-45 at 0.2 per cent at monthly interval during humid months.

FUSARIUM OXYSPORUM AND ROOT ROT

Fusarium pallidoroseum cause canker in collar region and bark splitting. The roots are also infected and vascular blocking takes place. *Fusarium oxysporum* and *F. moniliforme* have been reported to cause mortality of teak seedlings in nurseries. Disease commonly occurs due to moisture stress.

HELICOBASIDIUM ROOT ROT

Helicobasidium compactum Boed causes the death of young teak in the east Indies, Tanzania and Sudan (Waheed Khan, 1964). It causes wilting of foliage followed by root death. Felty cinnamon brown to purple fungal mats may occur at the roots and stem bases of affected trees. In plantations, disease in patches is developed (Hocking and Jaffer, 1966). The spread of diseases may be arrested when dead and dying trees are removed, possibly as a result of admission of sunlight.

AMYLOSPORUS CAMPBELLII (BERK.) RYV. ROOT ROT

This new root rot infection was observed in 10 years old teak multiplication garden and also in plantations. The initial symptoms of disease showed yellowing of leaves followed by gradual dieback and finally death of plants. The infection vary in different places. The detail examinations of infected roots revealed the presence of characteristics rhizomorphs between the bark and the wood of the teak roots. The sprophores of this fungus appeared near the tree base (butt region), which is attached with on tuft of while net of rhizomorphs (Soni and Jamaluddin, 2002).

ROOT KNOTS BY NEMATODES

Root knots caused by nematodes, *Meloidogyne arenaria, M. hapla* and *M. javanica* have also been reported from forest nurseries of western U.P., Himachal Pradesh (Sharma and Mehrotra, 1992) and Madhya Pradesh. Fresh infection starts after a few monsoon showers in July and by October seedlings show maximum infestation. Infection was found low during summer.

RHIZOCTONIA LEAF BLIGHT

The disease is reported to occur in nurseries in Dehra Dun (Mehrotra, 1992, cited in Tewari, 1992). It is caused by *Rhizoctonia solani* Khun anamorph of *Thanatephorus cucumeris* (Frank) Donk. The pathogen attacks the leaves. The major symptoms are development of water-soaked greyish brown patches that enlarge rapidly and cover a large part or the entire lamina. The blighted leaves often develop holes in the infected portion as a result of shedding of infected tissues during heavy rains. The infected leaves dry up and are eventually shed. The disease spreads laterally in the nursery through overlapping foliage of the adjoining seedlings often resulting in group blighting of seedlings. In case of severe infection, defoliation is as high as 100 per cent. The disease is most damaging during heavy monsoon rains in August. The pathogen is a soil inhabitant, which on activation climbs up the stem and infects the leaves. It may also infect the plants when it is lodged on plant parts alongwith soil particles by splashing during rains.

OLIVEA LEAF RUST

The rust fungus *Olivea tectonae* (Racib.) Thirum. causes defoliation of nursery seedlings and young plants in India. Infected leaves appear grayish on the upper surface, with pustules of orange brown spores on the under surface which are air borne and spread infection directly between teak plants (Thirumalachar, 1950). *Olivea tectonae* is an obligate pathogen confined to teak and unable to survive as a saprophyte; no alternative or collateral host is known. The rust infection is affecting the nursery plants to spore economic level compared to teak plantations.

The disease is favoured by hot dry weather and can cause serious loss in increment. Control is obtained by opening up the crop by thinning or pruning. In nurseries the rust was controlled by foliar spray of sulphur based fungicides (Khan, 1951; Bakshi *et al.*, 1972).

POWDERY MILDEW

Three members of powdery mildew fungi have been recorded in teak. *Uncinula tectonae* Salm cause powdery mildew on teak (*Tectona grandis* L.f.) which is widespread in M.P., Maharashtra, Gujarat and Orissa in nurseries and in plantations of different age groups. The upper surface of the infected leaves is covered with white mycelium containing black fruiting bodies of the fungus and presents a bluish grey mealy appearance. The causal fungus has been identified as *Uncinula tectonae* Salm. It may affect the photosynthetic activity of the plant. It occurs late in September or from October, and may cause early defoliation. The leaf surface appears bluish grey mealy due to development of cleistothecia.

PHOMOPSIS DIE-BACK AND CANKER IN TEAK

Large scale afforestation has been undertaken by Maharashtra Forest Development Corporation under teak improvement programme (Oka, 1986). Clonal teak seed orchards have also been raised using different clones collected from different states in India. During the survey of diseases in Chandrapur, mortality in three year old teak plantation was recorded at Janona centre. Canker was also noticed in twigs and branches in clonal teak seed orchard. The disease was caused by *Phomopsis tectonae*. It has also been noticed in nurseries and plantations of teak in M.P. Earlier Tiwari *et al.*, (1981) had reported *Phomopsis tectonae* causing leaf spot disease in *Tectona grandis* at Jabalpur. Patch dying was recorded in teak plantations due to this disease.

The disease was sporadic in Comptt. No. 488 at Janona Centre, Chandrapur. In a diseased patch 17 plants were completely dead while 108 plants were showing partial drying (half dead) symptoms out of 150 plants examined during August – September 1985. The disease was also detected during 1986 and sporadic mortality i.e. 3 to 6 percent could be recorded. This confirmed the annual occurrence of disease. This disease was also recorded from Raipur, Bilaspur, Sagar (M.P.). Detailed study was conducted for evaluating the disease situation, its symptoms, pathogenicity, epidemiology and control through application of fungicides (Dadwal and Jamaluddin, 1989). It could be controlled by spraying Dithane M-45 0.2 percent, cutting back of infected plants during April and May or during October / November and burning of leaf litter. The coppice shoots with high vigour should be allowed to grow. The disease was noticed during July to September. The climatic data indicated gap in rainy days and sudden increase in temperature during these days, which favoured the disease development. Warm and humid conditions favoured the disease development.

LEAF SPOTS

The infection was scattered all over the lamina. The spots on leaves first appeared as small white dots, which later on increased in size. The spots were generally surrounded by brownish margin and two or three concentric rings developed. Sometime two or more spots coalesced to form a larger spot. Small dot like pycnidia of the fungus appeared on the upper surface of the leaves. The infected area became brittle and easily shed off.

DIE BACK

The affected plants died from top to downwards. The tender shoots first got infected by the pathogen; later on the infection moved downward causing death of the plant. The bark of the stem splitted due to attack of the pathogen. The black pycnidia were noticed under the splitted bark. In some cases cracks in the bark were also noticed. The process of dying was so rapid that the dried leaves were found attached with the plants. The leaves also exhibited the infection *P. tectonae*.

Canker in twigs and branches

Development of canker was observed in twigs and the leader branches in different clones of teak in the teak seed orchard (TSO) at Chandrapur (M.S.). *P. tectonae* established infection in leaves also. Initially, infection developed in the leaves of the trees in the TSO which later spread in twigs and branches. The infection in twigs and branches killed the bark. The cankerous growth formed the boundary of sunken dead bark or exposed wood due to withering of bark. Small pin head size pycnidia of the pathogen were also detected.

The observation made in TSO at Chandrapur (1974 – 1980) indicated that only very few teak clones of M.P., Maharashtra, Gujarat, Arunachal Pradesh and Karnataka exhibited the infection while several teak clones of other states exhibited infection. The fungus could not kill the whole plant but it affected flowering. The fungus easily killed the young plants of 3 to 5 years in plantations.

OBSERVATION ON COPPICE TEAK PROBLEM IN HOSHANGABAD CIRCLE

The problem of coppice shoots was observed in felling coupes of different years in Temagaon and Rahatgaon Ranges of Harda Forest Division in Hoshangabad Circle. Most of the forests in these ranges have been categorized as teak forests with 70-80% teak. These teak forests appear to be of coppice origin of two or more rotations. These forests are presently being managed under coppice with reserve system (CWR).. Natural regeneration of teak is almost negligible or absent in this area. The problem of coppice development in saw-felled stumps was more as compared to axe-felled stumps. This problem was reported by Conservator of Forests, Hoshangabad Circle.

The callus shoots shows vigorous initial growth but after some period their growth retards. They are also easily subject to fall on the ground and become detached from the parent stool due to some shock or injury particularly due to biotic interference, high wind and wild life. As the callus shoots originate from the callus tissue in the stumps, they do not develop their independent root system and they have to depend for a longer period upon parent stump for nourishment. However, sawn stumps dressed with axe exhibited improved coppicing over only sawn ones.

In the management of teak coppice crop two side shoots are selected on a single stump and retained for future crop and these shoots are likely to grow healthy.

HEART ROT

Heart rot is the greatest single cause of damage to forest trees. Jamaluddin *et al.* (1985) reported heart rot in a large number of hardwood species in central India and estimated the losses. Harsh and Tiwari (1995) have estimated that nearly 38 % to 88 % teak trees were affected by heart rot entailing an average loss of about 11 % in wood volume in Madhya Pradesh *Perenniporia tephropora* (Mont.) Ryv. and *Phellinus caryophylli* (Cooke) Ryv. have been identified as the causal heart rot fungi.

HEART ROT IN DRY COPPICE TEAK

Decay in dry coppice teak in Gujarat, Maharashtra and Madhya Pradesh has been found in callus shoots originating from stools having decaying heart wood. The dry teak forests are worked under coppice system on a rotation of either 30 or 50 years. At the end of rotation, trees commonly exhibit hollowness (heart rot) at all base and which often extends up to varying heights (2 – 4 meters) in the stem. In the system of coppicing at ground level, incidence of decayed trees is high because the system encourages development of callus shoots, while side shoots are fewer due to cutting away of dormant buds. A coppicing height 10-15 cm was found ideal for encouraging development of low side shoots which have less chances of infection from mother stool (Bakshi *et al.*, 1972; Jamaluddin *et al.*, 1986). The unsoundness is due to decay in the heart wood, exhibited either by complete decay in the heart wood or by leaving a margin of apparently unaffected heart wood. The sap wood is sound and healthy. At the advanced stages of decay in heart wood (white and spongy rot), the rotten wood disintegrated and shed off leaving a clean hollow bole in the centre. The trees continue to survive with struggle (Bakshi *et al.*, 1972; Bakshi, 1957).

In coppice teak forest, the incidence of heart rot in stools is generally high. The forests which are worked out on a short rotation age of about ten years, mainly for small poles, may continue to be managed because the decay in the stool will not migrate in the coppice at that age when no heartwood develops in the later, but the incidence of decay is high with increase in rotation age. In such cases, the area is naturally regenerated and when the seedlings are established, the coppice trees may be felled and the stools are prevented from further coppicing by girdling the stool to a depth of 5 cm and killing the effective tissue which develops coppice with poison like 2,4-D.

PROBLEM OF TEAK MORTALITY IN CENTRAL INDIA

Mortality of teak (*Tectona grandis*) has become a common phenomenon in all teak growing areas of Central India. Like the mortality of sal (Prasad and Jamaluddin, 1986), large scale teak drying has attracted the attention of foresters, ecologists, forest based industries utilizing teak (particularly plywood manufacturing industries) and others. Though Khan and Yadav (1961) had reported mortality of teak in the seventies but the problem became more acute during 1979 – 1981. Chowdhary (1986) reported the case of teak drying from Melghat forests of Maharashtra. Large scale drying of teak was reported in Madhya Pradesh and Maharashtra State.

SYMPTOMS OF MORTALITY

Teak mortality was found occurring in trees of all age gradations (girth class), though the extent of mortality was observed to be more in middle aged trees (45 to 100 cm g.b.h.) than in very young or very old trees. Most of the trees, which had deve-loped heartwood, exhibited the dying phenomenon. The saplings and coppice plants without heartwood did not exhibit any sign of top dying. The top and side branches start drying and the leaves of the affected tree turn yellow and eventually dry. At advanced stages the top and the side branch exhibit moribundicity and half-dried trees remain standing. Finally, the whole tree dries starting from top and going downward (Table 3). The tree top and also the side branches exhibit rot in the heartwood. In few cases, the coppice plants exhibited signs of heart rot. The fire scars at tree bases were prevalent and loss in the wood was also noticed. The dried trees exhibited

Table 3. Average drying of teak in central India

Forest Division	Year of Mortality	% Mortality	Girth Class affected (GBH) cm	Total No. of Plants Died
East Melghat	1987	3 – 7 *	45 – 136	6590
Betul	1979	30 – 45	31 – 130	—
Khandwa	1986	30 – 50	31 – 130	19,00 (In Mundi Range)
Sagar	1983	25 – 45	31 – 130	13,753 (In Rehli Range)
				35,677 (In Gaurjhamar Range)
Damoh	1982	20 – 40	31 – 130	30,469 (In Singrampur Range)
				1,473 (In Damoh Range)
Balaghat	1983	15 – 35	45 – 130	Pendra Block
Seoni	1982	10 – 20	31 – 125	—

dry rot symptoms in the heartwood. Epicormic branches developed in moribund plants and also in half dead plants, which were killed during one season. Teak plants both of coppice and seedling origins exhibited drying but the condition was more alarming in coppice plants. Due to repeated coppicing, vigour of the plant is lost and ultimately they are affected by drought and fire, etc.

The root systems of the affected trees, both completely and partially dried, were examined. It was found that the root system of coppice tree was poor, shallow and unsound. Sometimes, fire scars and dry rot were also noticed. Few trees of seedling origin, which were in grip or drying phenomenon, were also examined. It was found that in these plants root system was generally more sound and such condition was noticed only in a few cases.

Drying of teak was quite common in areas where bamboo had flowered gregariously. Bamboo dying after flowering exposed the ground for desiccation. The mortality percentage was higher on river and nallah sides. It is presumed that due to heavy rainfall, the nutrient and soil cover was washed away. Soil was exposed and desiccated which affected the plants adversely.

DISEASE MANAGEMENT

Management of disease is necessary to minimize the losses through chemical, biological, cultural and silvicultural measures. The diseases in nurseries and plantations are being controlled through different management tactics like use of quality seeds; modification in cultural practices; use of graded seedlings for plantations, proper plant density; silvicultural measures; eradication of infected root stumps and alternate or collateral hosts; use of resistant species; biocontrol through mycorrhizae, antagonistic microorganisms and hyperparasites, and use of fungicides. There is need to gather information based on understanding and consideration of biological, economical, social and environmental processes, which will provide the basis for integrated pest management as a part of over all forest management. The integration of such control practices gives better protection against pathogens. The strategies for integrated disease management include avoiding, excluding and eradicating the pathogen; protecting the host from infection; developing resistant hosts and killing the pathogens in infected hosts. The disease causing organisms interfere with the management practices and involve risks or uncertainty in decision making. Integration and manipulation of all the available control measures to get a healthy crop of plants in keeping the disease below the economic threshold level at an effective cost is, therefore, required for overall management of tree species.

Integrated management of diseases

Losses caused by many forest diseases can be effectively minimized through management practices that promote tree and stand vigour under different site and stand conditions (Jamaluddin, 1992). The diseases in nurseries and plantations are being controlled through different management tactics like use of quality seeds in nursery,

Table 4. Diseases of *Tectona grandis* seed, nursery and plantations and control measures

Diseases	Pathogen	Symptoms	Control measures
Teak seed	*Fusarium oxysporum*	Root rot & wilt	Seed treatment with captaf
	F. pallidososeum	— do —	or thiram @ 3g/kg.
	Aspergillus niger	Seed rot in storage	— do —
	A. flavus	— do —	Seed storage in dry containers, seed
	Penicillium sp.	— do —	treatment with thirum @ 4g/kg during storage also effective.
Teak nursery	*Cercospora tectonae*	Leaf blight	Spray dithane M-45 0.2 %
	Dothiorella sp.	Leaf spot	— do —
	Fusarium moniliforme	Wilt	Soil drench with Bavistin 0.2 %
	Lepiosphaerulina trifolii	Leaf spot	Spray Dithane M-45 0.2 %
	Macrophomina	Leaf blight	— do —
	phaseolina	Leaf blight	— do —
	Phoma exigua	Leaf spot	Spray Benlate or Bordeaux mixture 0.1 %
	Phyllostica tectonae	Leaf spot	Dithane M – 45 0.25 %
	Phomopsis tectonae	Leaf rust	Spray 0.2 % sulfex.
	Olivea tectonae	Powdery mildew	Sulphur fungicide 0.3 %
	Unciunla tectonae	Wiltand leaf	Oxytetracycline 1000 ppm
	Pseudomonas tectonae	crankling	Spray of Dithane M-45 0.2 %
Teak plantations	*Cercospora tectonae*	Leaf spot	— do —
	Leptosbaerulina trfolii	Leaf spot	— do —
	Olivea tectonae	Leaf rust	— do —
	Phoma exigua	Leaf spot	— do —
	Phomopsis tectonae	Dia-back	— do —
	Phyllosticta tectonae	Leaf spot	— do —
	Uncinula tectonae	Posdery mildew	Spray Caliixin 0.2 %
	Helicobasidium	Collar rot & root	Removal of fruit bodies infected plants
	compatum	rot	— do —
	Amylosporus campbellii	Root rot	

modification in cultural practices, use of graded seedlings for plantations, proper crop density, silvicultural measures, eradication of infected root stumps and alternate or collateral hosts, use of resistant species, biocontrol through mycorrhizae, antagonistic organisms and hyperparasites and use of fungicides. In some cases integration of two or more such control practices are required and other amendments are needed to increase the vigour of tree species to avoid pathogen attack. However, before applying any control measure, assessment of losses from the diseases is essential.

The major objectives in disease management are prevention of losses and reduction in cost of control operations. The strategies for integrated disease management include avoiding, excluding and eradicating the pathogen, protecting the host from infection, developing resistant hosts and killing the pathogens in infected hosts. The disease causing organisms interfere with the management practices and involve risks or uncertainty in decision making. Integration and manipulation of all the available control measures to get a healthy crop of plants by checking the disease below the economic threshold level at an effective cost is, therefore, required for overall management of multipurpose tree species.

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Disease Problems and Their Management in Teak Root Trainer Nurseries in Kerala, India

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ABSTRACT

Introduction of root trainer technology in raising teak seedlings has had a major impact on seedling production system as well as nursery and plantation management as a whole. Even though, the new technology offers various advantages over the conventional nursery techniques, there is a paucity of data on status of seedling health in root trainers. A systematic disease survey was carried out in four Central nurseries in the State and also root trainer nurseries raised by Kerala Forest Research Institute at Peechi, Palappilly and Nilambur during 2000-2002. The study revealed that root trainer seedlings were almost free from soil-borne fungal diseases like damping-off, web blight, seedling blight, wilt, collar rot, etc. which were most prevalent in conventional nurseries and caused severe damage to the seedling crop. The common nursery pathogens of teak like *Rhizoctonia solani*, *Pythium* spp., *Fusarium* spp., *Sclerotium rolfsii*, etc. seldom recorded in root trainers. Often seedling congestion in root trainers led to foliage infection by weak pathogens like *Colletotrichum gloeosporioides*, *Pestalotiopsis spp.*, *Alternaria alternata*, *Curvularia* spp., etc. In general, severity and spread of foliage infection caused by most pathogens was low in all the nurseries, except a leaf blight caused by *Phoma glomerata* and *P. eupyrena*. Bacterial seedling infections viz., cotyledon rot, seedling wilt, seedling rot, etc. caused major threat to the planting stock in most nurseries. *Ralstonia solanacearum* (=*Burkholderia solanacearum*) was the bacterium identified as the causal agent. Fungicides and bactericide were screened against important fungal and bacterial pathogens using standard techniques and effective fungicides (Mancozeb, Bavistin) and bactericide (Streptomycin sulphate 90%w/w+ Tetracycline hydrochloride 10%w/w) were applied in the nurseries to control the diseases.

Keywords: Root trainer seedlings, teak, fungal disease, bacterial disease, disease management

INTRODUCTION

During the past few years, forest nursery practices in the State have undergone a tremendous change based on various microclimatic, edaphic and biotic factors, including host, pest and pathogen associations. Maintaining the seedlings under tropical climate is one of the major challanges confronting the nursery managers. During this period, disease may occur in succession and if timely intervention is not done the entire seedling crop may be devastated by one or other diseases. Introduction of root trainers in forestry sector and thereby the technological changes in seedling production has had a major impact on nursery management. In root trainers, the seedlings require a maximum period of 90 days of growth and hence a rigorous management is possible during this comparatively shorter period of maintenance than in conventional nurseries, where the maintenance period ranges from six months to 18 months. Due to the tropical climate prevailing in the State, diseases cause major havoc, which often play as a major limiting factor for raising and maintaining the nursery stock. As disease hazards in forest nurseries have became very common and often upset the entire planting programme, systematic studies and management of economically important diseases have been taken up during 1980s and 1990s and nursery management practices for important forestry species, including teak have been standardized (Sharma *et al.*, 1985; Sharma & Mohanan, 1992, Mohanan, 2001a). A detailed study on diseases occurring in conventional seedbed nurseries in the State and their management have been made by Mohanan *et al.*, (1997). Recently, a comparative account on disease incidence in more than 23 forestry species raised in conventional seedbed nurseries and root trainer nurseries was also made by Mohanan (2000a,b, 2001b) and appropriate remedial measures have been suggested. Even though, the new technology offers various advantages over the conventional nursery technique, especially in terms of seedling health, there is paucity of data on incidence, severity and spread of diseases in teak root trainer seedlings. The present study is aimed at carrying out a disease survey in teak root trainer nurseries in the State and to suggests remedial measures for producing healthy planting stock.

MATERIALS AND METHODS

Disease survey was carried out in Central nurseries located at Kulathupuzha (Trivandrum Forest Division), Chettikkulam (Trichur Forest Division), Valluvassery (Nilambur Forest Division), and Cheruvancherry (Kannur Forest Division). Besides, root trainer nurseries raised at Kerala Forest Research Institute Campus, Peechi and Forest Field Station at Palappilly, and KFRI Sub-Centre, Nilambur were also surveyed during 2000-2002. Disease incidence, severity and spread were recorded using a Disease scoring scale (Table 1) and disease specimens were collected and brought to the laboratory for isolation and identification of causal organisms.

Potato Dextrose Agar (PDA) medium was used for isolating and sub-culturing fungal organisms, while Nutrient Agar (NA) medium was used for isolating and maintaining bacterial pathogens. Isolation and purification of causal organisms were carried out employing standard procedures and identification up to species level was made. As far as possible, confirmation of pathogenicity of most causal agents was made through inoculation experiments employing root trainer seedlings.

Fungicides and bactericide were screened against important fungal and bacterial pathogens using standard techniques and most effective fungicides/ bactericide at appropriate dosage were recommended and applied in the nurseries for controlling the respective disease(s). Observations on the effect of chemical treatments against diseases were recorded from the nurseries. General nursery management practices followed in each nursery were recorded and data on potting media used, their composition, etc. were also collected.

RESULTS AND DISCUSSION

Disease survey conducted in root trainer nurseries located at different parts of the State revealed that root trainer seedlings are almost free from soil-borne fungal diseases like damping-off, web blight, seedling blight, wilt, etc. irrespective of the conducive climatic conditions prevailed in the nurseries. However, teak seedlings raised in root trainers suffered from one or the other foliage diseases, mostly incited by air-borne inocula of pathogens, the severity of which varied from nursery to nursery depending on the nursery management practices and prevailing environmental conditions. The common nursery pathogens like *Rhizoctonia solani* Kuhn, *Pythium* spp., *Sclerotium rolfsii* Sacc. which cause various diseases at different growth phases of seedlings were seldom recorded in root trainer nurseries. *Rhizoctonia solani*, the most potential pathogen in forest nurseries which exists in different Anastomosis groups and having a

Table 1. Disease scoring scale

Disease severity	Disease severity code	Disease severity scale Percentage seedlings affected
Nil	0	0
Low	L	1-25
Medium	M	26-50
Severe	S	51-75 or > 25% seedlings dead

wide host range was not encountered in the root trainer nurseries during 2000 and 2001. However, a mild collar rot infection was recorded in Central nurseries at Valluvassery (Nilambur Forest Division), Chettikulam (Thrissur Forest Division and Cheruvanchery (Kannur Forest Division) during 2002. Also, a weak aerial strain of *R. solani* was recorded as causing minor foliage infection.

Curvularia lunata

Seedling congestion in root trainers was found to be the major factor for the incidence and spread of foliage diseases. Pathogens like *Colletotrichum gloeosporioides* (Penz.) Sacc., *Pestalotiopsis* spp., *Alternaria alternata* (Fr.) Kiessler, *Phoma glomerata* (Corda.) Wollenw. & Hochapf, *P. eupyrena* Sacc, *Phomopsis variosporum* Sharma, Mohanan & Florence were found associated with the foliage diseases (Table 2). In general, severity and spread of foliage diseases caused by most pathogens was low in all the nurseries, except the foliage blight caused by *Phoma glomerata*. The pathogen was found widespread in root trainer nurseries and caused severe foliage infection in teak as well as in most of the forestry species raised. More than 22 forestry species raised in root trainer nurseries were found affected by the pathogen (Mohanan, 2000 a). In teak seedlings, *Phoma glomerata* along with *Phoma eupyrena* caused severe damage to the seedlings. The pathogens cause dark greyish brown necrotic lesions on foliage, usually at the margin and tip of the leaves or at the base of the petiole which coalesce and spread to the entire leaf lamina. The infected leaves show an upward curling and become brittle and withered. The disease also affects the leaf petiole and seedling stem. Severe infection leads to seedling blight.

Since, soil-less or soil-free potting media were used in root trainers and general hygienic conditions were maintained in nurseries, most of the soil-borne diseases were excluded from the nurseries. As inoculum of most of the nursery pathogens activates in presence of a susceptible host under high soil moisture, disease outbreak is common in conventional seedbed and container nurseries. However, in root trainers with soil-less potting medium, the inoculum potential of pathogen is considerably negligible and thus chances of seedling infection will be less even under conducive environmental conditions. Damping-off fungi usually survive as mycelia, sclerotia or spores and can be transmitted through soil and water and the inoculum becomes active and pathogenic when environmental conditions such as temperature, relative humidity, soil moisture content, soil pH, etc. become favourable (Sharma and Mohanan, 1992). Disease management

Table 2. Diseases recorded in teak root trainer seedlings from different nurseries

Sl.No.	Disease	Disease severity recorded	Pathogen(s) associated
1	Cotyledon rot	L	*Ralstonia solanacearum*
		L	*Curvularia lunata*
2	Collar rot	L	*Ralstonia solanacearum*
		L	*Rhizoctonia solani*
		L	*Fusarium solani*
3	Seedling wilt	L	*Ralstonia solanacearum*
4	Seedling blight	M	*Ralstonia*
		L	*Fusarium solani*
5	Leaf spot	L	*Colletotrichum gloeosporioides*
		L	*Ralstonia solanacearum*
		L	*Phoma glomerata*
		L	*Phoma eupyrena*
		L	*Phoma variosporum*
		L	*Rhizoctonia solani*
		L	*Alternaria alternata*
		L	*Pestalotiopsis sp.*
		L	*Curvularia lunata*
6	Seedling stem infection	L	*Curvularia lunata*

can be achieved through cultural, chemical or biological measures (Mohanan, 2001a). Most of the soil-inhabiting, disease causing fungi subsist mainly on dead organic materials and the presence of surplus, readily available nutrients in organic compost in root trainer cells makes less competition among the pathogens for the nutrients and thus least attractive for infection of seedlings.

Bacterial seedling diseases caused by *Ralstonia solanacearum* Yabuuchi *et al.* (= *Burkholderia solanacearum* (Smith) Yabuuchi) were also recorded in teak seedlings. The bacteria cause cotyledon rot, collar rot, seedling wilt, and foliage infection. The disease appears as water-soaked lesions on cotyledons and foliage and become dark greyish brown. The lesions spread and cause rotting of the affected tissues in cotyledon, seedling stem and foliage. The bacteria also cause seedling wilt in teak; the infection is systemic and produced symptoms characteristics of vascular wilt viz., drooping of leaves, epinasty, and wilting. As in conventional nursery beds, spread of disease through root contact is not occurring in root trainers, however, physical contacts of infected foliage to healthy seedlings in the root trainer blocks spread the disease to an epidemic proportion. Severe disease incidence and seedling mortality in teak seedlings were recorded at Central Nursery, Kulathupuzha during 2000. The source of inoculum may be either the potting medium or water. In the case of bacterial infection, all the affected seedlings are not killed outrightly. Often many seedlings may become carrier of bacterial pathogens, without showing any visible external symptoms of disease. Hence, there is possibility of transferring the disease from nursery to the field through mildly infected propagules. In conventional seedbed nurseries, bacterial collar rot and wilt cause severe damage to the nursery stock. The seedbed nurseries raised in high rainfall areas were reported to be affected severely by the bacterial pathogen (Sharma *et al.*, 1985; Mohanan, *et al.*, 1997). *Ralstonia solanacearum* occurs in different biotypes and has wide host range including several members of teak family, Verbanaceae.

Among the fungicides screened in the laboratory for their efficacy against pathogens like *Phoma glomerata, Phoma eupyrena, Colletotrichum gloeosporioides* and *Phomopsis variosporum*, Dithane M45 (Indofil, Mancozeb) @ 0.05% a.i. was found effective against *Phoma glomerata, Phoma eupyrena* and *Colletotrichum gloeosporioides* (Table 3). At a higher concentration of 0.1% a.i. it was effective against all the test fungi. Bavistin (Carbendazim) was found effective against *Phomopsis variosporum* and *Colletotrichum gloeosporioide* at both the concentrations tried. Fytolan was found effective only against *Phomopsis variosporum* at 0.1% a.i. The *in vitro* study recommends the use of Dithane M45 and Carbendazim at appropriate concentration to control the foliage infections.

In nurseries, application of fungicides viz., Carbendazim (0.05% a.i.), Dithane M45 (0.1% a.i.) against foliage diseases gave good results. For controlling seedling blight and foliage diseases caused by *Phoma glomerata* and *P. eupyrena*, application of Dithane M45 was found very effective. Application of a bactericide, Streptocyclin (Streptomycin sulphate 90% w/w + Tetracycline hydrochloride 10%w/w) at the rate of 6 g per 8 l of water by drenching the seedlings gave good control of seedling infection caused by *Ralstonia solanacearum.*

The quality of planting stock in teak nursery warrants not only the successful field establishment but also subsequent excellent growth and high

Table 3. Efficacy of fungicides in laboratory screening employing poisoned food technique

Sl. No.	Fungus	Mean colony dia*						
		Control	Dithane M45		Carbendazim		Fytolan	
			0.05%	0.1%	0.05%	0.1%	0.05%	0.1%
1	*Phoma glomerata*	83.50	7.75	0	59.00	45.75	69.00	54.75
2	*Phoma eupyrena*	79.50	5.50	0	32.00	15.00	46.50	42.00
3	*Phomopsis variosporum*	90.00	0	0	0	0	49.75	0
4	*Coll. gloeosporioides*	79.00	0	0	0	0	44.25	41.25

* Mean of values from three replicates

yield. Thus, forest nurseries play a vital role in any afforestation / reforestation programmes. Raising nurseries requires technical skills including careful planning for all the major components such as selection of quality seed, appropriate potting media, containers, organizing the work force, nursery hygiene and protection, etc. All these factors are equally important for producing healthy, disease-free, vigourous, quality planting stock.

Stump prepared out of 12 to 18-month-old teak seedlings are used as propagule for raising plantations in the State. By employing the root trainer technology, 90 days old seedlings as such are used for raising plantations. The technological changes in producing seedlings in root trainers rather than in seedbeds and polythene containers has had a major impact on seedling production system as well as the whole planting operations. However, a comparative data on plantations established using root trainer seedlings and stumps are required for any further analysis. It is evident from the present study that soil-borne diseases which pose major threat in seedbed teak nurseries seldom occur in root trainers, where the potting medium is generally free from pathogens. With the increase in environmental concern on use of pesticides in delicate ecosystems like forest nurseries, nursery managers are being instructed to use cultural measures as far as possible, for managing the nursery diseases and boosting the seedling growth. However, application of proper fungicide(s) at proper time is required to control the foliage diseases. Otherwise, mild foliage infection may flare up and cause severe damage to the seedlings.

CONCLUSIONS

In teak root trainer nurseries, soil-borne fungal diseases seldom occur mainly due to the use of soil-less or soil-free potting media and maintaining the nursery in hygienic conditions. Mild foliage and seedling stem infections caused by air-borne fungal pathogens affect the teak seedlings and seedling congestion may be the primary influencing factor for the incidence and spread of the disease. Among the fungal pathogens causing foliage infection, *Phoma glomerata* and *Phoma eupyrena* are the important ones. Seedling diseases in root trainers caused by fungal pathogens can be controlled by application of broad spectrum fungicides like Carbendazim or Dithane M45 as foliar drench or spray at proper time. Bacterial diseases caused by *Ralstonia solanacearum* occur in most of the nurseries surveyed and can be controlled by application of Streptomycin sulphate or any other bactericide (Plantamycin) at appropriate concentration as soil drench or foliar spray. To ensure that planting stock is not carrying any nursery-borne fungal or bacterial pathogens, prophylactic chemical treatment has to be carried out before transporting the root trainer seedlings to the planting site.

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Clonal Variation in the Incidence of Phytophagous Insects: Some Thoughts on Divergence of Teak

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ABSTRACT

Characters are known to diverge over time in spatially separated populations. We studied the population divergence of teak (*Tectona grandis*) across the state of Karnataka, India with respect to the incidence of phytophagous insects. Data on the incidence of the teak defoliators – *Hyblaea puera* and *Paliga machoeralis* (both indigenous species) and the spiraling whitefly, *Aleurodicus dispersus* (recently introduced polyphagous species) were recorded from two clonal assemblages for a period of three years. Individual clones as well as the provenances did not show any significant variation with respect to the incidence of either *H. puera* or *P. machoeralis*. Interestingly, variation in the incidence of *A. dispersus* was detected across individual clones indicating divergence in the populations of teak. The results show that the defoliators are not directly responsible for the variations that exist across clones and provenances and that these defoliators are able to overcome the existing variations and continue building pestiferous populations.

Keywords: Teak, population divergence, clonal variation, *Paliga machoeralis*, *Hyblaea puera*, *Aleurodicus disperses*

INTRODUCTION

The occurrence of teak (*Tectona grandis* L.) in varied habitats has led to substantial provenance variation resulting in a tremendous potential for selection. Of the several biotic and abiotic factors that contribute to such variations, pest populations are expected to be one among them. Prominent among the pestiferous insect species occurring on teak are the defoliators, *Hyblaea puera* (Hyblaeidae : Lepidoptera) and *Paliga machoeralis* (=*Eutectona machaeralis*) (Pyralidae : Lepidoptera). These defoliators are nearly monophagous and are reported to cause substantial reduction to the incremental growth of teak stands (Varma et al., 1998). Clonal Germplasm Banks (CGBs) have often served as test sites for studying variations in tolerance to phytophagous insect populations. Studies by Ahmed (1987) and Roychoudhury and Joshi (1996) have shown considerable variation among clones from different provenances with respect to damage caused by the two defoliators. Such studies throw some evidence towards divergence in the population of teak with respect to the defoliators. In other words defoliators may be selecting populations of teak. The above studies have been conducted over a large scale by considering clones from provenances that are spatially far apart. Selections resulting from such studies usually end up with problems related to naturalization of the selected clones/provenances, which finally takes more time before finding their applications. However, when Nair *et al.* (1989) considered clones from Kerala, from provenances that are spatially nearer to each other, they obtained no evidence to prove genetic resistance against *H. puera* in spite of the pest being reported to cause substantial incremental losses (Varma *et al.*, 1998). The present study aimed at assessing the clones from Karnataka with respect to the incidence of not

Table 1. Details of the two clonal germplasm banks where the study was conducted

Location	*Year of establishment*	*Provenances*	*Clones*
Gottipura	1995	Bhadravati, Chikkamagalur, Haliyal, Kakanakote, Nagarahole, Shimoga, Titimatti	BAH-25, 26, 27, 28, 29, 30 CHI-47, 49 HAL-1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 33, 34 KKT-35, 36, 37, 38, 39 NGH-42, 43, 44, 45 SHI-12, 13, 14, 15 TMT-16, 17, 20, 21, 22, 23, 24
IWST Campus	1995	Bhadravati, Chikkamagalur, Haliyal, Kakanakote, Koppa, Nagarahole, Shimoga, Titimatti	BAH-25, 28, 29 CHI-49HAL-2, 3, 4, 5, 7, 10, 11 KKT-35, 36, 37, 38, 39 KPA-46 NGH-42 SHI-12, TMT-16, 20, 21, 22, 23

only the above mentioned defoliators but also of the recently introduced polyphagous *Aleurodicus dispersus* (Aleurodidae : Homoptera). It was expected that differences in clones with respect to the incidence of defoliators would mean that the defoliators have been a selective force (considering the fact that these species are indigenous and occur in large populations on teak) and further selections would be meaningful. However, differences in clones with respect to only *A. dispersus* would nevertheless indicate variation among the selected provenances but would rule out the possibility of defoliators being responsible for this variation.

MATERIAL AND METHODS

This study was carried out at two CGBs established at Gottipura and IWST campus (Table 1). The CGBs contain clones from various provenances of Karnataka, India, which is one of the areas where teak is naturally distributed. It is to be noted that the assemblage of clones are from plus trees selected based on various sivicultural and economic characters. The CGBs were regularly irrigated and de-weeded; usage of insecticides was curtailed during the period of observation. The ramets at both the CGBs were regularly pruned and maintained as

Table 2. ANOVA for the incidence of the defoliators across different clones at Gottipura

a) *H. puera* (No. of clones = 41; No. of ramets / clone = 9; No. of observations = 7)

Source of variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	**F calculated**	**F critical (? = 0.05)**
Clones	40	12361.68	309.04	1.23	1.44
Observation dates	6	99416.56	16569.43	66.01	2.14
Error	240	60240.91	251		
Total	286	172019.15			

b) *P. machoeralis* (No. of clones = 41; No. of ramets / clone = 9; No. of observations = 8)

Source of variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	**F calculated**	**F critical (?= 0.05)**
Clones	40	11608.96	290.22	1.41	1.44
Observation dates	7	47354.05	6764.86	32.83	2.04
Error	280	57704.65	206.09		
Total	327	116667.65			

Table 3. Paired t-test for deviation of per cent incidence of the defoliators on each of the provenances from the overall incidence

a. *H. puera*

Date of observation	Mean incidence (%)						
	BAH	HAL	KKT	NGH	SHI	TMT	Overall
17th Sept. 1997	14.59	27.33	29.03	19.36	23.97	22.95	23.56
17th Sept. 1998	28.77	26.37	27.43	22.58	28.76	23.22	26.29
28th April 1999	6.72	12.84	14.25	15.52	13.11	7.73	11.67
9th July 1999	14.16	18.24	8.10	13.52	12.08	10.51	13.99
19th August 1999	12.05	8.84	4.98	11.37	5.45	6.18	8.45
21st Oct. 1999	23.09	26.41	24.69	23.99	23.31	24.30	24.73
25th Feb. 2000	6.45	5.56	5.18	6.12	14.97	15.12	8.19

Paired t-test results

Pairs compared	Test result	Pairs compared	Test result
BAH v/s Overall	Non-significant	HAL v/s Overall	Non-significant
KKT v/s Overall	Non-significant	NGH v/s Overall	Non-significant
SHI v/s Overall	Non-significant	TMT v/s Overall	Non-significant

b. *P. machoeralis*

Date of observation	Mean incidence (%)						
	BAH	HAL	KKT	NGH	SHI	TMT	Overall
11th June 1997	15.75	15.06	19.41	13.17	19.67	17.93	16.62
17th Sep. 1997	11.05	1.36	9.31	11.89	8.05	4.24	5.85
17th Sep. 1998	4.32	4.88	7.26	3.29	6.39	5.96	5.25
28th April 1999	7.24	11.69	10.75	13.11	8.99	7.79	10.17
9th July 1999	15.60	22.90	17.51	19.72	14.97	13.44	18.36
19th Aug. 1999	10.06	5.32	5.80	14.84	9.18	7.32	7.96
21st Oct. 1999	20.73	23.83	20.57	14.49	8.55	8.98	18.08
25th Feb. 2000	9.09	7.37	12.83	8.46	9.48	12.80	9.77

Paired t-test results

Pairs compared	Test result	Pairs compared	Test result
BAH v/s Overall	Non-significant	HAL v/s Overall	Non-significant
KKT v/s Overall	Non-significant	NGH v/s Overall	Non-significant
SHI v/s Overall	Non-significant	TMT v/s Overall	Non-significant

hedge gardens. Data on the occurrence of *H. puera, P. machoeralis* and *Aleurodicus dispersus* were recorded from 1997 to 2000 on the basis of visual whole-plant counts. The number of plants in each clone hosting each of the folivorous species (presence of the insect and/or its feeding mark) was recorded.

Two-way ANOVA was used to analyze for variability among different clones across populations of each of the folivorous species. Later, the clones were grouped according to the provenances and paired t-test was used to compare the deviations of provenance means from the overall mean. Populations of *A. dispersus* were absent at CGB, Gottipura while the populations of both the defoliators were negligible at IWST campus, and hence were not considered for analysis.

RESULTS AND DISCUSSION

Tables 2a and 2b show that the incidence level of both *H. puera* and *P. machoeralis* is the same ($p>0.05$) across all the clones. Tables 3a and 3b also show similar results when comparisons were made across provenances with respect to the incidence levels of the defoliators. This shows that no variation has evolved among the various provenances of Karnataka with respect to these two important defoliators. Although Varma *et al.* (1998) reported

Table 4. ANOVA for the incidence of *A. dispersus* across different clones at IWST campus (No. of clones = 24; No. of ramets / clone = 9; No. of observations per clone = 10)

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F calculated	F critical (á = 0.05)
Clones	23	20520.87	892.21	5.99	1.58
Observation dates	9	46748.61	5194.29	34.85	1.93
Error	207	30853.92	149.05		
Total	239	98123.4			

Post ANOVA t-test showing differences among various clones to the incidence of *A. dispersus*

Clone	Mean incidence (%)*	Clone	Mean incidence (%)*
HAL-05	45.66 a	KKT-35	63.99 defghi
KKT-39	48.54 ab	BAH-28	67.01 efghij
NGH-42	48.77 ab	HAL-02	67.04 efghij
KKT-37	48.90 ab	BAH-29	68.24 fghij
KPA-46	51.22 abc	TMT-21	69.81 fghij
KKT-38	54.62 abcd	KKT-36	70.63 ghij
BAH-25	54.95 abcd	SHI-12	70.65 ghij
CHI-49	57.20 bcde	HAL-04	70.65 ghij
TMT-23	59.82 cdef	HAL-11	73.36 hij
HAL-10	61.38 cdefg	HAL-07	74.02 ij
TMT-16	62.87 defg	HAL-03	74.13 ij
TMT-22	63.15 defgh	TMT-20	76.74 j

* mean represented by the same letter do not differ significantly

substantial losses in terms of incremental growth during the early part of the plant's growth; defoliation might not actually be reducing the plant's fitness. Results also indicate that the incidence of the defoliators varied significantly with time. Incidence of *H. puera* was lowest during February 2000 (22.00 ± 18.00%) and highest (85.00 ± 21.00%) during September 1998, whereas incidence of *P. machoeralis* was lowest during September 1998 (14.00 ± 14.00%) and highest (54.00 ± 20.00%) during July 1999.

Table 4 shows that the incidence of *A. dispersus* varied between clones. The clones HAL-05, KKT-39, NGH-42, KKT-37, KPA-46, KKT-38 and BAH-25 recorded significantly lower incidence than the other clones. Incidence on the clones BAH-28, HAL-02, BAH-29, TMT-21, KKT-36, SHI-12, HAL-04, HAL-11, HAL-07, HAL-03 and TMT-20 was the highest. As clones within provenance varied, between provenances comparisons were not made. *A. dispersus* has been introduced to India in very recent times. This polyphagous whitefly has taken to teak only during the last couple of years. Because of its polyphagous nature and recent introduction, its adaptation to teak would be low and could form a suitable indicator of inherent variations among clonal assemblages. The results clearly indicate that there has been a divergence in the population of teak in Karnataka. However, the defoliators have been able to overcome all the inherent variations existing among the selected provenances and are able to build pestiferous populations. In general, it is felt that searching for variability in tolerance to pest populations among clones that are spatially near (indicating geographical similarity), rather than looking at an assemblage of vast number of clones of very diverse origins, might result in selections that could be easily taken to the field.

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Quality Timber Products of Teak from Sustainable Forest Management pp 472-484

Productivity of Teak Stands in Kerala: Role of Arbuscular Mycorrhizal Association and Diversity of AM Fungi

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ABSTRACT

An exhaustive survey on mycorrhizal association in teak plantations in different parts of Kerala State was made during 1998-2002. The arbuscular mycorrhizal (AM) fungal association was detected in young feeder roots of all the sampled teak plants. The percent root infection as well as AM fungal species association varied with age of the plants and soil physical and chemical properties. The morphological diversity of AM fungal structures observed within the same root samples indicated colonization by several different AM fungal species. The overall extent of root colonization varied from 2 to 86 percent with a mean of 32.42 percent. Soil pH, soil moisture contents and soil nutrient status were found influencing the AM fungal root colonization and distribution of spores in rhizosphere soil. Among various factors, soil pH, magnesium and sodium levels were found influencing the AM fungal root colonization. The AM fungal spores retrieved from different soil samples ranged from 29-810 with a mean value of 216/10 g soil. The relation between AM fungal spore density and AM fungal root infection showed a weak linear relation. The AM fungi associated with teak showed diversity in their temporal and spatial distribution. Altogether 85 species of Glomalean fungi belonging to six genera viz., *Glomus, Acaulospora, Gigaspora, Scutellospora, Sclerocystis* and *Entrophospora* were recorded. The AM fungal community in teak soils consisted of 12-39 species belonging to different genera. Among the AM fungi, *Glomus* and *Acaulospora* were the most predominant genera. Relative abundance of AM fungi measured using Shannon-Wiener and Simpson's indices ranged from 1.5532 – 3.0032 and 3.0508 – 16.6012 respectively. Gamma and beta diversity of AM fungi estimated were 98 and 69 respectively.

Keywords: Arbuscular mycorrhiza, teak, AM fungi, association, diversity

INTRODUCTION

Productivity of teak plantations in the State is at an alarmingly diminishing phase. Even though, many factors such as poor sivicultural measures, pests and diseases, etc. are partly responsible for this, edaphic factors are the most critical ones. Physical and chemical characteristics of soils under teak stands have been extensively studied, however, biological properties of soils under teak have been given least importance. Rhizosphere microorganisms, especially arbuscular mycorrhizal (AM) fungi in inducing wide range of growth responses in co-existing plant species has been well documented (Azcon-Aguilar et al., 1992; Bolan, 1991; Durga and Gupta, 1995). Mycorrhizal association is beneficial to plants in many ways, as it increases the rhizosphere for water and nutrients absorption, decreases disease susceptibility, increases tolerance to adverse edaphic conditions and increases biomass productivity of stands. Improving the soil nutrient status as well as their mobility by mycorrhizal manipulation is a long-term strategy as well as self-sustainable one. Sustainability of soil-plant system requires a well-balanced functional mycorrhizal association. However, our knowledge on mycorrhizal status of teak as well as the diversity of AM fungi in teak rhizosphere soils is very limited. Earlier, AM mycorrhizal association in teak was reported from Tamil Nadu (Mohan Kumar and

Mahadevan, 1987; Raman *et al.*, 1997), Andhra Pradesh (Kanakadurga *et al.*, 1990), Madhya Pradesh (Verma and Jamaluddin, 1995) and Karnataka (Gurumurthy and Srinivasa, 2000). However, information on mycorrhizal status of teak is not available from Kerala. A systematic study encompassing 70 teak plantations of different age classes grown under different edaphic and climatic conditions in the State was carried out and results on mycorrhizal status, AM fungal diversity in rhizosphere soils, possible influencing factors for AM fungal infection, etc. are presented.

MATERIALS AND METHODS

Selection of sample plots and sampling method

A reconnaissance survey was made in teak plantations in the State and sample plots from plantations falling under different age classes, viz., 1-10 yr, 11-20 yr, 21- 40 yr, > 40 yr were selected for the study. Line transect method was followed for sampling and a distance of 50 m was given between each sample tree and five sample trees were selected and paint-marked in each plantation. Information on age of the plantation, cultural and management practices adopted including fertilizer application, fire incidence, etc. was also collected. The selected plantations/plots were visited during 1998-2001 and rhizosphere soil and root samples were collected from the selected host plants. Details on elevation of the area, girth at breast height (gbh) and approximate height of the sample trees, etc. were also recorded.

Collection and processing of rhizosphere soil and roots

About three kilogram of rhizosphere soil along with young feeder roots from 10 to 20 cm depth was collected from each host tree from different plantations. The soil and root samples collected were kept in polythene bags and transported to the laboratory. Young feeder roots were separated using sieve (1 mm) and processed. The moisture content (%MC) of the soil was determined by oven dry method and soil pH was measured. The soil samples were kept in polythene bags and stored at 5°C until they were further processed.

Separating arbuscular mycorrhizal fungal spores from soil

The rhizosphere soil samples were air-dried and wet sieving-decanting method (Gerdemann and Nicholson, 1963) was employed for retrieving the arbuscular mycorrhizal (AM) fungal spores from soil samples. AM fungal spore preparations with and without Melzer's reagent were made to reveal details on spore inner-wall layers and other spore characteristics of taxonomic importance. Identification of the AM fungal taxa was made by following the taxonomic descriptions of Schenck and Perez (1990) and Morton (1993).

Processing of mycorrhizal root samples and detection of AM fungal infection

Roots were separated from the rhizosphere soil and washed thoroughly with tap water over a 1-2 mm screen. After washing, the roots were kept moist in polythene bags and refrigerated at 50°C. A working sample of the roots was drawn by chopping the selected fine roots ca. 1 cm in length and mixing them thoroughly. Then random sub-samples were drawn and kept in Petri dishes at 50°C.

The root bits (1cm in length) were cleared by immersing in KOH 40% w/v solution in beakers and autoclaving for 45 min at 15 p.s.i. After clearing the roots, bleaching was carried out by using alkaline H_2O_2 for 20 to 30 min. The roots were then neutralized with 1N HCl for 1-3 min and then stained with Trypan blue (Phillips and Hayman, 1970; Kormanik and McGraw, 1982). After staining, the root bits were observed under a light microscope for the presence of AM fungal structures, viz., arbuscules, vesicles, internal hyphae, spores, etc. From each sub-samples, 100 root bits were observed and the percentage root colonization (%RC) was calculated (Giovannetti and Mosse, 1980) by using the formula:

$$\%RC = \frac{\text{No. of root bits with vesicles and arbuscules}}{\text{Total number of root bits observed}} \times 100$$

Evaluation of physical and chemical properties of rhizosphere soils

Rhizosphere soil samples collected from different hosts were brought to the laboratory and analyzed for their physical and chemical characteristics (Keeney, 1980; Hefferman, 1985; Rayment and Higginson, 1992). Soil moisture content was determined by oven dry method and soil pH was measured using digital pH meter.

Statistical analysis

The relation between mycorrhizal root infection percentage and the set of extraneous variables like age of the plantation and soil variables was investigated through multiple linear regression. Stepwise regression was employed to identify the most influential set of variables affecting the mycorrhizal root infection percentage. The root infection percentage was transformed to angular scale before the regression analysis. Biodiversity indices were worked out for each sample plot. Relative abundance was measured using Shannon-Wiener index and Simpson's index. Shannon-Wiener index was calculated as:

$$H' = -\sum p_i \ln p_i$$

where quantity p_i is the proportion of individuals found in the *i*th species and ln indicates natural logarithm. Simpson's index was calculated as:

$$D = 1/\sum p_i^2$$

where D is the diversity and p_i is the proportion of the *i*th species in the total sample. The levels of diversity viz., Gamma diversity and Beta diversity of AM fungal species in plantations were estimated. Beta diversity was estimated using the following index:

$$\bar{S} = \beta_w = (S/\bar{S}) - 1$$

where S = Total number of species recorded in the system

Average sample diversity where each sample is of standard size and diversity is measured as species richness

RESULTS AND DISCUSSION

Arbuscular mycorrhizal association in teak

All the sampled teak plants in different Forest Ranges throughout the State, irrespective of their difference in age, altitude and edaphic factors, exhibited AM fungal association. However, the percent root infection as well as the AM fungal species association varied with the age of the plants as well as soil physical and chemical properties. All typical AM features, such as arbuscules, vesicles, intra-cellular hyphal coils, extra and intraradical hyphae, were observed in the root samples (Plate 1). The morphological diversity of the different fungal structures observed within the same root samples indicates that teak roots were colonized by several different AM fungal species. The overall extent of root colonization varied from 2.00 to 86.1 per cent with a mean of 32.42 per cent. The highest values were registered in root samples collected during the month of April. It is well known that root infection by AM fungi varies from season to season depending on the soil physical and chemical characteristics as well as host's response.

Of the 15 teak plantations belonging to the Group1 (1- to 10-year-old), AM fungal root infection was observed in all the sampled trees and infection ranged from 3.6 to 83.9 per cent. However, the average root infection was 27.18 per cent. The highest mycorrhizal root infection of 83.9 per cent in this Group was recorded in a nine-year-old plantation at Vazhachal, Vazhachal Forest Range (Table 1), and lowest root infection in a one-year-old plantation at Dhoni, Olavakkode Forest Range. The young teak plantations located at different altitudes (30 to 800 m a.s.l.) did not show any marked difference on AM fungal root colonization. However, there is a possible relationship between root infection and soil characteristics. Rhizosphere soil samples from most teak plantations were moderately to strongly acidic, except plantation soils at Olavakkode, Kodanad, and Thundathil Forest Ranges, which were near neutral to basic. The lowest root infection was observed in a very young plantation (1-year-old), where the soil pH was comparatively high (pH 7.3) and with a low soil moisture content (3.6%). Whereas the highest

Table 1. AM fungal root infection in teak plantations (1-10 years-old) in different parts of the State

Sl. No.	Sample Plot No.	Locality	Forest Range	Altitude (m)	Age (yr)	Root infection %	AMF spore count	Soil pH	Soil MC%
1.	T5	Begur	Begur	800	8	30.3	289	5.53	2.16
2	T11	Vazhachal	Vazhachal	270	9	83.9	164	4.81	10.01
3	T15	Cherupuzha	Karulai	40	4	43.6	100	5.32	10.01
4	T23	Valluvassery	Nilambur	90	9	26.4	421	4.99	6.09
5	T24	Valluvassery	Nilambur	90	7	22.3	139	4.85	4.89
6	T31	Mallana	Kodanade	90	2	13.1	358	6.76	0.56
7	T34	Perumthode	Kodanade	90	2	8.1	182	6.8	2.02
8	T35	Karimpani	Thundathil	90	5	12.8	364	6.83	4.31
9	T41	Dhoni	Olavakkode	150	1	3.6	690	7.3	3.16
10	T43	Banglamkunnu	Olavakkode	150	3	23.6	216	7.46	4.05
11	T55	Kumaramperoor	Konni	30	3	17	181	4.76	20.3
12	T57	Aryankavu	Aryankavu	200	9	18	187	4.93	16.02
13	T59	Kumbharukadavu	Achankovil	160	4	35	108	5.46	9.34
14	T61	Kodamala	Achankovil	50	9	15	117	5.71	10.86
15	T66	Elimullumplackal	Konni	100	3	55	89	4.76	17.81

Table 2. AM fungal root infection in teak plantations (11 to 20- year-old) in different parts of the State

Sl. No.	Sample Plot No.	Locality	Forest Range	Altitude (m)	Age (yr)	Root infection%	AM F sporecount	Soil pH	Soil MC%
1	T4	Panavally	Tholpetty	760	18	38.2	631	5.35	8.16
2	T8	Irumbupalam	Vazhachal	505	20	73.6	810	5.13	12.34
3	T9	Irumbupalam	Vazhachal	505	17	82.1	357	5.04	13.32
4	T13	Kariammurium	Nilambur	160	19	33.5	98	5.49	9.34
5	T22	Nellikkuthu	Karulai	100	13	25.6	401	5.23	10.03
6	T25	Mailady	Nilambur	30	12	28	65	4.87	19.01
7	T30	Mulamkuzhy	Kalady	80	20	27.5	239	6.92	0.31
8	T36	Karimpani	Thundathil	90	19	22.9	295	6.59	5.63
9	T47	Kottappara	Kodanad	50	16	27.1	168	5.73	7.86
10	T56	Cheruvalam	Erumely	80	16	27	244	5.53	19.33

root infection in this group was recorded in plantation with a soil pH of 4.81 and soil moisture content of 10.01 per cent. In general, plantation soils with comparatively high soil pH (6.8 to 7.3) and low soil moisture content (0.56 – 4.31%) showed low AM fungal root infection.

Among the ten teak plantations belonging to the age group of 11 to 20-year-old (Group 2), AM root infection ranged from 22.9 to 82.1 per cent. The average mycorrhizal infection was 38.55 per cent. From all the teak plantations, except one 19-year-old plantation at Karimpani, Thundathil Forest Range, more than 25 per cent of AM root infection was recorded (Table 2). In this Group also, high per cent AM root infections (73.6%, 82.1%) were recorded in plantations with low soil pH.

All the 24 teak plantations belonging to the age group of 21 to 40-year-old (Group 3) showed AM root infection which ranged from 6.8 to 86.1 per cent. The average mycorrhizal infection was 34.59 per cent. The highest percentage of AM root infection was recorded in a 37-year-old teak plantation at Vazhachal, Vazhachal Forest Range (Table 3). In this category of plantations also low AM root infection was recorded in plantation soils with high soil pH. Teak plantations at Vattappara (Walayar Forest Range), Perunthode (Kodanad Forest Range), Thundamthodu (Thundathil Forest Range), where the soils were near neutral to basic (pH ranged from 6.81 to 7.45), exhibited comparatively a low AM root infection than the other plantations with low soil pH.

Twenty one teak plantations falling under the group

Table 3. AM fungal root infection in teak plantations (21-40- year-old) in different parts of the State

Sl. No.	Sample Plot No.	Locality	Forest Range	Altitude (m.a.s.l.)	Age (yr)	Root infection%	AMF sporecount	Soil pH	Soil MC%
1	T1	Kaimaram	Tholpetty	810	38	53	621	5.79	9.82
2	T2	Camp road	Tholpetty	820	23	58	357	6.02	8.43
3	T6	Chembuvalli	Begur	810	22	31.6	174	5.76	2.74
4	T7	Bavali	Begur	800	36	23.1	231	6.01	2.69
5	T10	Vazhachal	Vazhachal	290	37	86.1	461	5.51	15.61
6	T12	Kariummurium	Nilambur	110	23	38	168	5.24	8.68
7	T14	Thannikkadavu	Vazhikkadavu	120	27	36.1	93	5.09	9.34
8	T16	Cherupuzha	Karulai	80	26	30.8	156	5.23	10.03
9	T20	Poolakkappara	Karulai	80	30	32	101	5.22	10.39
10	T28	Edakkode	Edavanna	80	23	43.2	67	5.08	6.11
11	T32	Perumthode	Kodanade	88	37	6.8	238	7.01	1.8
12	T33	Perumthode	Kodanade	90	23	9.8	151	6.81	3.01
13	T37	Thundamthodu	Thundathil	95	27	11	196	6.81	3.61
14	T45	Vattappara	Walayar	210	23	16.6	171	7.45	1.25
15	T48	Kulathupuzha	Kulathupuzha	90	37	32.8	103	6.7	3.12
16	T49	Decentmukku	Kulathupuzha	90	39	65.2	120	5.6	2.9
17	T51	Nadavanoorkadavu	Kulathupuzha	80	37	35.7	78	5.3	4.15
18	T52	Valara	Neriamangalam	310	35	8	160	4.8	6.8
19	T58	Palaruvi	Aryankavu	210	33	39	169	5.36	11.03
20	T62	Valayam	Mannarppara	40	40	14	169	5.75	9.69
21	T65	Perumthammoozhy	Naduvathoomuzhy	110	38	53	153	6.18	16.97
22	T68	Parambikulam	Parambikulam	550	38	31	209	6.56	11.24
23	T69	Orukomban	Orukomban	540	36	46	88	6.5	14.56
24	T70	Sungam	Sungam	520	38	29.5	237	6.26	16.16

of >40 –year-old (Group 4) showed AM root infection which ranged from 2 to 56.9 per cent. The average AM fungal root infection was 27.22 per cent. Age of the teak plantation varied from 41 to 90 years. The 90-year-old teak plantation at Nedumkayam (Karulai Forest Range) showed 31.23 per cent AM root infection, while a 45-year-old teak plantation at Chakkolatharisu (Pattikkad Forest Range) showed the highest per cent AM root infection of 56.9. However, teak plantations at Olavakkode and Walayar Forest Ranges, where the soils were basic (soil pH ranged from 7.83-7.96), exhibited a very low per cent AM root infection. The lowest per cent AM root infection (2%) was observed in a 65-year-old teak plantation at Dhoni (Olavakkode Forest Range). The teak plantations with comparatively high soil pH (7.48 to 7.96) and low soil moisture content (0.76 to 3.89%) showed low AM root infection. However, highest value for AM root infection in teak plantations belonging to this Group was observed in plantation with soil pH 6.78 and soil moisture content of 5.98% (Table 4).

Factors influencing AM association in teak plantations

Arbuscular mycorrhizal infection in plants is usually influenced by the prevailing edaphic and environmental factors. Physical and chemical properties of the rhizosphere soil samples from the teak plantations showed a wide range of differences. Soil pH ranged from 4.03 to 7.96; most of the plantation soils were moderately acidic to highly acidic. Only soil samples from plantations in Olavakkode, Kodanad, Thundathil, Kalady and Walayar Forest Ranges were near neutral to basic. Soil moisture content in the teak plantations also ranged from 0.31 to 19.33 per cent with a mean of 6.63 per cent. Organic carbon in the soil samples ranged from 0.99 to 5.88 with a mean of 2.45 per cent. In most of the plantation soils, the ratio of OC % to N% was found about 10:1 ratio indicating the nutrient richness of the soils. Exchangeable cations viz., Na, Ca, Mg, and K also showed high variation. Sodium (Na) ranged from 0.052 to 0.109

Table 4. AM fungal root infection in teak plantations (>40 year-old) in different parts of the State

Sl. No.	Sample Plot No.	Locality	Forest Range	Altitude (m.a.s.l.)	Age (yr)	Root infection%	AMF spore count	Soil pH	Soil MC%
1	T3	Naikkatty	Tholpetty	800	46	43.6	619	5.95	8.03
2	T17	Nedumkayam	Karulai	80	90	31.2	83	5.24	9.69
3	T18	Pulimunda	Karulai	90	41	31.23	86	5.02	10.02
4	T19	Poolakkappara	Karulai	70	50	38	68	5.33	10.11
5	T21	Nellikkuthu	Karulai	90	67	39.4	164	5.36	9.81
6	T26	Chliarmukku	Nilambur	20	45	31.8	29	4.03	19.08
7	T27	Akampadam	Nilambur	50	45	46	64	5.17	8.31
8	T29	Mulamkuzhy	Kalady	75	45	26.5	282	6.48	0.08
9	T38	Irumbupalam	Pattikkad	80	44	23	136	6.65	5.35
10	T39	Chakkolatharisu	Pattikkad	90	45	56.9	110	6.78	5.98
11	T40	Vallikkayam	Peechi	110	41	10	190	6.92	3.78
12	T42	Dhoni	Olavakkode	160	65	2	129	7.83	3.89
13	T44	Dhoni-Quarters	Olavakkode	160	43	8.2	138	7.48	2.42
14	T46	Walayar	Walayar	260	41	14	146	7.96	0.76
15	T50	Kattilappara	Thenmala	90	41	15.8	141	5.4	4.16
16	T53	Vithura	Paruthipally	110	42	43	88	4.49	14.91
17	T54	Nhaloor	Konni	25	51	12	206	4.05	17.59
18	T60	Kuttippara	Kallar	80	44	26	167	5.76	10.19
19	T63	Acahankovil	Achankovil	80	44	22	194	5.97	10.46
20	T64	Konni	Konni	100	55	10	388	5.69	14.77
21	T67	Kannavam	Kannoth	80	43	41	164	5.72	19.02

(meq/100g), calcium (Ca) ranged from 0.166 to 3.804 (meq/100g), and magnesium (Mg) ranged from 0.041 to 0.541 meq/100g. Total nitrogen (N) and phosphorus (P) percentage varied from 0.09 to 0.515 and 0.01 to 0.31 respectively (Table 5-8).

In general, rhizosphere soil samples (5-20 cm depth) from teak plantations throughout the State showed high organic carbon (OC) and available nitrogen (N) percentage. In most of the soils, 10:1 ratio for OC% to N% was observed which indicates the high nutrient status of the teak rhizosphere soils. The available phosphorus was also found in good percentage in most of the teak plantations. However, as most of

Table 5. Chemical and physical properties of soil and AM root infection and spore density in teak plantations (1 to 10-year-old)

Sample No.	Locality	Root infection %	AM F sporecount	Soil pH	MC %	OC %	Nam eq/ 100g	Km eq/ 100 g	Cam eq/ 100 g	Mgm eq/ 100 g	N (%)	P (%)
T5	Begur	30.3	289	5.53	2.16	3.56	0.07	0.055	3.09	0.452	0.32	0.31
T11	Vazhachal	83.9	164	4.81	10.01	1.87	0.06	0.049	0.83	0.104	0.19	0.08
T15	Cherupuzha	43.6	100	5.32	10.01	0.99	0.06	0.038	0.78	0.124	0.09	0.13
T23	Valluvassery	26.4	421	4.99	6.09	1.5	0.08	0.051	0.78	0.125	0.17	0.05
T24	Valluvassery	22.3	139	4.85	4.89	1.49	0.08	0.032	1.4	0.163	0.15	0.05
T31	Mallana	13.1	358	6.76	0.56	4.4	0.08	0.057	0.45	0.054	0.49	0.18
T34	Perumthode	8.1	182	6.8	2.02	2.65	0.07	0.057	0.39	0.046	0.04	0.12
T35	Karimpani	12.8	364	6.83	4.31	3.14	0.07	0.063	0.34	0.065	0.34	0.12
T41	Dhoni	3.6	690	7.3	3.16	2.91	0.09	0.177	1.56	0.197	0.37	0.11
T43	Banglamkunnu	23.6	216	7.46	4.05	2.66	0.07	0.06	1.41	0.156	0.33	0.13
T55	Kumaramperoor	17	181	4.76	20.3	3.5	-	-	-	-	-	-
T57	Aryankavu	18	187	4.93	16.02	1.47	-	-	-	-	-	-
T59	Kumbharukadavu	35	108	5.46	9.34	2.39	-	-	-	-	-	-
T61	Kodamala	15	117	5.71	10.86	1.63	-	-	-	-	-	-
T66	Elimullumplackal	55	89	4.76	17.81	2.96	-	-	-	-	-	-

- samples not analysed

Table 6: Chemical and physical properties of soil and AM fungal root infection and spore density in teak plantations (11 to 20-year-old) in different parts of the State

Sample Plot No.	Locality	Root infection%	AMF spore	Soil pH	MC %	OC %	Nam eq/ 100 g	Km eq/ 100 g	Cam eq/ 100 g	Mgm eq/ 100 g	N(%)	P(%)
T4	Panavally	38.2	631	5.35	8.16	2.314	0.109	0.054	2.107	0.22	0.227	0.088
T8	Irumbupalam	73.6	810	5.13	12.34	2.992	0.057	0.072	0.672	0.11	0.34	0.16
T9	Irumbupalam	82.1	357	5.04	13.32	2.176	0.065	0.115	0.861	0.12	0.245	0.096
T13	Kariammurium	33.5	98	5.49	9.34	2.67	0.062	0.063	1.942	0.179	0.21	0.068
T22	Nellikkuthu	25.6	401	5.23	10.03	1.925	0.059	0.023	0.819	0.162	0.213	0.052
T25	Mailady	28	65	4.87	19.01	1.979	0.063	0.048	0.642	0.103	0.232	0.049
T30	Mulamkuzhy	27.5	239	6.92	0.31	5.882	0.056	0.056	0.722	0.111	0.515	0.111
T36	Karimpani	22.9	295	6.59	5.63	2.99	0.074	0.063	0.416	0.09	0.328	0.117
T47	Kottappara	27.1	168	5.73	7.86	2.662	0.068	0.055	0.236	0.048	0.282	0.132
T56	Cheruvalam	27.0	244	5.53	19.33	3.8	-	-	-	-	-	-

- samples not analysed

the soils were moderate to highly acidic, the nutrient availability as well as mobility depend on interrelationships among the various chemical and physical factors of the soils.

Under natural conditions it is believed that AM fungi play a major role in plant nutrient uptake and also stress tolerance mechanism. Arbuscular mycorrhizal fungi increase the volume of soil exploited by plants (Bolan, 1991) by their network of hyphae. Root colonization by AM fungi often results in enhanced uptake of relatively immobile micro-nutrients (Faber et al., 1990; Kothari et al., 1990; Li et al., 1991).

Among soil nutrients, phosphorus availability in particular has been shown to play a major role in

Table 7. Chemical and physical properties of soil and AM fungal root infection and spore density in teak plantations (21 to 40- year-old) in different parts of the State

Plot No.	Locality	Root infection%	AMF spore	Soil pH	MC %	OC %	Nam eq/ 100 g	Km eq/ 100 g	Cam eq/ 100 g	Mgm eq/ 100 g	N(%)	P(%)
T6	Chembuvalli	31.6	174	5.76	2.74	3.196	0.071	0.073	3.804	0.258	0.22	0.057
T7	Bavali	23.1	231	6.01	2.69	1.936	0.06	0.058	0.846	0.541	0.142	0.054
T10	Vazhachal	86.1	461	5.51	15.61	2.547	0.052	0.058	0.809	0.1	0.262	0.15
T12	Kariummurium	38	168	5.24	8.68	1.216	0.069	0.157	0.521	0.09	0.103	0.042
T14	Thannikkadavu	36.1	93	5.09	9.34	1.574	0.059	0.027	0.775	0.207	0.178	0.039
T16	Cherupuzha	30.8	156	5.23	10.03	1.46	0.063	0.07	1.354	0.207	0.177	0.099
T20	Poolakkappara	32	101	5.22	10.39	1.592	0.064	0.036	0.865	0.111	0.196	0.088
T28	Edakkode	43.2	67	5.08	6.11	3.278	0.061	0.043	0.836	0.127	0.274	0.038
T32	Perumthode	6.8	238	7.01	1.8	2.137	0.068	0.067	0.558	0.106	0.298	0.114
T33	Perumthode	9.8	151	6.81	3.01	3.16	0.077	0.057	0.606	0.097	0.301	0.12
T37	Thundamthodu	11	196	6.81	3.61	2.395	0.062	0.044	0.286	0.041	0.285	0.153
T45	Vattappara	16.6	171	7.45	1.25	1.522	0.067	0.071	1.993	0.126	0.195	0.105
T48	Kulathupuzha	32.8	103	6.7	3.12	1.683	0.09	0.06	0.369	0.135	0.179	0.073
T49	Decentmukku	65.2	120	5.6	2.9	2.591	0.058	0.07	0.936	0.204	0.375	0.056
T51	Nadavanoor kadavu	35.7	78	5.3	4.15	2.81	0.086	0.108	0.166	0.075	0.373	0.079
T52	Valara	8	160	4.8	6.8	2.79	-	-	-	-	-	-
T58	Palaruvi	39	169	5.36	11.03	1.6	-	-	-	-	-	-
T62	Valayam	14	169	5.75	9.69	2.32	-	-	-	-	-	-
T65	Perumthammoozhy	53	153	6.18	16.97	2.41	-	-	-	-	-	-
T68	Parambikulam	31	209	6.56	11.24	2.68	-	-	-	-	-	-
T69	Orukomban	46	88	6.5	14.56	3.12	-	-	-	-	-	-
T70	Sungam	29.5	237	6.26	16.16	3.67	-	-	-	-	-	--

Samples not analysed

Table 8. Chemical and physical properties of soil and AM fungal root infection and spore density in teak plantations (>40- year-old)

Sample Plot No.	Locality	Root infection%	AM F spore	Soil pH	MC%	OC%	Na meq/ 100 g	Kmeq/ 100 g	Ca meq/ 100 g	Mg meq/ 100 g	N(%)	P(%)
T3	Naikkatty	43.6	619	5.95	8.03	3.562	0.07	0.047	1.823	0.259	0.183	0.051
T17	Nedumkayam	31.2	83	5.24	9.69	2.218	0.053	0.029	2.161	0.28	0.22	0.068
T18	Pulimunda	31.23	86	5.02	10.02	1.839	0.065	0.031	1.426	0.195	0.203	0.051
T19	Poolakkappara	38	68	5.33	10.11	1.217	0.061	0.057	0.94	0.199	0.169	0.01
T21	Nellikkuthu	39.4	164	5.36	9.81	1.288	0.062	0.038	1.026	0.137	0.136	0.066
T26	Chliarmukku	31.8	29	4.03	19.08	1.895	0.079	0.058	1.441	0.223	0.238	0.053
T27	Akampadam	46	64	5.17	8.31	2.688	0.06	0.076	1.182	0.117	0.274	0.049
T29	Mulamkuzhy	26.5	282	6.48	0.08	3.33	0.057	0.04	0.188	0.042	0.355	0.099
T38	Irumbupalam	23	136	6.65	5.35	2.55	0.067	0.067	0.661	0.114	0.292	0.124
T39	Chakkolatharisu	56.9	110	6.78	5.98	2.349	0.082	0.093	1.637	0.262	0.339	0.145
T40	Vallikkayam	10	190	6.92	3.78	3.365	0.073	0.097	1.705	0.248	0.307	0.089
T42	Dhoni	2	129	7.83	3.89	2.46	0.083	0.095	2.096	0.232	0.295	0.101
T44	Dhoni-Quarters	8.2	138	7.48	2.42	2.783	0.069	0.073	1.938	0.155	0.33	0.131
T46	Walayar	14	146	7.96	0.76	2.045	0.073	0.117	2.689	0.199	0.232	0.106
T50	Kattilappara	15.8	141	5.4	4.16	3.447	0.059	0.172	1.437	0.429	0.419	0.071
T53	Vithura	43	88	4.49	14.91	2.58	-	-	-	-	-	-
T54	Nhaloor	12	206	4.05	17.59	2.53	-	-	-	-	-	-
T60	Kuttippara	26	167	5.76	10.19	1.89	-	-	-	-	-	-
T63	Achankovil	22	194	5.97	10.46	1.49	-	-	-	-	-	-
T64	Konni	10	388	5.69	14.77	2.32	-	-	-	-	-	-
T67	Kannavam	41	164	5.72	19.02		-	-	-	-	-	--

- samples not analysed

plant/mycorrhizal relations (Mosse, 1973; Hayman, 1983). Low phosphorus availability has been repeatedly shown to encourage AM fungal colonization, which in turn improves plant phosphorus nutrition (Daft, 1969; Hayman and Mosse, 1971). The AM fungal root infection in teak plants was found in the range of 2 to 86.1 per cent with a mean of 32.42 per cent and highest per cent infection was recorded in teak plantations belonging to 11 to 20-year-old. In general, young (1 to 10- year-old) as well as old (> 40- year-old) plantations showed comparatively low per cent AM fungal root infection.

The relation between AM fungal root infection percentage and the set of extraneous variables like altitude, age of the plantation and the soil variables like soil pH, soil moisture content (MC%), organic carbon (OC%), total nitrogen (N) and phosphorus (P) percentage, exchangeable cations (Na, Ca, Mg) were analysed through multiple linear regression. Stepwise regression employed to identify the most influential set of variables affecting the root infection percentage showed that soil pH, altitude, soil magnesium (Mg) and sodium (Na) levels influenced the root infection. However, of these soil pH accounted for around 35 per cent of the total variability in AM root infection percentage followed by altitude, magnesium and sodium levels. Effects of all the above variables were significant at 0.05 level, while that of the variables like soil moisture content (MC%), organic carbon (OC%), total available nitrogen (N) and phosphorus (P) and cation (Ca), etc. were found insignificant in the model used (Tables 9-11).

AM root infection and AM fungal spores in rhizosphere soils

The AM fungal spores retrieved from different soil samples ranged from 29 to 810 with a mean value of 216 per 10 g of soil. The AM fungi produce the reproductive structures viz., spores and sporocarps in soil or in infected root tissues. Production of the asexual spores depends on the intrinsic characteristics of the AM fungal species, and influenced by the physical and chemical characteristics of the soil and also the host plants.

Table 9. Analysis of variance of data on AM root infection percentage, altitude and soil physical and chemical characteristics

Source	Degree of freedom	Sum of squares	Mean square	*F* value	*P* > *F*
Model	4	4908.55560	1227.13890	14.16	<.0001
Error	46	3985.46546	86. 64055		
Corrected Total	50	8894.02106			

*Significant at P = 0.05

Table 10: Parameter estimates of regression model relating AM fungal root infection percentage, altitude and soil physical and chemical characteristics

Variables	Parameter Estimate	Standard Error	Type II SS	*F* value	*P* >*F*
Intercept	101.50613	11.13848	7195.42570	83.05	<.0001
Altitude	0.02619	0.00625	1519.71229	17.54	0.0001
Soil pH	-7.70467	1.46454	2397.86919	27.68	<.0001
Na	-296.07794	129.42053	453.44745	5.23	0.0268
Mg	-43.03769	15.23967	690.98420	7.98	0.0070

* Significant at P= 0.05

Table 11. Summary of stepwise selection

Step	Variables entered	Partial R^2	Model R^2	C (p)	*F* value	*P* >*F*
1	Soil pH	0.3537	0.3537	23.0251	26.82	<.0001
2	Altitude	0.0786	0.4324	16.5040	6.65	0.0130
3	Mg	0.0685	0.5009	11.0781	6.45	0.0144
4	Na	0.0510	0.5519	7.5539	5.23	0.0268

* Significant at P = 0.05

Most AM fungi produce spores in large numbers, while a few species produce a limited number of spores in the substratum. Also the available technology employed to assess the spores in soil samples may be inefficient to record all the available spores. Hence, there is limitation in assessing the spore density of AM fungi in soils and requires periodic assessment to get a clear picture about the AM fungal population dynamics. However, total spore density and species-wise frequency were taken into consideration to assign the most predominant AM fungal species in the population. The relation between AM fungal spore density in rhizosphere soil and AM fungal root infection in teak showed a weak linear relation; the correlation coefficient was found non-significant (Figure 1). Correlation between root infection and AM spore count = 0.149226

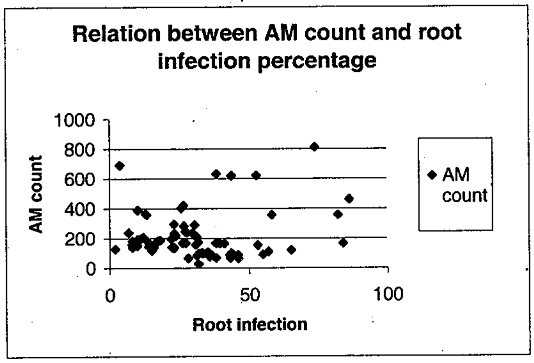

Figure 1. Relation between AM fungal spore density and AM fungal root infection

AM fungal diversity in teak plantations

Teak exhibited varying degree of mycorrhizal root infection under different edaphic and environmental conditions. The AM fungi associated with it also showed diversity in their temporal and spatial distribution. Altogether, 85 species of Glomalean fungi belonging to six genera viz., *Glomus, Acaulospora, Gigaspora, Entrophospora, Scutellospora* and *Sclerocystis* were recorded from the rhizosphere soils from 70 teak plantations. The

Table 12. Distribution of AM fungi in soils under teak plantations in the State

Sl. No.	AM fungi	No. of AM fungal species	Mean No. of AMF spores per plantation	Total No. of AM fungal spores
1	*Glomus*	43	119.44	8361
2	*Sclerocystis*	7	44.52	3117
3	*Scutellospora*	13	8.98	629
4	*Acaulospora*	13	20.35	1425
5	*Entrophospora*	2	1.0	70
6	*Gigaspora*	7	7.2	504
7	Unidentified	-	10.34	724
	Total	85	211.85	14830

AM fungal community in soils under teak consisted of 12 to 39 species belonging to different genera with a mean spore density of 211.85 per sample plot (Table 12).

Among the Glomalean fungi, *Glomus* was the most predominant genus in all the rhizosphere soils samples collected from teak plantations in the State. A total of 43 species belonging to *Glomus* were identified. Of these, 24 species were found widespread in teak soils throughout the State and their mean spore density ranged from 0.76 – 30.61 per sample plot. Among these, *Glomus australe* (Berk.) Berch, *G. botryoides* Rothwell & Victor, *G. deserticola* Trappe, Bloss & Menge, *G. fasciculatum*, *G. geosporum* (Nicol. & Gerd.) Walker, *G. macrocarpum* Tul. & Tul, *G. mosseae*, *G. multicaule* Gerd & Bakshi are the most frequently encountered species and their spore density ranged from 3.65 – 30.61 (Figure 2). Another 16 *Glomus* species were found sparsely distributed in soils under teak in the State with a mean spore density of 0.028 – 0.385 per plot.

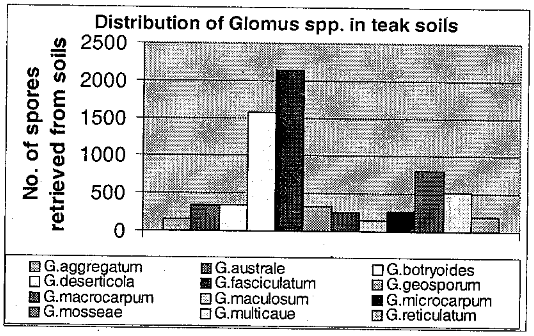

Figure 2. Distribution of *Glomus* spp. in soils under teak plantations

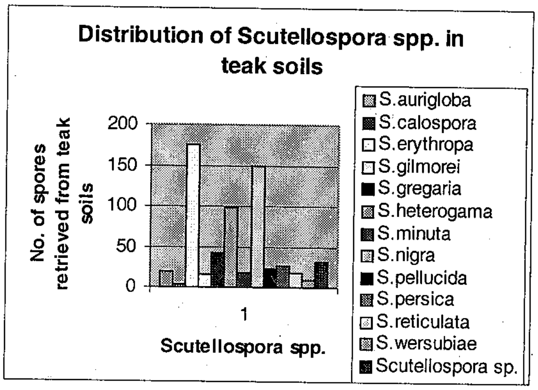

Figure 3. Distribution of *Scutellospora* spp. in soils under teak plantations

Thirteen species of *Scutellospora* were recorded from the teak rhizosphere soils. Among these, *Scutellospora erythropa* (Koske & Walker) Walker & Sanders, *Scut. heterogama* (Nocol. & Gerd.) Walker & Sanders, *Scut. nigra* ((Redhead) Walker & Sanders, and *Scut. persica* (Koske & Walker) Walker & Sanders were the most widely distributed species (Figure 3). Many spores belonging to *Scutellospora* could not be identified up to species level due to lack of murographic evidences.

A total of 13 *Acaulospora* species were recorded from the teak rhizosphere soils from the State. The spore density of individual species varied from 1.14 – 8.08 and the mean spore density of of sample plot recorded was 20.35. *Acaulospora appendicula*, *A. scorbiculata* Trappe, *A. rehmii* Sieverding & Toro, *A. spinosa* Walker & Trappe were the most frequently encountered species in teak soils. Even though, the spore density recorded was comparatively less than

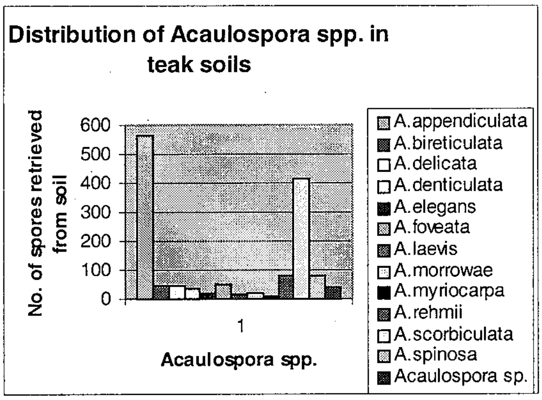

Figure 4. Distribution of *Acaulospora* spp. in soils under teak plantations

the above species, *A. bireticulata* Rothwell & Trappe, *A. foveata* Trappe & Janos and *A. delicata* Walker, Pfeiffer & Bloss were also represented in most of the teak soils (Figure 4). A large number of spores (> 40) of *Acaulospora* could not fit into descriptions of known species. Even though, the present study indicates a predominance of *Glomus* over other AM fungal genera, the genus *Acaulospora* represented all the soil samples from teak plantations and is one of the important component of the AM fungal community.

The genera *Acaulospora* and *Scutellospora* are diverse in the tropics (Walker, 1992; Allen et al., 1995) and are often associated with acidic soils (Morton, 1986; Abbott and Robson, 1991). Similar observations have also been made in the tropical soils by Raghupathy and Mahadevan (1993), Thapar and Khan (1985) and Muthukumar and Udaiyan (2000). In the present study also *Acaulospora* and *Scutellospora* species recorded a moderately high frequency of occurrence in most of the soil samples. The soil samples from teak plantations except in Olavakkod, Walayar and Kodanad Forest Ranges were moderately to highly acidic. However, no difference could be recorded on their distributional pattern in near neutral or basic soils.

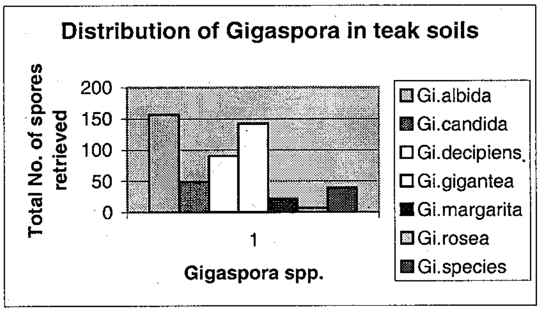

Figure 5. Distribution of *Gigaspora* spp. in soils under teak plantations

Seven species of *Gigaspora* were recorded from the rhizosphere soils collected from different teak plantations with a mean spore density of 7.2 per sample plot. Among these *Gigaspora albida* Schenck & Smith, *Gi. decipiens* Hall & Abbott and *Gi. gigantea* (Nicol. & Gerd.) Gerd. & Trappe)were the most frequently observed and widely distributed species in teak plantations (Figure 5). Many spores (> 39) belonging to the genus *Gigaspora* could not be identified up to species level due to want of more murographic information. Usually *Gigaspora* and *Scutellospora* were observed more frequently in sandy soils. *Gigaspora* species have been reported to predominate in soils with a high sand content (Day et al., 1987; Lee and Koske, 1994).

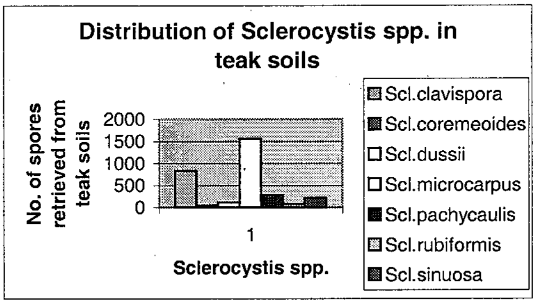

Figure 6. Distribution of *Sclerocystis* spp. in soils under teak plantations

Seven species of *Sclerocystis*, viz., *S.clavispora* Trappe, *S. coremeoides* Berk. & Broome , *S. dussii* (Pat.) von Hohn., *S. microcarpus* Iqbal & Bushra, *S. pachycaulis* Wu & Chen, *S. rubiformis* Gerd. & Trappe, and *S. sinuosa* Gerd. & Bakshi were recorded in soils from teak plantations, suggesting the common and diverse occurrence of this genus in tropical plantation soils. Among these, *Sclerocystis microcarpus* and *S. clavispora* are the most widely distributed species (Figure 6). *Sclerocystis dussii* and *S. rubiformis* were recorded from 36-year-old and 20-year-old teak plantations respectively at Baveli (Begur Forest Range) and Irumpupalam (Vazhachal Forest Range). *Sclerocystis coremeoides* was recorded from 40-year-old teak plantation at Mannarappara and *S. sinuosa* was recorded from 46-year-old teak plantation at Naikatty (Tholpetty Forest Range), 37year-old teak plantation at Perumthode (Kodanad Forest Range), and 50-year-old plantation at Kottappara (Kodanad Forest Range). The mean spore density was 44.52 spore per sample plot. Species of *Sclerocystis* produce spores in sporocarps and usually by wet seiving and decanting method, intact sporocarps are obtained apart from freed single spores. However, individual spores have been taken as propagule unit for the spore density studies and hence the comparatively high spore density per sample plot. Frequency of distribution of *Sclerocystis* species was found comparatively low when compared with other Glomalean fungi.

Among the Glomalean fungi, *Entrophospora* represented only two species, viz., *Entrophospora columbiana* Spain & Schenck and *E. infrequens* (Hall) Ames & Schneider in rhizosphere soils of teak plantations in the State. The distribution of the genus was found very limited and many of the spores (>58) belonging to *Entrophospora* could not be identified up to species level due to lack of characteristic features. In general, *Entrophospora* showed a poor representation in the Glomalean fungal community in the teak rhizosphere soils. Relative abundance of AM fungi in teak plantation soils was measured using Shannon-Wiener index and Simpson's index. The Shannon-Wiener index ranged from 1.5532 to 3.0032, whereas Simpson's index ranged from 3.0508 to 16.6012.

Gamma diversity, and beta diversity of AM fungal species in teak plantation soils were worked out separately. Gamma diversity is the number of fungal species that occur in a heterogeneous region. Within this region, the fungi are adapted for the general conditions, but within different habitats they may have specialized for exploiting different resources. The actual species may be different in the habitats, so the species turnover is important. Beta diversity, the species turnover in a heterogeneous habitat was estimated by dividing gamma diversity by alpha diversity. Gamma and beta diversity of AM fungi estimated in teak plantation were 98 and 69 respectively.

CONCLUSIONS

Teak growing under different edaphic and climatic conditions in the State exhibits a high arbuscular mycorrhizal association and different AM fungi were found associated with the infection of feeder roots. Among various factors influencing the AM fungal association, soil pH is found to be the most important one. Teak soils through out the State, except in three to four plantations are moderately to highly acidic and the AM fungi were found thriving best in these soils. Teak rhizosphere soils harbour a rich Glomalean fungal flora and the species composition, species richness, etc. vary depending upon the physical and chemical characteristics of the soils as well as environmental conditions. The presence of rich Glomalean flora in soils under teak as well as high arbuscular mycorrhizal dependency of teak suggest the possibility of improving the biological properties of soils under teak as well as stand productivity through mycorrhizal manipulations. Efficient AM fungal candidates can be selected from the existing natural population and introduced in rhizosphere of young seedlings for early mycorrhization and improvement of the planting stock.

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Status of Colonization and Spore Population of Arbuscular Mycorrhizal Fungi in *Tectona grandis* L. from Bangladesh

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ABSTRACT

The status of colonization of Arbuscular Mycorrhizal (AM) fungi in the roots and spore population in the rhizosphere soils of Teak (*Tectona grandis* L.) were assessed. Roots and rhizosphere soils of teak plants both from nursery and plantations were collected from different areas of Bangladesh. All the samples showed to be colonized by AM fungi. Percent root colonization varied widely irrespective of age and sites of collection. The range of colonization was 56-95%. Maximum colonization (95) was from Singra plantation and the minimum (56) was from Rajosthali plantation. The intensity of structural colonization was also variable irrespective of age and sites of collection. Spore population was found in all soil samples. The highest population was (659) from the soil of Rajosthali nursery and the lowest was (169). from Hazarikhil forest. *Glomus* was highest (67%) in Madhupur plantation and lowest (23%) in Chittagong University nursery. *Acaulospora* was minimum (13%) in Dharmapur plantation and maximum (31%) in Singra plantation. *Gigaspora* was highest (77%) in Chittagong University nursery and lowest in (03) in Khaskhali nursery. Biodiversity of structural colonization in the roots and AM fungal spore population in the rhizosphere soils of teak growing areas highlights the dependency of teak on arbuscular mycorrhizal fungi. Hence it is necessary to uptake the AM technology in the nursery and plantation for better, useful and ecofriendly management of teak.

Keywords: Teak, *Tectona grandis*, mucorrhizae, rhizosphere

INTRODUCTION

Tectona grandis L. occurs naturally in India, Myanmar, Thailand, Laos, Indonesia, and some of the smaller islands in the archipelago (Negi, 1996). The plantations were started in India as early as 1840 and extended in Africa, Latin America, Bangladesh, Philippines, Vietnam, Fiji etc. (Kadambi, 1972; Negi, 1996; Ryan, 1982; White, 1991). The inherent good qualities of the timber, its early fast growth and the ease in the plantation establishment make teak the most preferred species among users, farmers and private entrepreneurs in many countries (Indira and Basha, 1999). It grows well in the soils with slight acid pH ranging 6.0-7.4 and precipitation range 1250-2500 mm (Zabala, 1989). Arbuscular Mycorrhizal (AM) fungi, an ubiquitous soil borne Zygomycetous (Morton and Benny, 1990) fungi, are now well being considered as biofertilizers in the forestry management (Alexander, 1989; Janos, 1980; Mridha *et al.*, 2001; Verma and Jamaluddin, 1995). They help the forest trees in up-taking nutrients particularly phosphorus (Smith and Read, 1997), make disease resistance (Dehne, 1982; Jalali and Jalali,1991), improve water relations (Auge, *et al.*, 1987; Auge, 2001), and drought tolerance (Bethlenfalvay *et al.*, 1988) and thus accelerate the ability of the forest plants to compete for resources contributing to efficient recycling of nutrients. AM association in the roots, mycorrhizal dependency and the biodiversity of AM fungi in the rhizosphere soils of teak were studied in India by many workers(e.g. Verma and Jamaluddin, 1995; Kumar *et al.*, 2000). In

Bangladesh, Rahman *et al.*, (2000) studied the effect of presowing treatment on the AM colonization in teak. Vertical distribution of AM fungi in the rhizosphere soils of teak was also studied (Rahman and Mridha, 2003). The present study was accomplished to observe the status of the biodiversity of the arbuscular mycorrhizal colonization in the roots and spore population in the soils of growing nurseries and plantations in different parts of Bangladesh.

MATERIALS AND METHODS

Site selection

Rhizosphere soils and roots of *T. grandis* were collected from Chittagong University campus, Dharmapur, Singra, Hazarikhil (Fatikchari, Chittagong), Rajosthali (Rangamati), Aagoonia forest (Rangunia, Chittagong), Thandachari (Rangunia Chittagong), Khaskhali (Rangunia, Chittagong), Madhupur (Tangail) forests.

Sample collection

Samples were collected from nurseries and plantations. From nurseries seedlings grown in polythene bags were collected for roots and soils. From plantations rhizosphere soils were collected from 0-15cm. depth. Plants were selected randomly irrespective of age.

Spore extraction

Fine roots were separated from soils in the laboratory and preserved in 5% formalin for future use. The soils were sieved with 2mm sieve to remove the gravel and other particles. To avoid the damage or desiccation of the spores, soils were assessed immediately after collection. From each sample, 100 gm of soils were taken in a bucket of 5-litre capacity and 1 litre of water was mixed with the soils. The soils were mixed well with water by the soft pressure of the thumb and index fingers and a soil-water suspension was made. The suspension was left for five minutes for settle down of insoluble and heavy particles. The suspension was passed through the 400¼m, 240 ¼m, 100 ¼m and 60 ¼m. sieves gradually to extract the spores following by wet sieving and decanting method (Gerdemann and Nicolson, 1963). The supernatants on the sieves were taken separately in wash glasses and observed under stereo-binocular microscope at 10 X 2.5 magnifications. Larger spores, sporocarps and any structures resembling AM spores were separated from the supernatants of the sieves of 400¼m and 240 ¼m. by soft forceps. They were further observed under compound microscope at 10 X 10 and 10 X 40 magnifications. Relatively smaller spores were collected in a wash glass from the 100 μm. and 60 μm. sieves with water. The suspension of water and spores were filtered by the Whatman filter paper-1. Squares were drawnb on the filter paper by intersecting lines for easy counting of spores. Total number of spores were counted as the sum of larger and smaller spores and sporocarps if found. Morphologically similar spores were mounted in Melzer's reagent and PVLG separately and they were observed under compound microscope for identification at 15 X 10 and 15 X 40 magnifications. Identification of spores was done by following the manual of Schenk and Perez (1990) and Morton and Benny (1990).

Root staining

Roots of the collected specimens preserved in the formalin were washed very well to remove formalin and were chopped into 1cm pieces and stained in aniline blue by following the procedures of Phillips and Hayman, (1970). After distaining the roots in acidic glycerol they were mounted on the slides five pieces on each side and thus ten pieces per slide. A total of 100 segments of stained roots were studied for each sample. Presence of mycelium was treated as AM positive. Percent colonization and percent intensity were calculated by the following formulae:

$$\%\ \text{Colonization} = \frac{\text{Total number of AM positive segments} \times 100}{\text{Total number of segments studied}}$$

The intensity was recorded as poor, moderate and abundant. The intensity of mycelial, vesicular and arbuscular colonization were recorded as Poor (less than 10% area covered), Moderate (more than 10 % area covered) and Abundant (more than 25% area covered).

RESULTS

Results of the biodiversity of structural colonization in the roots and the spore population of Arbuscular Mycorrhizal fungi in the rhizosphere soils of *T. grandis* varied considerably. Percent root colonization of AM fungi ranged 53 to 95 (Table- 1 & 2). The highest colonization was recorded with the samples from Singra plantation and the lowest was from Rajosthali nursery. In all samples the intensity of mycelial colonization was variable. Vesicles and arbuscules were found in all specimens. Arbuscules were absent in nursery seedlings from Chittagong University Campus and trees from Madhupur plantation.

AM fungal propagules were observed in all the soil specimens. The highest number population of AM spores (659) was observed in the soils of nursery seedlings from Rajosthali and the lowest population (169) was from Hazarikhil plantation. All kinds of AM fungi under six established genera were discovered in Bangladesh from the specimens under study. *Glomus* was found in all samples and the range was minimum (23%) in the nursery seedlings from Chittagong University Campus and maximum (67%) in the plantation samples from Madhupur. *Acaulospora* was present in all samples except samples from nursery seedlings from Chittagong University campus, Aagoonia forest plantation and Madhupur plantation. Maximum *Acaulospora* (31 %) was from Singra plantation and minimum (13%) was from Dharmarpur plantation. *Entrophospora* was observed in four samples and these are from plantation in Chittagong University campus, Rajosthali nursery, Aagoonia forest plantation and Madhupur plantation. Highest percent was (10) from Rajosthali nursery and Chittagong University campus. The lowest (6) was from Madhupur plantation. *Gigaspora* was found in 10 samples. The percentage was 3-77. The lowest was with Khaskhali nursery seedlings (3) and highest was with nursery seedlings from Chittagong University campus (77). *Sclerocystis* was found in three samples and 2-18% *Sclerocystis* was found in the study. Khaskhali nursery seedling produced the highest.

Plants with higher ages showed comparatively

Table 1. Biodiversity of structural colonization in the roots of *Tectona grandis* growing in the Nurseries from different parts of Bangladesh.

Location	Age (Yr)	Total Colonization (%)	Mycelium			Vesicles			Arbuscules		
			P	M	A	P	M	A	P	M	A
Ctg. Unv. Campus	1	87	45	48	7	63	15	22	-	-	
Rajastholi	1	53	12	13	28	15	17	22	12	15	18
Khaskhali	1	69	35	24	-	18	29	30	20	22	-

P= Poor:; M= Moderate and A= Abundant number

Table 2. Bio-diversity of structural colonization in the roots of *T. grandis* grown in the plantations from different parts of Bangladesh

Location	Age (Yrs)	Total Colonization(%)	Mycelium			Vesicles			Arbuscules		
			P	M	A	P	M	A	P	M	A
Ctg. Unv. Campus	18	90	32	20	48	22	24	22	8	16	4
Dharmapur	20	85	21	50	14	12	24	17	15	34	10
Singra	25	95	22	26	47	14	21	11	8	11	16
Rajosthali	10	56	12	15	29	14	18	14	10	24	13
Rajosthali	15	68	27	24	17	24	28	24	13	27	22
Hazarikhil	25	86	20	26	40	-	60	40	-	40	-
Aagoonia	18	72	20	28	24	12	18	30	-	42	38
Thandachari	15	77	13	25	42	24	22	21	15	18	20
Madhupur	20	77	22	33	22	14	5	14	-	-	-

P= Poor M=Moderate and A=Abundant

Table 3: Biodiversity of arbuscular mycorrhizal fungi in the rhizosphere soils of *T. grandis* growing in the Nurseries from different parts of Bangladesh.

Location	Age (yrs)	Total spore	Glom.	Scle.	Acaul.	Entro.	Gigas.	Scut.	Unid.
Ctg.Univ. Campus	1	337	23	-	-	-	77	-	-
Rajastholi	1	659	50	-	22	10	15		7
Khaskhali	1	326	61	18	18	-	3	-	

Note: Ctg Univ.- Chittagong University ,Nrsry- Nursery, Plntn-Plantation, Glom- *Glomus*, Scle- *Sclerocystis*, Acaul- *Acaulospora*, Entro- *Entrophospora*, Gigas- *Gigaspora*, Scut-*Scutellospora*, Unid- Unidentified

higher colonization. The range of colonization was 56-95%. 10 years old plants showed the minimum and 25 years plant showed the maximum colonization. Nursery seedlings of 1-year age showed moderate colonization (53-87%). AM fungal spore population was higher for the samples of 1-year nursery seedlings (326-659) and it was moderate for the samples of older plants (169-440). Status of AM fungi was diverse in the soils of older plant samples than the nursery seedlings.

DISCUSSION

All the teak samples in the study showed AM colonization irrespective of age and location. Percent root colonization, intensity of mycelial, vesicular and arbuscular colonization varied considerably irrespective to the sites and locations. Earlier studies have shown variation in percent colonization in the roots and AMF spores in the rhizosphere soils of various arid zone tree species under different sites or soil conditions (Mohan and Verma, 1995; Mohan *et al.*, 1995; Mohan and Singh, 1996, 1997; Mohan and Mishra, 1998). The variation in percent root colonization and intensity of colonization were also reported by Verma and Jamaluddin (1995), Rahman *et al.*, (2000) and Rahman and Mridha (2003). Percent colonization was observed lowest in the Rajosthali nursery seedlings whereas the samples from Chittagong University campus showed the highest. This variation may be due to variation in the soils properties of different locations. The intensity of colonization was not homogeneous and mycelial, vesicular and arbuscular intensity varied independently. Vesicular intensity was more or less moderate and abundant in all species. Arbuscular intensity was mostly moderate and abundant. It may be explained that all specimens were mycotrophic and arbuscular mycorrhizal association was active in nutrient uptake and growth of teak plant in all locations and sites. The intensity of AM colonization in roots and spores in the soils of *T. grandis* in nurseries and plantation sites varied irrespective of age of the plants and site factors. In the nurseries, general practices like fertilization, irrigation, mulching etc. are practiced as schedule work. Verma and Jamaluddin (1995) reported that removal of grasses, weeds and other cultural practices might

Table 4. Biodiversity of arbuscular mycorrhizal fungi in the rhizosphere soils of *T. grandis* from different parts of Bangladesh

Location	Age (yrs)	Total spore	Glom.	Scle	Acaul	Entro	Gigas	Scut	Unid.
Ctg.Univ. Campus	18	287	43	2	21	10	18	6	-
Dharmapur	20	267	50	-	13	-	19	6	12
Singra	25	294	62	-	31	-			7
Rajosthali	10	296	36	-	25	-	10	2	25
Rajosthali	15	198	40	-	24	-	12	-	24
Hazarikhil	25	**169**	61	-	17	-	-	-	22
Aagoonia	18	217	45	-	-	7	22	9	17
Thandachari	15	270	52	12	14	-	18	-	6
Madhupur	20	440	67	-	-	6	22	2	2

Note: Ctg Univ.- Chittagong University ,Nrsry- Nursery, Plntn-Plantation, Glom- *Glomus*, Scle- *Sclerocystis*, Acaul- *Acaulospora*, Entro- *Entrophospora*, Gigas- *Gigaspora*, Scut-*Scutellospora*, Unid- Unidentified cause low colonization. In the present study no correlation was observed between the percent colonization and spore populations. It differs with the comment of Verma and Jamaluddin (1995). Many authors reported the positive correlation between highest colonization and highest spore population, e.g. Saif and Khan (1975).

Differences in colonization were attributed to root hairs, root length, root production, root fibrosis and root geometry (Ikram, 1995). The mixed AMF inoculum may have its component reacting differently in different soils. The variation in the percent root colonization in the roots and spores in the soils of different species might explain the generally held view that plants with coarse root system gain more AM fungal colonization (Mahmud *et al.*, 1999.) compare to those with fine roots. These differences might be due to the presence of diverse type of AMF in soils of specimens from different locations and sites or might be a great host susceptibility to AMF (Mehrotra, 1998); variation in water availability (Allen, 1983; Mohan *et al.*, 1995) and many other factors (Abbott and Robson, 1991). In the seedlings, arbuscules were very few. It might be due to the low moisture content in the substratum soils of the seedlings. Arbuscules were more in the roots of higher aged plants than the nursery seedlings indicated that AM fugal symbionts were highly active during nutrient uptake in the plantations sites. Reports reveal that sufficient moisture in the soil favors the arbuscules formation (see Siguenza *et al.*, 1996). In the plantation sites, canopy of the plantations saves enough moisture in the forest floor; whereas substratum soils of nursery seedling become dry for which the variation of the arbuscular intensity in the nurseries and plantations might occur.

Glomus was found to be the most predominant fungi. This study corroborates with the earlier findings of AM association with tree species by many researchers (Gerdemann and Trappe, 1974; Blaszkowski, 1989; Talukder and Germida, 1993; Thapar and Khan, 1988; Mukerji and Kapoor, 1986; Tarafder and Rao, 1990; Thapar *et al.*, 1992; Mohan *et al.*, 1995; Mohan and Singh, 1996, 1997;) *Glomus* spp. are widespread and consistent both in nurseries and plantations, which makes them most favorable for mass multiplication and seedling inoculations of *T. grandis*. In the study, the total spore density did not correlate with mycorrhizal colonization probably because of the presence of different AM fungal species (Mehrotra, 1998). Species richness and spore density of AMF depend on the area-sampled, season of sampling and annual variation in precipitation and temperature (Allen *et al.*, 1995). The factors like edaphic factor, climatic conditions, host-fungus compatibility, root properties and soil microorganisms might influence the abundance of spore population and mycorrhizal colonization. Spore density in the soils was reported to be related to the soils moisture content and the phenology of the host plant like growing season, flowering seasons, fruit developing stage etc.(Siguenza *et al.*, 1996).

Samples in the present investigation were collected from different agro-ecological zones of which the soil factors and other soil related factors were variable. Muthukumar *et al.*, (1994) reported the positive correlation between soil moisture and root colonization. These varying properties of soils of different places need to be studied in the assessment of AMF species diversity in the soils of teak growing areas. Most of the teak growing areas are hilly and the topography is high to moderately steep. Variation in spore population of AM fungi was reported by Mridha *et al.* (1995) regarding steepness of the hills. Findings of the present study reveal that the low fertility in the soils of teak growing areas enhances the AM fungal colonization in the roots for mineral acquisition.

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Significance of Micronutrients on the Growth of Teak Seedlings

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ABSTRACT

A study was conducted to assess the importance of micronutrients on the growth of teak seedlings using sand culture technique. Two-month-old teak seedlings were grown in white quartz sand and they were supplied with modified Hoagland nutrient solutions deficient in Fe, Cu, Zn, Mn, Mo and B. After a period of about 45 days, the plants started to develop various types of abnormalities. Regular observation revealed that the deficiency of all the micronutrients resulted in the retardation of plant growth. Compared to control, maximum height reduction was noticed due to the shortage of Mo and the least due to B. There was a drastic reduction in the number of healthy leaves due to the deficiency of all micronutrients, the more reduction with Fe deficient plants and the least with B. Deficiency of micronutrients also resulted in shortened internodes, production of long abnormal leaves and termination of apical growth in teak seedlings.

Keywords: Micronutrients, deficiency, teak, seedling growth

INTRODUCTION

Production of healthy and vigorous seedlings in nurseries demands balanced supply of both macro- and micronutrients. Compared to macronutrients, the requirement of micronutrients by the plants is very small, but their deficiency usually leads to abnormal or retarded growth. Teak being one of the high valued timbers of Kerala, large number of seedlings are produced and supplied every year for establishment of plantations. Teak planting stock is usually produced in raised beds or polybags, uprooted after one year, and used to produce stump, which is planted in crowbar holes at the outplanting site. Continuous production of seedlings at the same place leads to depletion of site fertility. Failure to recoup the lost fertility or recoupment with fertilizers devoid of micronutrients often results in micronutrient deficiencies. Recently, seedlings of teak are also being raised in root trainers using compost as the main potting media. Even though, compost is a rich source of plant nutrients, the root trainer grown seedlings often suffer from imbalanced nutrition leading to deficiencies of micronutrients. Even though the studies (Angadi *et al.*,1988; Kamala *et al.*,1986; Sujatha, 2003) on the foliar diagnosis of micronutrient deficiencies in teak seedlings are available, the importance of micronutrients on the growth of teak seedlings is yet to be analysed. Hence the present study mainly focuses on the influence of micronutrients on the growth of teak seedlings

MATERIAL AND METHODS

Germinated seedlings of teak were transplanted to the polythene bags containing potting mixture of sand, soil and cow dung. After a period of two months, the seedlings were uprooted; roots were washed thoroughly with deionised water and then transplanted to the pots containing acid washed white quartz sand (Plate1). The pots with the seedlings were kept under glasshouse condition and arranged in seven groups, each group containing 10 pots. The plants were supplied with 50 ml of deionised water twice a day during the first four days and after that once a day regularly. Modified Hoagland No. 2 nutrient solutions containing all the micro and macronutrient solutions were prepared separately (Table 1). After a period of two weeks, nutrient solutions deficient in Zn, Fe, Cu, Mn, Mo and B respectively were supplied to the first six groups @ 50 ml/pot twice a week for the first 30 days and after that on alternate days and on other days they were fed with deionised water only. Two ml of $FeSO_4$ was added separately to all the plants except those, which were labelled as –Fe. The pots in the seventh group were kept as control.

All the plants were observed regularly. Data on plant height and number of healthy leaves were recorded during three and six months after planting. Details on the expression of other abnormalities specific to each nutrient were also recorded.

RESULTS AND DISCUSSION

Growth of plants in all the pots was monitored regularly and the growth parameters mainly the height and total number of healthy leaves were

Plate 1. General view of the teak seedlings grown in white quartz sand

Plate a. Control with Fe deficient plant

Plate b. Control with Cu deficient plant

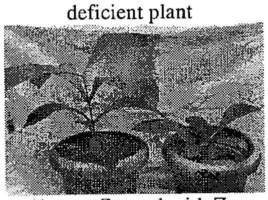

Plate c. Control with Zn deficient plant

Plate d. Control with Mn deficient plant

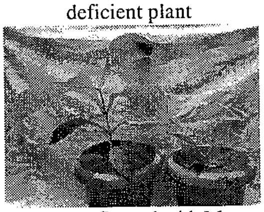

Plate e. Control with Mo deficient plant

Plate e. Control with Mo deficient plant

Plate 2. Comparative growth performance of teak seedlings deficient in micronutrients

Table 1. Composition of modified Hoagland No.2 solution

	Compound	Concentration of stock solution, M	Vol. of stock solution per litre of final solution, ml
Macronutrient	KNO_3	1.0	6
	$Ca(NO_3)_2$	1.0	4
	$NH_4H_2PO_4$	1.0	2
	$MgSO_4.7H_2O$	1.0	1
Micronutrient	KCl	50	
	H_3BO_3	25	
	$MnSO_4.H_2O$	2.0	1
	$ZnSO_4.7H_2O$	2.0	
	$CuSO_4.5H_20$	0.5	
	H_2MoO_4	0.5	
	$FeSO_4$	20	

recorded during three and six months after planting. Total biomass, which is also a measure of growth, was not taken into consideration since in some cases the deficiency of nutrients leads to the development of large abnormal sized leaves which may lead to some erratic results. Compared to control, deficiency of all the nutrients resulted in drastic retardation in the growth of plants (Plate 2a to 2f). As revealed in the Plates 3a, 3b, 3c and 10d the deficiency of Fe, Cu, Mn and Mo respectively led to the shortening of internodes and clustering of branches. Similarly, development of long leaves (Plate 4a to 4d) were seen due to the deficiency of Cu, Zn, Mn and Mo. There was considerable reduction in the height of the plants (Table 2) due to the deficiency of micronutrients when compared with control. The reduction in height varied between 18 and 45% during three months after planting and it increased to 20-52% six months after planting. Among the nutrients, Mo and Cu caused more growth reduction and B the least at early stage. Similar observations were recorded six months after planting also. Similarly, the number of healthy leaves in B deficient plants were on par with control during three months after planting. During this stage Fe deficient plants had less number of healthy leaves; 69.2% less than control. The reduction in healthy leaves over control was 38.5% in Cu and Zn deficient plants and 23.1% in Mn and Mo deficient plants. But at the severe stage of deficiency, the number of healthy leaves were 87.5% less in Fe, Mn, and B deficient plants and 81.5% less in Cu, Zn and Mo deficient plants than control.


Plate a. Fe deficient plant

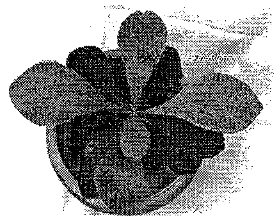
Plate b. Cu deficient plant

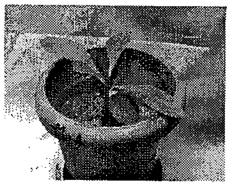
Plate c. Mn deficient plant

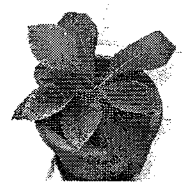
Plate d. Mo deficient plant

Plate 3. Shortening of internodes due to the deficiency of micronutrients

As shown in Plate 5, the growth of root system was considerably affected when all the micronutrients were not supplied. But, when each nutrient was considered individually, only the deficiency of Cu resulted in retardation of root growth (Table 2).

Thus it was observed that even though the reduction in plant growth due to the deficiency of micronutrients was less during the early stage, it was severe at advanced stage

CONCLUSION

The study in general revealed that the deficiency of

Table 2. Growth of teak seedlings due to the deficiency of micronutrients

Treatment	At the time of planting		Three months after planting				Six months after planting				
	Ht. (cm)	No. of leaves	Height		Healthy leaves		Height		Healthy leaves		Dry root weight (g)
			cm	%reduction	No.	%reduction	cm	% reduction	No.	% reduction	
Control	2.6	6	42.2	-	13	-	62.3	-	16	-	12.64
Fe	2.5	6	28.4	33	4	69.2	33.6	46	2	87.5	13.82
-Cu	1.9	5	24.3	42	8	38.5	35.4	43	3	81.3	7.79
-Zn	2.6	5	26.1	38	8	38.5	32.8	47	3	81.3	14.45
-Mn	2.6	6	27.3	35	10	23.1	35.9	42	2	87.5	10.92
-Mo	2.6	6	23.1	45	10	23.1	29.6	52	3	81.3	12.92
- B	2.6	6	34.8	18	13	—	49.6	20	2	87.5	10.22

n=10

Plate a. Cu deficient plant

Plate b. Zn deficient plant

Plate c. Mn deficient plant

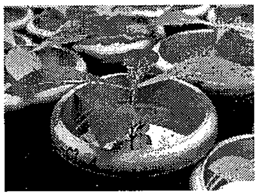

Plate d. Mo deficient plant

Plate 4. Production of long abnormal leaves due to the deficiency of micronutrients

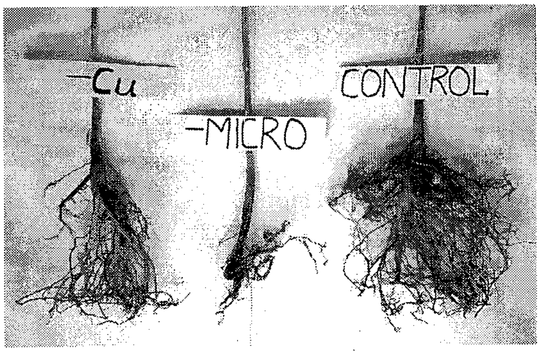

Plate 5. Retardation of root growth due to the deficiency of micronutrients

each micronutrient expressed some common abnormalities such as growth retardation, shortening of internodes, production of long abnormal and unhealthy leaves, etc. The reduction in height was more in Mo and Cu deficient plants and the minimum in B deficient plants at severe stage deficiency. Similarly, there was a drastic reduction in the number of healthy leaves due to the deficiency of all micronutrients, the more reduction in Fe deficient plants and minimum with B. Even though, the reduction in plant growth due to the deficiency of micronutrients was less during the early stage, it was severe at advanced stage of deficiency.

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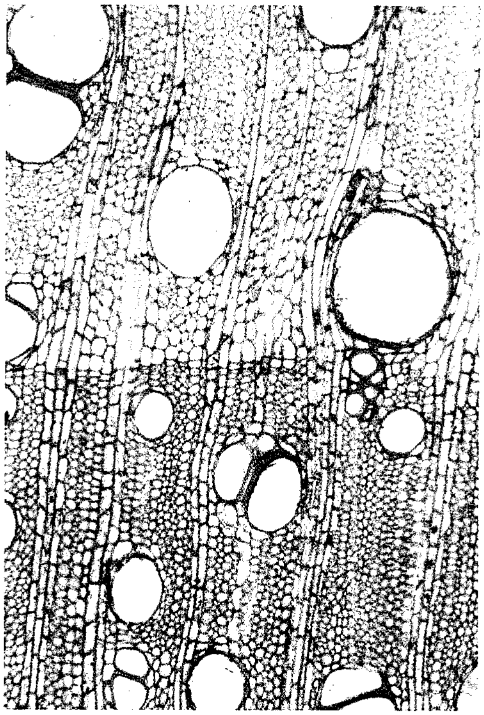
Growth, Wood Formation and Productivity



Some Characteristics of Wood Formation in Teak (*Tectona grandis*) with Special Reference to Water Conditions

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ABSTRACT

Three areas of teak plantation were selected to investigate some characteristics of wood formation in relation to water conditions. In Java Island of Indonesia, trees of two areas, namely Sukabumi (West Java) and Cepu (Central Java) were compared. In Sukabumi, trees belonging to tropical rainforests had less distinct growth rings, as compared to Cepu, which has a clearly dry season. Heartwood colour of Sukabumi trees was also darker than those of Cepu. In Malaysia, growth rings of 14-year-old plantation grown trees were investigated. Forty growth rings or growth ring-like structures were counted from bark to pith, which indicates the complexity of conditions related to wood formation. Preliminary measurements of leaf water potential were carried out in Thailand to study the physiological role of water to wood formation. Short period of low water potential in rainy season affected the cambial activity resulting in the formation of weak growth ring boundaries.

Keywords: Growth ring, annual ring, heartwood, leaf water potential, tropical rainforest, seasonal forest, starch, lipids.

INTRODUCTION

Teak (*Tectona grandis*) is a tree species that is indigenous to monsoon Asia, including India, Myanmar, Thailand, etc. It is also widely planted in tropical and sub-tropical areas because of its excellent wood quality. Many studies have been carried out on various aspects of teak (Ferguson, 1934; Burmester and Wille, 1975; Datta and Kumar, 1987; Sanwo, 1987). For the production of quality timber, it is important to examine how far the meteorological conditions affect the wood quality. In tropical areas water conditions are considered to be the key factor influencing the wood formation. In this study, some aspects of wood formation in teak are examined with special reference to water conditions.

Three sites were selected for the study: Java Island, Indonesia, Peninsular Malaysia and North -eastern part of Thailand. Growth ring structure was studied in three sites. Heartwood characteristics were investigated in Indonesia and the relationship between leaf water potential and wood formation was studied in Thailand.

STUDY SITES AND METHODS

Java Island, Indonesia

Java Island extends from west to east. The meteorological conditions especially of rainfall are different between west and central and eastern parts. It is, therefore, said that wood characteristics such as heartwood color are different between two areas. In the present study two sites, Sukabumi in West Java and Cepu in Central Java were selected.

The monthly rainfall in two areas is shown in Fig. 1.

Safranin stained transverse sections were observed under a light microscope to investigate growth ring structure. For the observation of cell contents, light microscopic observation of radial longitudinal sections was carried out after staining with I2KI for starch grains or Sudan IV for lipid droplets. Total lipids were measured using chloroform and methanol extraction method (Folch *et al.*, 1957). Heartwood color was measured by a colorimeter and a*, b* and L* were compared between two sites.

Peninsular Malaysia

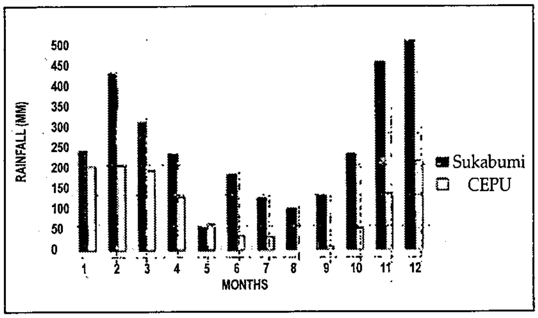

Figure 1. Meteorological condition of monthly rainfall (average from 1994 to 1998) in Cepu and Sukabumi, Java Island.

Fourteen-year-old plantation grown teak was selected for the investigation. A disk cut from the lower part of the stem (0.8m above the ground level) was investigated. All of the growth rings or growth ring-like structure were numbered. A radial strip was cut from the disk. Transverse sections from the bark to the pith were observed under a light microscope to investigate growth ring structure.

Thailand

Plantation grown trees in Northeastern part of Thailand were used. The forest belongs to seasonal tropical forest with dry and rainy seasons. Seasonal changes of leaf water potential were measured using a pressure chamber. Leaves from the upper part of crown (sun leaf) were measured just before sunrise and in the afternoon. The data before sunrise were used for the analysis. Radial growth was investigated by reading the scale of a band-type dendrometer (Liming,1957). Seasonal characteristics of wood formation were also investigated through pinning experiment (Wolter, 1968; Ogata *et al.*, 1996) and the observation of cambial zone.

RESULTS AND DISCUSSION

Comparison of wood formation characteristics in two areas of Java Island

Cytological observation of reserve substances and analysis of lipids

Starch grains and lipid droplets were observed. In ray and axial parenchyma cells outer part of sapwood contained higher amount of starch grains and small amount of lipid droplets (Figs. 2a, b). Parallel with the decrease of starch in the inner part of sapwood, the amount of lipid droplets increased. In the heartwood ray and axial parenchyma cells had much amount of lipid droplets with complete lack of starch grains (Figs. 2 c, d). Nobuchi *et al.*, (1996). also reported similar results. In addition to ray and axial parenchyma cells wood fibers also contained starch grains and lipid droplets. They were, therefore, considered to be the living wood fibers.

The presence of many lipid droplets in both sapwood and heartwood was responsible for the waxy nature of teak wood. To get the qualitative

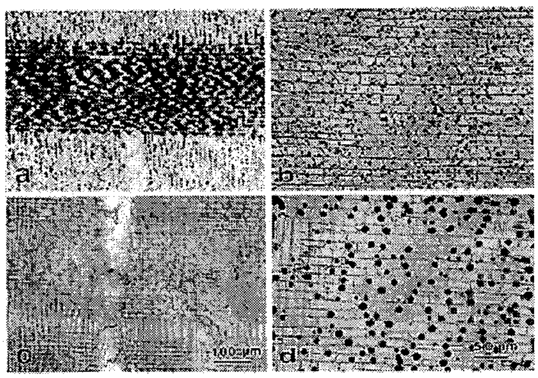

Figure 2. Comparison of reserve substances in outer sapwood and outer heartwood. (a) Outer sapwood (I2KI, starch grains), (b) outer sapwood (Sudan IV, lipid droplets), (c) outer heartwood (I2KI), (d) outer heartwood (Sudan IV).

data of lipids chemical analysis was carried out. The lipid content was 4.7-5.8% in sapwood and 6.8-8.6% in heartwood. High values of lipid content even in sapwood supported the result of light microscopy. There was no difference in lipids between Cepu and Sukabumi.

Growth ring structure

Fig. 3 shows the growth ring structure of teak from Cepu and Sukabumi together with that of Thailand. These three sections were from the sample trees of the same age class, similar size of trunk and the similar position within the trunk. They can, therefore, be reasonably comparable. From Fig. 3 the growth ring structure of Cepu was similar to that of Thailand that had large sized pores in pore zone different from the sample of Sukabumi.

Heartwood color

In Java Island, it is said that the teak wood in Central and Eastern parts has brighter color of heartwood than that of western Java, which has higher amount of rainfall. As the first step to investigate the relationship between heartwood color and water conditions, heartwood colors were physically measured by a colorimeter. The samples of Sukabumi showed smaller values of L*, which indicated darker color than those of Cepu.

From the investigation described above, the samples of Sukabumi where rainfall was higher (tropical rainforest area) showed less clear boundary of growth ring together with darker colored heartwood. We propose to investigate in future the relationship between wood formation and water conditions as physiological factors.

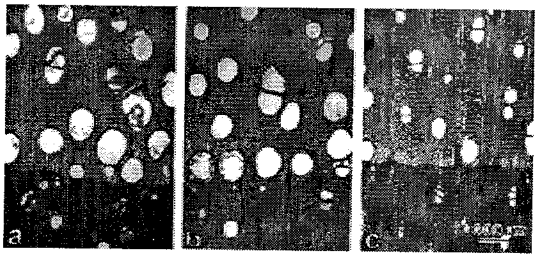

Figure 3. Comparison of growth ring structure among three sites. (a) Thailand, (b) Cepu, (c) Sukabumi.

Growth ring structure in the plantation grown teak in Peninsular Malaysia

Fourteen-year-old plantation grown teak was examined to see whether the rings corresponded to annual growth or not. Fig. 4 shows a transverse section of a trunk (0.8m above the ground level). The numbers of the ring-like structure from the cambium to the pith were 40. It meant that not all the rings corresponded to the annual rings but some of them were false rings. Fig. 5 shows a transverse section of a part of the disk in which some of the growth rings had small sized pores in the pore zone. An incomplete ring joining another ring along the circumference was observed. From the observation mentioned above teak tree in tropical rainforest was considered to have some growth rings in a year.

Preliminary investigation of leaf water potential in Thailand

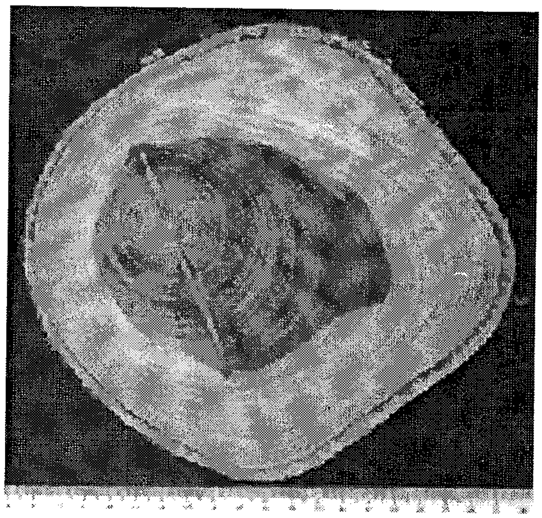

Figure 4. Transverse section of a trunk of 14- year-old tree

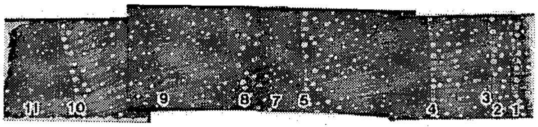

Figure 5. A light micrograph showing some growth rings.

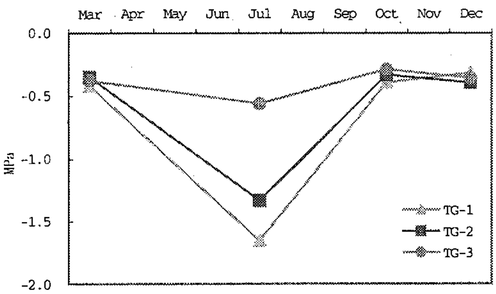

Figure 6. Seasonal changes of leaf water potential measured just before sunrise

The result of growth ring structure in Malaysia indicated the importance of water conditions to growth ring structure. As the first step to investigate the physiological role of water to cambial activity, leaf water potential was measured.

Fig. 6 shows the seasonal changes of leaf water potential of three sample trees. At the site in Thailand, trees shed leaves in the dry season. The data in Fig. 6, therefore, show only the measurements in rainy season. Even in the rainy season leaf water potential showed lower values when the amount of precipitation was small. In that period weak growth ring-like structure was formed indicating that water potential in a tree sensitively affected wood formation.

From the investigation described above it was clarified that wood formation or growth ring structure was sensitively affected by water conditions. In addition to wood formation, heartwood color was also affected by water conditions. We are planning to carry out more detailed investigations of wood formation and heartwood formation in relation to water conditions.

ACKNOWLEDGEMENT

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A Dendrochronological Study of Teak (*Tectona grandis* L. f.) in Puerto Rico

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ABSTRACT

In Puerto Rico, an island in the West Indies, large areas of primary forests have been cut and converted to farmlands or secondary forests. After a while, as the farmlands were not very fertile, they were abandoned. Different tree species have been planted in order to recover the degraded land and to generate timber. Teak is a species of great potential in Puerto Rico, in areas of low altitude and deep, well drained soils. During the last 50 years, teak plantations have been established on the island in such areas. Teak had been planted at Rio Abajo in the wet limestone region of central Puerto Rico during 1940s and 1960s. A dendrochronological study of the species was undertaken in order to investigate patterns of growth and to determine the effect of climate on the growth of teak at Rio Abajo. The growth of teak and that of *Hibiscus elatus* Sw. (Malvaceae), a tree species native to Cuba and Jamaica, used in the manufacture of fine furniture, and planted in Rio Abajo were compared. The chronology showed decreased growth during several hurricane years, followed by increased growth in the following year. Both species are growing well at Rio Abajo, and teak growth was slightly better than that of Hibiscus (Mahoe), suggesting that teak is a good choice for Rio Abajo and similar areas in the wet limestone region of Puerto Rico.

Keywords: Growth periodicity, dendrochronology, timber management

INTRODUCTION

Teak (*Tectona grandis* L.f.) is one of the most valuable and best-known tropical timbers (Weaver and Francis, 1990; Weaver, 1993). The species is native to India, Burma, Thailand, Indochina and Indonesia and has been extensively planted within its natural range as well as in tropical areas of Latin America and Africa (Chudnoff, 1984). In Puerto Rico, an island in the West Indies, large areas of primary forest have been cut and converted to farmland or to secondary forest. Subsequently the farmlands decreased in fertility and were abandoned. Various native and exotic tree species have been planted to restore the degraded land and to provide timber (Weaver and Francis, 1990). A few teak trees were introduced in the Caribbean region around 1880 and plantations were first established in 1913 (Brooks, 1939). Teak was introduced in Puerto Rico from Trinidad before 1940, and by 1990 it occupied approximately 130 ha in various parts of the island. Teak appears to be a species with great restoration and economic potential for Puerto Rico in areas with low altitude and deep, well-drained soils (Weaver and Francis, 1990).

Teak was planted at Rio Abajo in central Puerto Rico in the 1940s and 1960s and at Sabana in the eastern part of the island. We carried out a dendrochronological study of the species in order to investigate patterns of growth and to determine the effect of climate on the growth of teak at the sites. We compared the growth of teak with that of mahoe (*Hibiscus elatus* Sw. (Malvaceae)), a native of Cuba and Jamaica used in the manufacture of fine furniture, (Francis and Weaver, 1988), that had also been planted at Rio Abajo. Although measuring growth rings in tropical species can be difficult because the annual rings may not be distinct, recent dendrochronological studies in India and Java (Pant, 1983; Bhattacharyya *et al.*, 1992; Jacoby and D'Arrigo, 1990) and Panama (Devall *et al.*, 1995) show great potential for some tropical species, especially teak.

MATERIALS AND METHODS

Rio Abajo soils are clay loam and clay while Sabana soils are loam, however, both sites are in the subtropical wet forest life zone. The area has a short dry season in February-March (Weaver and Francis, 1990). We sampled 30 teak trees and 12 mahoe trees growing in pure stands at Rio Abajo and 31 teak trees from a stand at Sabana. We collected two cores per tree in case some cores were unusable. The cores were air-dried, mounted on wooden blocks, and hand sanded with three grades of sandpaper. Cores were then scrutinized for defects and selected for the analysis; cores with indistinct rings, rotten spots, or fungal growth were eliminated. We measured ring widths and cross-dated the tree-ring series (Table 1) using software developed by Van Deusen (1987; 1993). Identification of marker rings helped establish correct cross dating, but use of the software was the primary method of cross dating.

After cross dating, we developed a mean chronology for each species. In order to optimize the climate component of the ring widths and the disturbance signal common to most of the trees (see Graybill, 1982), we standardized the cores by using the first difference of the inverse hypersine (Van Deusen, 1987; 1990). This removed the biological growth trend and achieved homogeneous variances.

We obtained total monthly rainfall plus mean monthly temperatures from NOAA for Dos Bocas, a weather station near Rio Abajo and Juncos, near Sabana (Fig. 2). Data were collected at Dos Bocas since 1936 and at Juncos since 1909. We used the ALLREGS program, one of the DYNACLIM system of programs (Van Deusen, 1993), to screen all possible climate models to determine which factors had the most effect on growth for each of the species. The program ALLREGS computes all possible least-squares regressions of the dependent variable, the standardized chronology, against all of the independent variables (climate). We analyzed the 12 monthly precipitation and temperature variables and one and two year lags of these variables. We also studied this data set to detect any extreme values. We used the program DYNAOLS to study climate models by conducting all possible regressions with ALLREGS. We fit climate models

Table 1. Correlations of core *i* with all the other cores by species.

Core	Sabana Teak	Rio Abajo Teak	Mahoe	Core	Sabana Teak	Rio Abajo Teak	Core	Sabana Mahoe	Rio Abajo Teak	Mahoe Teak
1	31	42	23	19	32	41	30	37	59	80
2	44	37	43	20	18	58	26	38	48	75
3	44	54	58	21	39	51		39	24	56
4	32	58	47	22	46	32		40	30	48
5	30	44	46	23	20	32		41	28	57
6	55	32	47	24	21	43		42	33	33
7	27	57	35	25	38	56		43	18	73
8	20	65	16	26	41	52		44	20	70
9	18	61	31	27	57	35		45	39	38
10	42	38	46	28	32	52		46	26	75
11	43	30	32	29	57	55		47	18	44
12	46	52	44	30	54	71		48	64	
13	22	71	29	31	46	21		49	43	
14	44	51	45	32	22	37		50	28	
15	41	48	26	33	65	33		51	27	
16	34	50	54	34	46	42		52	81	
17	51	45	40	35	21	73		53	53	
18	33	42	24	36	29	53		54	57	

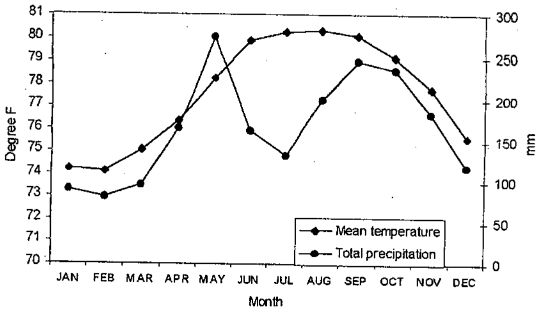

Figure 2. Mean monthly temperature and total monthly precipitation in west central Puerto Rico; data from the NOAA station at Dos Bocas near Rio Abajo.

to the chronologies. The program DYNAOLS allows one to perform ordinary least squares and to evaluate regression diagnostics.

To examine the stand growth pattern through time and to detect periods of disturbance/release, a horizontal straight-line standardization was used (Veblen *et al.*, 1991; 1992). This approach damps out some of the within and among core variance, but the age-related effect is retained in the ring width index series. Let MSRW represent mean standardized ring width. Percent change in radial growth is computed as MSRW – lag (MSRW)/lag (MSRW) x 100, where lag means an earlier value. A growth release is defined as a 40% or greater change in MSRW sustained for at least five years (Devall *et al.*, 1998).

RESULTS AND DISCUSSION

The untransformed chronologies of teak and mahoe are presented in Fig. 3 and mean annual radial increment (MARI) values are given in Table 2. The overall growth of teak is somewhat better than that of mahoe. The teak MARI averaged over 30 years is 5.33 mm at Rio Abajo and 5.59 mm at Sabana in contrast to 4.51 mm for mahoe at Rio Abajo. In Table 2 the mean annual radial increments are compared using one-way analysis of variance. When looking at individual ages the growth rarely appears to be different between teak and mahoe. However, the cumulative effect over 30 years clearly shows that on average the teak grows significantly better than the mahoe.

Teak

The oldest teak core from Rio Abajo dated to 1941, but 1945 was the first year in which more than one tree was present. Our analysis used first differenced inverse hypersine data; taking the first difference of the ring widths eliminated the first observation, so 1946 was the starting year. Current July and November temperature and November temperature lagged one year (Table 3) were the best predictors of growth of teak ($R^2 = 0.53$, $p < 0.000$). The observed and expected values of the standardized ring widths of teak are shown in Fig. 4. Predicted growth was obtained from the program DYNAOLS with the

Table 2. Mean annual radial increment (MARI) growth in millimeters

	Rio Abajo		Sabana			
Age	**Teak-MARI**	**Mahoe-MARI**	**Teak-MARI**	***F***	***P*-value**	**RMSE**
3	7.79	6.37	9.07	2.4	0.095	4.89
5	7.32^{a,b}	5.79^{b}	8.70^{a}	3.9	0.023	4.13
10	5.68	5.09	6.37	1.3	0.288	3.31
15	4.98	4.20	4.82	0.5	0.629	3.05
20	3.94	4.36	3.35	1.6	0.208	2.33
25	3.41^{a,b}	3.73^{a}	2.41^{b}	3.4	0.036	2.21
30	2.98^{a,b}	3.45^{a}	1.82^{b}	4.2	0.022	1.73
35	3.97	3.62		0.1	0.826	3.44
40	2.98	3.41		0.1	0.789	2.89
45	2.44	3.01		0.1	0.833	2.31
30 Year Average:	5.33^{a}	4.51^{b}	5.59^{a}	14.7	<0.001	4.06

Note: MARI compared using one-way analysis of variance. Where the *F*-statistic is significant at the 0.05 level, Tukey's test was applied to separate means. RMSE is root mean squared error.

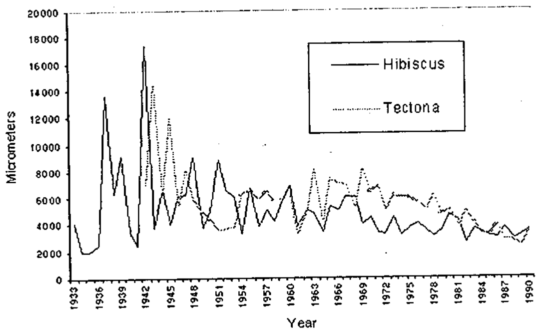

Figure 3. The untransformed chronologies of teak and mahoe from Rio Abajo, Puerto Rico.

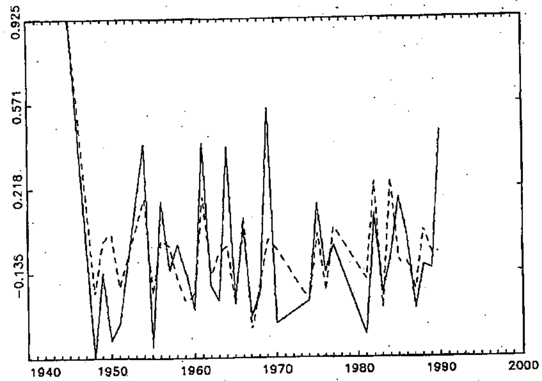

Figure 4. Teak at Rio Abajo, the observed (solid line) vs predicted (dashed line) values calculated with the climate variables of July and November temperature of the current year and November temperature of the previous year.

climate variables mentioned above. The observed and predicted values are similar and run in the same direction most of the time.

For the five-year period 1943-1948 initial growth rates were high as the planted teak expanded to occupy the site (Fig. 5). After 1948 the teak growth leveled, with some short term punctuated growth in the 1960's and early 1970's. From 1978 through 1990 growth decreased somewhat, reflecting age and competition effects from other trees in the stand. This horizontal line chronology shows a normal plantation growth development with no real periods of disturbance/release. For the hurricanes in 1956, 1961, 1964, 1979 and 1989, there is a growth decline in the hurricane year followed by a year of increased growth. There were two years of growth increase after hurricane Donna in 1961.

January temperature of the current year and February and July temperature of the previous year (Table 3) were the best predictors of the growth of teak at Sabana ($R^2 = 0.73$, $p < 0.000$). The observed and expected values of the standardized ring widths of teak are shown in Fig. 6.

The teak at Sabana were mostly planted in the early 1960's and have a high relative growth rate from 1960 to 1966 before dropping off (Fig. 7). As at Rio Abajo, there were no periods of growth release. The teak at Sabana are an exception for the 1961 hurricane, where growth declined in 1962. These were very young trees and probably did not have sufficient root system, crown development, and reserves to take advantage of the decreased competition the year after the hurricane.

Mahoe

1948 was the first year in which more than one mahoe tree was present, so 1949 was the starting year. Current October mean temperature, current September precipitation and October temperature of the previous year (Table 3) were the top estimators of growth of mahoe ($R^2 = 0.53$, $p < 0.000$). The observed and expected values of the ring widths of mahoe are shown in Fig. 8.

Compared to the two teak chronologies, mahoe seems to grow at a slow but steady pace (Fig. 9).

Table 3. Correlations between species growth chronologies and climate variables at Rio Abajo in east central Puerto Rico. cor = correlation, est = estimate, prob = probability, mn t = mean temperature

Teak (*Tectona grandis*)			**Teak**			**Mahoe (*Hibiscus elatus*)**		
Variable + cor	est	prob	Variable + cor	est	prob	Variable + cor	est	prob
-0.64 Jan temp	-0.02	<0.00	-0.53 Jul temp lag 0	-0.58	<0.00	+0.29 Oct temp lag 0	0.66	<0.00
-0.09 Feb temp -1	-0.11	0.02	-0.34 Nov temp lag 0	-0.51	<0.00	+0.24 Sep rain lag 0	0.38	<0.00
0.36 July temp -1	0.35	<0.00	0.08 Nov temp lag 1	0.45	<0.00	-0.36 Oct temp lag 1	-0.71	<0.00

The young plantation does not display early rapid growth as found in teak. There are no release events evident in the chronology or in the percent change analysis. The mahoe stand reacts the same as the teak stands in response to hurricanes, with a decrease in growth during the year of the storm followed by a year of better growth.

The principle of limiting factors is important to dendrochronology (Fritts, 1976). The range of rainfall reported for teak in its native habitat in Southeast Asia is 1200-3400 mm (Salazar *et al.*, 1974).

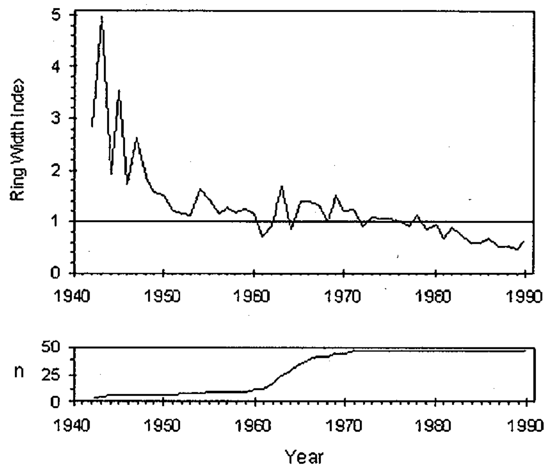

Figure 5. Mean horizontal line standardized ring width chronology illustrating growth pattern of teak at Rio Abajo. Graph of core sample size appears below chronology.

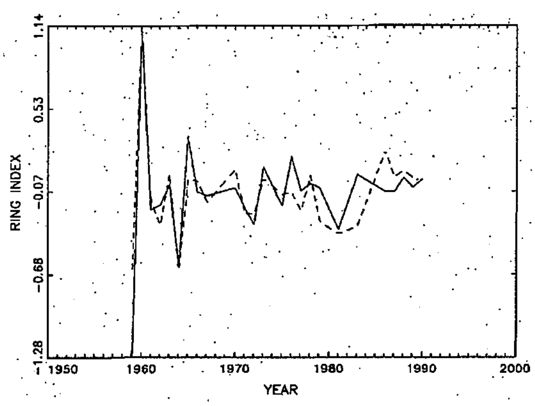

Figure 6. Teak at Sabana, the observed (solid line) vs predicted (dashed line) values calculated with the climate variables of January temperature of the current year and February and July temperature of the previous year.

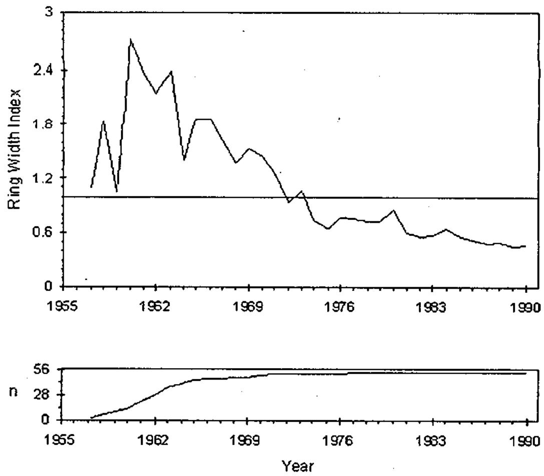

Figure 7. Mean horizontal line standardized ring width chronology illustrating growth pattern of teak at Sabana. Graph of core sample size appears below chronology.

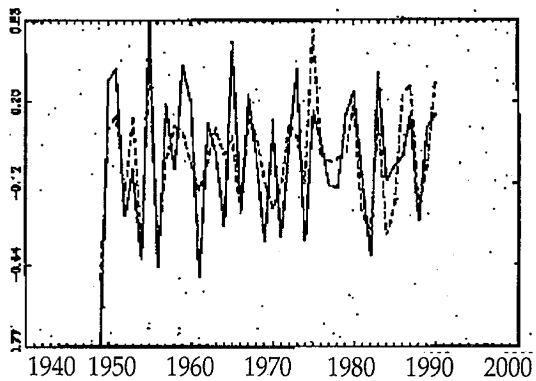

Figure 8. Mahoe, the observed (solid line) vs predicted (dashed line) values calculated with the climate variables of October mean temperature, September precipitation and October temperature of the previous year.

The 2000 mm per year of rainfall at Rio Abajo appears to be sufficient for the two species during most of the year, so mean temperature becomes the limiting factor. Current July and November temperature were negatively correlated with the growth of teak, indicating that radial growth of the species is greater when the temperature is lower than average in July and November. Lower temperature could also result in lower potential evapotranspiration which would benefit growth by reducing water stress. In contrast, the growth of mahoe was positively correlated with October mean temperature of the current year and of the previous year. The two species exhibit contrasting growth

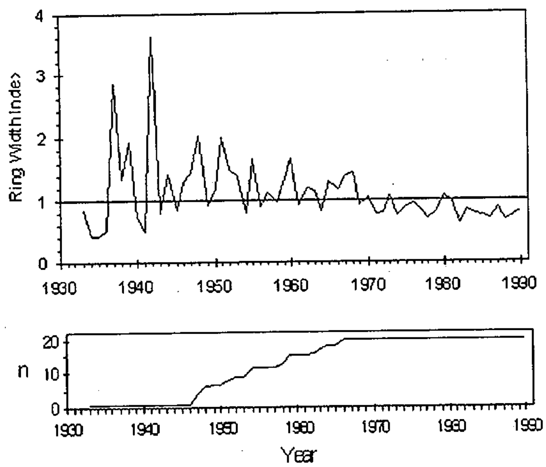

Figure 9. Mean horizontal line standardized ring width chronology illustrating growth pattern of mahoe at Rio Abajo. Graph of core sample size appears below chronology.

strategies, but both are influenced by temperature at about the same time of the year. At Sabana, temperature, not rainfall, is also a limiting factor.

July temperature proved to predict the teak chronology at Rio Abajo better than other months of the current year or past two years. Growth in this month apparently has a significant influence on the variation in total annual teak increment. Although the months selected were the best in predicting the ring widths over all the years (July and November temperature and November temperature of the previous year), they may not have been the best for any individual year. Rain and temperature during other months also influenced growth. There is less rainfall in July than in the other summer months and June-September is the warmest time of the year (Fig. 2). With less rainfall there would be more clear days with increased heat and decreased humidity. It appears that in July, days with lower temperature are more favorable for the growth of teak.

October and November of the previous year were important to the growth of mahoe and teak at Rio Abajo. Bud formation, storage of photosynthates, formation of growth hormones and other growth processes occur the year before radial growth develops, so previous variation in climate can affect the ring width of the current year (D'Arrigo and Jacoby, 1992).

Hurricanes passing over or near the island likely are evidenced in the chronologies because they cause leaves to fall and branches to break during the time of the hurricane, causing a decrease in radial growth for that year. However, the thinning effect from other trees falling and the nutrients provided from the fallen organic matter cause increased growth the following year. Teak is apparently more sensitive to hurricanes than mahoe, perhaps because mahoe developed in an environment of hurricanes.

CONCLUSION

Both teak and mahoe are growing well at the two sites, but teak growth is better than that of mahoe, a native of similar nearby islands, suggesting that teak is a good choice for the subtropical wet forest region of Puerto Rico.

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Investigations on Inheritance of Growth and Wood Properties and Their Interrelationships in Teak

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ABSTRACT

Genetic improvement of teak, which started during the 1960's in India and has made substantial progress in terms of selection of plus trees, creation of seed production areas and establishment of seed orchards. During the last decade much emphasis has been given on genetic testing of clones selected from different teak growing areas of the country, which resulted in the identification of 31 good general combiners for growth-related traits and also generated knowledge on inheritance patterns and type of gene action prevalent in teak of South and Central India. Though teak is valued for its wood, teak improvement work focussed on enhancement of growth rate and adaptability. Though a few studies on wood properties of teak have been undertaken, information on inheritance pattern including estimation of heritability in a narrow sense is almost non-existent. Earlier reports in teak suggest that tree-to-tree variation is more important than variation between provenances in the improvement of wood specific gravity. Furthermore, trees specifically selected for growth and form also exhibit considerable variation in many wood characters. Considering this, an investigation was undertaken to (i) assess the extent of genetic variation for growth and wood characters, (ii) estimate narrow sense heritability and genetic gain, and (iii) identify best general combiners. The investigation was carried out on a 20-year-old genetic test trial established with 27 half-families of teak of Orissa origin. Data on growth (height, dbh, basal area) and wood (specific gravity, sapwood and heartwood percentage) parameters were collected and analysed, followed by estimation of genetic parameters. Results indicated that growth and wood characters are moderate to strongly inherited and most of the traits are under the influence of additive gene action, indicating scope for improvement through selection and sexual reproduction. The paper shortlists the parents on the basis of their general combining abilities and also discusses the implications of interrelationship among different growth and wood parameters.

Keywords: Genetic variation, wood characters, heritability, genetic gain, general combining ability

INTRODUCTION

Although wood is usually the desired product of a forestry programme, unfortunately many tree improvement activities around the world do not include wood improvement in the programmes (van Buijtenen and Zobel, 1998). Wood technologists spend much time adjusting to the defects in timber, which may be minimized while the trees are growing (Harris, 1983). A significant improvement in these defects may be obtained while screening the large natural variability in wood properties through the application of genetics. Research has shown that most wood qualities, as well as tree form and growth characteristics that affect wood are inherited strongly enough to obtain rapid gains through genetic manipulations (Zobel and Talbert, 1984).

However, the greatest gains are achieved when the improvement programmes concentrate on a few characteristics. This advocates necessity of determining the most important characteristic of wood properties. Among different wood properties, wood specific gravity or wood density is by far the most important wood characteristic significantly affecting nearly all wood products (Barefoot *et al.*, 1970). Genetic manipulation improves wood properties in several ways including alteration in tree form, growth rate, wood morphology, wood chemistry and others.

Teak (*Tectona grandis*) is one of the most important plantation species owing to its desirable wood properties, fine grain, durability and amenability for plantation. It occurs naturally in India, Myanmar, Thailand, Indonesia and Lao People's Democratic Republic. Tropical Asia accounts for 94 per cent of global teak plantations, with India's share of about 44 per cent. Considering the magnitude of genetic diversity and high commercial value of teak, genetic improvement programme of the species was started in India during sixties of the bygone century and up to now good progress has been made in terms of plus tree selection, creation of seed production areas, establishment of clonal and seedling seed orchards. During the last decade much emphasis was given on genetic testing of clones selected from different teak growing areas of the country. These investigations resulted in identification of 31 good general combiners for growth related traits and generated knowledge on inheritance pattern and type of gene action prevalent in teak of south and central India (Mandal and Rambabu, 2001).

Though teak is valued for its wood, genetic improvement work so far concentrated only on improvement in growth rate and adaptability. Review of world literature shows existence of significant genetic variation in wood properties of different species. However, most of the literature is confined to conifers and among broad leaved species, the genera *Populus* and *Eucalyptus* are well studied. Though a number of studies on wood properties of teak have been undertaken by different workers (Rao and Dave, 1981; Rajput *et al.*, 1982; Venugopal and Krishnamurthy, 1989; Pandey *et al.*, 1991), information on inheritance pattern including estimation of heritability in narrow sense is not available. Recently, Bhat and Indira (1997 a; b; c) and Indira and Bhat (1997) examined the scope for choosing specific gravity as a selection criterion in genetic improvement of teak for timber. Earlier reports in teak suggest that tree to tree variation is more important than variation between provenances in improvement of wood specific gravity. Kjaer *et al.* (1999) while studying wood properties in five provenances of teak concluded that it would be valuable to analyze progeny trials in order to estimate heritability of these traits. Furthermore, it is very interesting that trees specifically selected for growth and form also exhibited considerable variation in many wood characters. In this paper we report, for the first time, the results of investigation carried out on a 20-year-old genetic test trial and discuss the implication of findings in teak wood improvement programme.

MATERIALS AND METHODS

The present investigation was carried out on a 20-year-old progeny trial established with 27 half-sib families of teak of Orissa origin. The trial was established in 1982 at Dhandatopa Research Station, Orissa. There were 25 progenies of each family replicated thrice at an espacement of 2.5m x 2.5 m. The crop was protected and standard silvicultural management was provided so as to raise a good crop. Data was recorded on three randomly selected trees in each plot on growth [height (cm), clear bole height (cm), girth at breast height (cm)] and wood [bark thickness (cm)]. For generating data on wood parameters increment cores (6 mm) were extracted from selected trees. Width of heartwood and sapwood was measured and expressed as percent of diameter at breast height. Specific gravity was estimated by oven-dry method. Data so recorded were subjected to analysis of variance followed by estimation of genetic parameters after Zobel and Talbert (1984).

RESULTS AND DISCUSSION

Good estimates of genetic parameters form an important basis for formulating an efficient breeding scheme. The present study centers on 20-year-old progeny trial of teak. Analysis of variance indicated significant to highly significant variation for heartwood and sapwood percentage, and specific gravity at family level (Table 1). This strongly suggests scope for family selection wherein inferior families as well as inferior individuals within families are eliminated, thereby effecting improvement in the above wood characteristics. Non-significant family x replication variation for these characters indicated that the development of these characters is not influenced by environmental variation. On the contrary the present analysis revealed signification family x replication variation for height, clear bole height and bark thickness which indicated significant genotype x environment interaction that occurred within and between all of the test plantations. Teak is a long rotation species. Therefore, time may show more distinct differences in contract to earlier report (Swain *et al.*, 1996).

Individual and family heritability values ranged from 5.35 to 90.37 and 9.48 to 68.15 percent respectively (Table 2). Sapwood percent recorded highest whereas girth at breast height recorded lowest values of heritability. Estimates of genetic advance expressed in percent of population mean followed similar trend. Specific gravity, the most important wood property, recorded 31.41 and 46.28 per cent heritability values at individual and family level respectively. Similar values were earlier reported for *Eucalyptus saligna* (King, 1980), *Populus nigra* (Nepveu *et al.*, 1978) among other hardwood species. The values of heritability for height and girth were found similar as reported by Sharma *et al.* (2000). In addition to individual tree heritability, information on magnitude of family heritability becomes important when selection is practiced on families as well as on individuals (Zobel and Talbert, 1984). As indicated above the present material offers scope for similar selection to effect genetic improvement in wood related traits including specific gravity. While heritability values express the proportion of variation in the population that is attributable to genetic differences among individuals, genetic advance indicates average improvement in the progeny over the mean of the parents. Genetic advance is realized by selection in the parental generation and its magnitude depends on selection intensity, parental variation and heritability. In population improvement programme like this where many selected parents are mated together, only additive genetic variance can be utilized. Additive genetic variance arises due to additive effect of genes. Values of narrow sense heritability coupled with moderate to high estimates of genetic advance in the present study for height, specific gravity and heartwood

Table 1. Analysis of variance (only mean sum of squares) for growth and wood traits

Source	Character							
	d.f.	Height	Clear bole height	Girth	Bark thickness	Heart wood %	Sap wood %	Specific gravity
Rep	2	41.983	99.110	133.535	0.07782	194.800	221.820	0.000934
Families	26	10.381	9.243	78.521	0.07699	531.085*	507.058**	0.001160**
Fam x rep	52	7.725**	7.651**	71.069	0.05021*	187.109	161.474	0.0006223
Tree within plot (Error)	162	2.716	2.363	56.070	0.03259	132.880	116.591	0.0007385

* Significant at 5 % level. ** Significant at 1 % level.

Table 2. Estimates of narrow sense heritability and genetic advance.

Parameter	Character						
	Height	Clear bole height	Girth	Bark thickness	Heart wood %	Sap wood %	Specific gravity
Mean	14.20	5.82	49.12	0.96	57.76	29.60	0.51
Heritability (Individual)	25.21	12.06	5.35	28.72	80.81	90.37	31.41
Heritability (Family)	25.58	13.13	9.48	34.78	64.76	68.15	46.28
Genetic gain (% of mean)	7.92	9.03	1.77	12.56	39.63	81.99	3.51

Table 3. Phenotypic correlation coefficients among growth and wood traits

	Clear bole height	Girth	Bark thickness	Heart wood %	Sap wood %	Specific gravity
Height	0.7254**	0.3883*	0.0137	0.1927	-0.1561	0.0244
Clear bole height		-0.0277	-0.2253	0.2946	-0.2632	-0.1163
Girth			0.5060**	-0.1878	0.3144	0.1420
Bark thickness				-0.3324	0.2352	-0.0317
Heart wood %					-0.9906**	0.1276
Sap wood %						-0.1049

Table 4. General combining ability (gca) for growth and wood traits

Family	General combining ability Height	Clear bole height	Girth	Bark thickness	Heart wood %	Sap wood %	Specific gravity
ORPUB – 1	-0.6937	-0.0390	2.5459	0.1512	-1.9882	0.8289	0.0083
ORPUB – 2	0.1963	-1.1490	2.0959	0.0412	2.9619	-2.8311	0.0253
ORPUB – 3	-0.3037	-1.2590	0.8759	-0.0188	-4.6481	4.8389	-0.0037
ORPUB – 5	-0.1337	-0.0390	5.4359	0.0712	-4.0182	4.1389	0.0003
ORPUB – 6	0.4163	0.7910	-3.9041	0.0512	-0.0581	-1.9911	-0.0237
ORPUB – 7	-0.2537	-0.3190	0.4359	0.1112	1.3919	-2.6611	-0.0027
ORPUB – 8	0.2463	0.3510	-0.4541	-0.0388	2.2819	-1.6211	-0.0197
ORPUB – 9	-0.3037	0.0110	-0.5641	-0.1488	-5.0582	6.7489	0.0093
ORPUB – 10	0.5263	-0.7090	0.7659	0.0612	-4.4282	4.0389	0.0083
ORPUB – 12	-1.5937	-0.2090	-1.1241	0.0612	-3.0781	1.9289	0.0023
ORPUB – 13	-0.0237	0.9610	-3.7941	0.0012	5.3219	-6.3111	-0.0097
ORPUB – 15	1.5863	-0.0590	4.8759	0.1612	-4.2181	3.5689	-0.0007
ORPUB – 17	-0.5837	-0.6490	-2.4541	0.0212	-19.2882	18.5689	-0.0027
ORPUB – 18	0.3663	0.5710	4.7659	0.0312	-17.3782	18.4689	-0.0117
ORPUB – 19	0.1963	0.1210	0.6559	-0.0288	-11.2682	11.3289	-0.0027
ORPUB – 20	-0.0837	-0.8790	1.0959	0.0012	-2.1382	2.3289	0.0033
ORPUB – 21	0.0263	-0.0390	-0.9041	0.0812	-1.0781	-0.2111	0.0113
ORPUB – 22	-0.6337	-0.7090	-0.3441	-0.0188	5.1819	-4.8611	0.0193
ORPUB – 23	0.3663	0.2910	2.8759	0.0212	9.2119	-8.6311	-0.0007
ORPUB – 24	-0.1337	-0.8190	0.0959	-0.1388	9.1119	-7.4511	-0.0057
ORPUB – 25	-1.0237	0.2910	-4.9041	-0.1588	7.7319	-6.7911	0.0033
ORPUB – 26	2.6963	1.9010	4.4359	0.0012	12.3119	-11.261	-0.0047
ORPUB – 27	3.0263	3.4610	-3.1241	-0.1788	8.8319	-7.1311	0.0133
ORPUB – 28	-1.5837	-1.3590	-3.0141	-0.0388	5.1019	-6.0511	0.0003
ORPUB – 29	-0.2537	-0.0990	-1.0141	0.1012	1.5619	-2.9011	-0.0137
ORPUB – 30	-1.5237	-0.9290	-5.2341	-0.1288	0.1019	0.3389	-0.0067

percentage indicates the presence of additive gene action for these traits.

Low but positive correlation was found between height, heartwood and specific gravity; heartwood and specific gravity; and girth at breast height and specific gravity (Table 3). Though their relationship is not very strong in the present materials, the desirable association situation can be used to the advantage of the breeder. These findings are in agreement with the earlier report of Kjaer (1999) in teak. Interestingly sapwood exhibited negative association with specific gravity and growth traits as reported earlier by Varghese *et al.*(2000).

As many as 11 parents showed positive gca effects for specific gravity and ORPUB 2 and ORPUB 22 were found to be good general combiners for this trait (Table 4). None of the parents exhibited positive gca values for all the traits studied. However, at least five parents exhibited positive gca values for five characters. Interestingly none of the parents showed negative values for all the characters. As positive values of general combining ability of parents indicate constellation of additive genes, such parents are expected to throw out good segregants for different combination of characters (Swain *et al.*, 1996). It is suggested that these elite parents may be used for establishing advanced generation seed orchards and breeding arboreta for improvement of teak for specific or combination of characters. Genetic thinning should also be carried out in the first generation orchard established with the present set of parents. The slow growth rate of the species is a drawback in a tree improvement programme. Superior plus trees are selected at a mature stage while their breeding values are assessed from progeny tests at a younger age. One must, therefore, rely on a good concordance between juvenile performance and performance at harvesting stage. However, since the present estimates were obtained at age of 20 years, their reliability will be of greater relevance in taking breeding decisions for improvement of important wood traits including specific gravity.

CONCLUSION

Teak has worldwide reputation for its superb quality wood suitable for a number of end uses. The results of the present study indicate presence of enough variation for wood specific gravity. The specific gravity is also positively associated with other wood traits including tree size and heartwood percentage. A few parents have also been identified as good general combiners for wood specific gravity. It is suggested that till much more information is generated on important wood traits either using full or half-sib materials, the present findings can be useful in teak improvement programme.

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Assessment of Growth Rate, Basic Density and Heartwood Content in Selected Teak Clones of CSO, Thithimathi, Karnataka

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ABSTRACT

Teak Clonal Seed Orchard (CSO) was established by the Karnataka Forest Department at Majjigehalla beat of Thithimathi Range during 1978-79 in an area of 16 hectares. A total of 1369 grafts, representing 37 clones and 37 ramets, were grafted with spacing of 8 m x 8 m. This CSO became the source material for further tree improvement programmes. A need to initiate wood quality studies which include environmental and genetic variations, which is of economic interest, were included in the breeding programme. Keeping this in view, the work was carried out in teak to investigate variations in wood properties in SPAs and CSOs. The study provided data on growth rate, basic density and heartwood content of 21 logs (clones), which were felled during a natural calamity, and were made available for the investigation. Observations indicated that the average diameter and heartwood content were more in Haliyal clones (9 clones), as compared to rest of the clones (7 clones of Thithimathi, 2 clones of Kakanakote, 1 each of Nagarahole, Bhadravathi and Shimoga). The average basic density was more in Thithimathi clones. The rings /inch was same for Thithimathi and rest of the clones (3) compared to Haliyal clones (4). Clone-to-clone variation was observed in all the parameters. Simple correlations carried out revealed a negative relationship between growth rate and basic density for Thithimathi clones and a positive correlation between diameter and heartwood content for the clones of Kakanakote, Nagarahole, Bhadravathi and Shimoga. The range and average values of different parameters studied in different clones are also discussed in the paper.

Keywords: Wood properties, cloned teak.

INTRODUCTION

Although tree improvement programme was initiated in India in early 1960's (Kedharnath, 1980), little attention has been paid for breeding quality planting stock of teak from the point of view of wood quality. Earlier studies pertaining to wood quality of teak were confined to understand the variability in growth rates and possible anatomical influence on them but not related to the selection of trees (Ramesh Rao *et al.*, 1966; Purkayastha and Ramesh Rao, 1969; Purkayastha *et al.*, 1972; 1973; Priya, 1998; Nuthan, 2000; Varghese *et al.*, 2000). Kaosa-ard (1993), who initiated teak improvement programme in Thailand emphasized the urgent need of associating wood quality studies which includes environmental as well as genetic investigations into variations in those wood properties which are of economic interest so that specific wood properties can be included in the breeding programme.

Teak clonal seed orchard (CSO) was established at Majjgehalla beat of Thithimathi range (12^0 3'N latitude and $76^0$3.5'E longitude) during 1978-1979 by Karnataka Forest Department for production of quality seeds. A total number of 1369 plants were grafted with an espacement of 8m x 8m representing 37 clones and 37 ramets in an area of 16 ha. This CSO became the source material for teak improvement programme by way of seed collection (improved quality) for general planting or for progeny trials.

This Institute established a vegetative multiplication garden at Gottipura and at the Institute of Wood Science and Technology campus and a progeny trial near Tirupathi using this CSO as source material. An attempt was made for the first time to generate data and understand the variation in wood quality in individual trees, which can be used subsequently for the purpose of selection either for seed collection or mass propagation. The data generated on wood quality from Seed Production Area (SPA), Dandeli provided some interesting results (Vijendra Rao *et al.*, 2001). The present paper provides information on the wood quality of the selected ramets of certain clones which were made available by the Silviculturist Madikeri, Karnataka Forest Department from their CSO. The results obtained on variation on heartwood percentage, growth rate and basic density pertaining to Haliyal clones, Thithimathi clones, and few other clones are presented.

MATERIALS AND METHODS

Twenty one trees representing clones from Haliyal (HAL-9 clones), Thithimathi (TMT-7 clones), Shimoga (SHI-2 clones), Kakanakote (KKT-1 clone) Nagarahole (NGH-1 clone), Bhadravathi (BAH-1 clone) were the subject of investigation for the present work. At the time of felling after 16 years of tree growth, the average diameters found for the 21 trees were in the range of 14.21-18.81cm. Cross sectional discs of 15 cm thickness were cut at breast height level. The percentage of heartwood was determined based on colour difference and average values obtained from the four cardinal points for individual trees. Basic density was determined using green volume/oven dry weight. For determination of growth rate, the surface of disc was smoothened by a plain cut followed by sanding to expose the growth rings. The number of rings / 2.5 cm (inch) was taken as a unit of measurement of fast or slow growth. Standard error and coefficient of variation (CV%) were calculated at clonal level and regressions were carried out and equation was fitted wherever significant correlations were observed.

RESULTS

From the Table 1, it can be seen that the average diameter and heartwood percentage of Haliyal clones representing 9 billets was more as compared to 7 billets of Thithimathi and 5 billets of other clones. There was an intra-clonal and inter-clonal variation in heartwood percentage. Among the Haliyal clones, the heartwood percentage varied from 43% to 83% within average of 61.56%. Among Thithimathi clones, the heartwood proportion varied from 35-66 % with an average of 53.23% and in the rest from 25-68% with an average of 54.54% (Fig. 1). The average basic density was found better in Thithimathi clones than the rest. The average growth rate (3 rings/inch) of Thithimathi clones was comparable with the rest of the clones. However, the average growth rate of the Haliyal clones was slightly more (4 rings/inch). Clone to clone differences within the source material may be large or small compared to the average value (Table 1). Thus HAL 7 and HAL 10 had higher percentage of heartwood and about 4 rings/inch and basic density of 0.52 g/cm^3 - 0.57g/cm^3. Similarly among Thithimathi clones, the maximum percentage of the heartwood (66%) was found in TMT 20/26 with about 3 rings/inch and basic density of 0.540 g/cm^3. However, TMT 19/79, though differed in the heartwood percentage (65%) compared to the earlier clone, had a higher basic density (0.561g/cm^3). The growth rate for both the clones was similar. Among the other clones KKT-55 had a high percentage of heartwood (68%), 2.5 rings/inch and basic density of 0.561 g/cm^3. Besides the average values for all the parameters studied, information gathered on the width of the growth ring related to the distance from the pith for HAL, TMT and other clones are provided in Fig.2. From the figures it can be seen that the width of the ring differed across the radius with no definite pattern up to a particular radial position depending

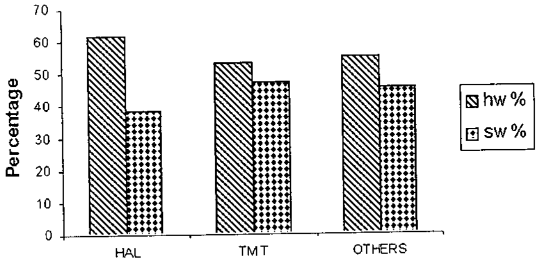

Figure 1. Average percentage of heartwood and sapwood in clones of respective localities

Table 1. Details of girth, heartwood, sapwood percentage, basic density and growth rate in Haliyal, Thithimathi and other clones of CSO, Teak

CLONE	Dia (cm)	HW%	SW%	Basic density	GR/ inch
HAL-4/94	18	67.22	32.78	0.46	6.5
HAL-11/32	19.03	42.56	57.44	0.473	3.43
2-HAL-77	24.13	53.56	46.44	0.488	3.7
HAL-7	15.2	70.61	29.39	0.523	3.67
HAL-6/97	14.87	67.47	32.53	0.532	2.5
HAL-1/7	16.97	55.78	44.22	0.535	4.23
HAL-10	23.87	82.81	17.19	0.569	4.5
HAL-9/26	18.63	56	44	0.573	4
HAL-8/60	18.57	58	42	0.602	1.39
AVERAGE	**18.81**	**61.56**	**38.44**	**0.53**	**3.77**
SD	3.29	11.74	11.73	0.04	1.39
SE	1.09	3.91	3.91	0.01	0.46
CV%	17.50	19.07	30.53	9.10	37.12

CLONE	Dia (cm)	HW%	SW%	Basic density	GR/ inch
TMT-16	13.4	45.34	54.66	0.498	4
TMT-17/38	13.47	56.92	43.08	0.548	2.4
TMT-18/56	12.97	35.21	64.79	0.509	4
TMT-19/79	18.83	64.61	35.39	0.561	3
TMT-20/26	16.37	66.38	33.62	0.540	2.95
TMT-22/17	18.13	57.36	42.64	0.581	3.14
TMT-5/32	17.8	46.82	53.18	0.681	2.12
AVERAGE	**15.85**	**53.23**	**46.77**	**0.56**	**3.09**
SD	2.52	11.26	11.26	0.06	0.71
SE	0.95	4.26	4.25	0.02	0.27
CV%	15.89	21.15	24.08	10.84	23.29

CLONE	Dia (cm)	HW%	SW%	Basic density	GR/ inch
NGH-45	14.97	61.46	38.54	0.45	3.25
SHI-15/29	15.8	66.67	33.33	0.493	3.47
22-BAH	12.9	50.9	49.1	0.516	3.27
KKT-35	11.83	25.36	74.64	0.553	3
KKT-55	15.57	68.29	31.71	0.561	2.46
AVERAGE	**14.21**	**54.54**	**45.46**	**0.51**	**3.09**
SD	1.75	17.66	17.66	0.045	0.38
SE	0.78	7.90	7.90	0.02	0.17
CV%	12.3	32.39	38.86	8.83	12.61

upon the clone. Further the width of the rings in HAL clones showed some sort of uniformity compared with TMT and other clones. Thus HAL clones can be envisaged to perform uniformly in terms of ring widths when other clones are taken into consideration.

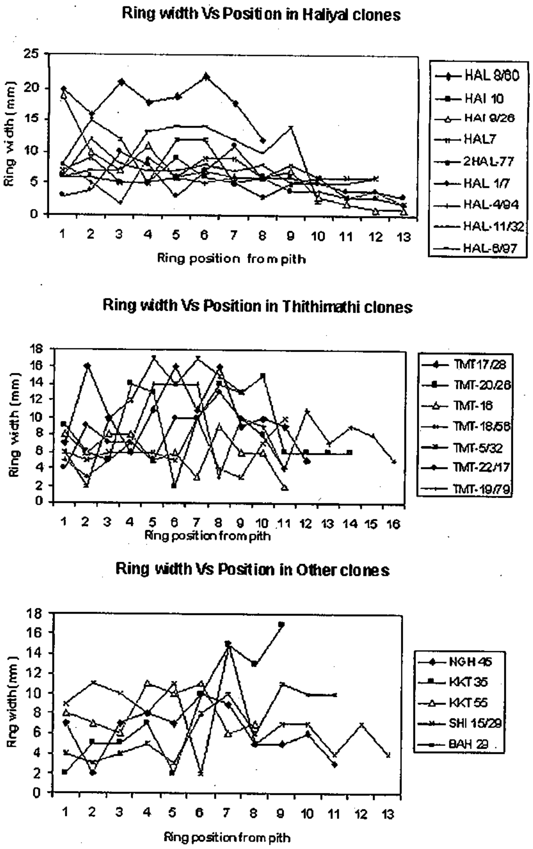

Figure 2. Pith to periphery variation in ring width in different clones of CSO, Teak, Thithimathi

The correlation coefficient among the properties of these clones indicated a significant negative relation between growth rate and basic density for Thithimathi clones and a positive correlation between diameter with the heartwood for rest of the clones (Table 2, Fig.3)

DISCUSSION

Purkayastha *et al.* (1973) observed that density and number of rings /cm vary significantly between locations but not between seed origins. This was further, reaffirmed by Purkayastha and Satyamurthi (1975) and Indira and Bhat (1998) from the studies made on plantations. Nuthan (2000) observed significant variation in percentage of sapwood (15.22-28.4 %), relative growth rate (3.89-5.85) and basic density (0.49-0.59 g/cm^3) of the

Table 2. Correlation coefficient among properties of Haliyal (HAL), Thithimathi (TMT) and other clones

			HAL Clones			
	dia(cm)	*hw%*	*sw%*	*Basic density*	*GR/inch*	
dia(cm)	1					R=0.666 NS
hw%	0.0412	1				
sw%	-0.0412	-1	1			
Basic density	0.0009	0.2823	-0.2823	1		
GR/inch	0.1651	0.2596	-0.2595	-0.5595	1	
			TMT Clones			
	dia	*hw%*	*sw%*	*Basic density*	*GR/Inch*	
dia	1					r=0.754
hw%	0.5877	1				
sw%	-0.5877	-1	1			
Basic density	0.6571	0.1000	-0.1000	1		
GR/Inch	-0.4897	-0.4642	0.4642	**-0.7941**	1	
			Other Clones			
	dia(cm)	*hw%*	*sw%*	*Basic density*	*GR/Inch*	
dia(cm)	1					
hw%	**0.9464**	1				r=0.878
sw%	**-0.9464**	-1	1			
Basic density	-0.3555	-0.3723	0.3723	1		
GR/Inch	-0.0557	-0.0353	0.0353	-0.7193	1	

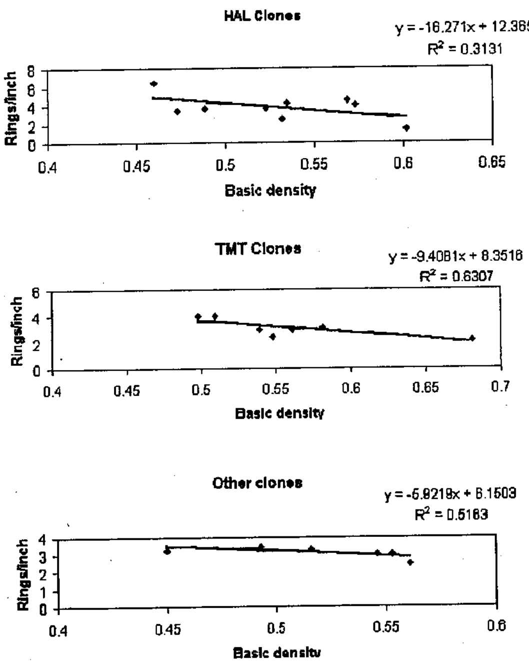

Figure 3. Linear model between basic density and growth rate in Haliyal (HAL), Thithimathi (TMT) and other clones

provenance studies he made in Karnataka. While, earlier workers (Nair and Mukerji, 1960; Mukerji and Bhattacharya, 1963; Nuthan, 2000) found significant correlation between ring width and basic density, the present study disagrees for the same so far as Haliyal clones and rest of the clones are considered and agrees for TMT clones where a significant negative relationship was found. Considering the data obtained for the individual clones of all the parametres, it is important to see how these clonal materials behave in terms of heritability when the seeds are raised either as plantations or for the establishments of seedling seed orchard both within and without the State of Karnataka. It is important to bear in mind, as found by Indira and Bhat (1997) and also as indicated in the present study, that it is the individual tree variation that is important while breeding for wood density and not the provenances or seed origins. The data generated on the 21 clonal materials is a beginning in this direction for its use and comparison in the future teak improvement programmes wherever the seed source is from – CSO of Thithimathi. Further, the data generated on the clones suggest the potential the CSO has got for wide variations found among them depending upon the trait that was investigated.

CONCLUSION

Twenty-one clonal materials investigated for heartwood percentage, basic density and growth rate showed wide variation in their properties. Average values suggested that Haliyal clones performed better for heartwood percentage while average basic density was more for Thithimathi clones. The growth rate rather remained more or less 3 to 4/inch for both sources.

ACKNOWLEDGEMENT

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Optimal Management of Teak Plantations

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ABSTRACT

An efficient way to increase productivity of teak plantations is to optimize their density and rotation age. Both measures require no expenses and, as shown in this paper, will give more than double returns. Using straightforward process models, it was found that the long-term optimal density index for teak plantations in Kerala, southern India, is 475. Analysis of data from the Inventory of Teak Plantations in Kerala-1997, consisting of 1170 sample plots representing teak plantations in Kerala, showed that only 4.8 per cent of the stands had optimal density. Bringing up the density of under-stocked stands (index less than 400) and reducing the index of overstocked stands will increase productivity by 42 per cent. Economic analysis indicated that the net present value is maximized at 50 years. Bringing down the rotation age from the current 60 years to 50 years will increase the returns by 2.6 per cent. Shortening the rotation age from 60 to 50 years will result in an increase in the harvest area by 20 per cent. The combined effect of all these would be an almost doubling (1.42 x 1.026 x 1.2 = 1.75) of the returns from the existing plantations at no extra costs. Growth simulation studies with the developed model also indicated that by controlling understory species in teak plantations, the mean annual increment in volume of teak can be increased by 30 per cent. Removal of understory growth would also lead to social benefits by providing firewood to the local inhabitants other than its effects on the growth enhancement of teak trees. Although these results pertain to only one region in southern India, the developed methodology may be useful for other places and species.

Keywords: Teak, growth model, simulation, process model, optimum stand density, rotation age, understory competition, plantation management, productivity.

INTRODUCTION

Teak (*Tectona gandis* L.f) is one of the most valuable timber species in the tropics. As per the yield tables established for this crop in various countries, the potential productivity in best sites is as low as 6.5 m^3 ha^{-1} yr^{-1} of mean annual increment (MAI) in volume in Trinidad and Tobago, and as high as 17.6 m^3 ha^{-1} yr^{-1} in Indonesia. In India, the MAI in site quality I is around 10 m^3 ha^{-1} yr^{-1}. However, the actual productivity is much lower in many countries (Pandey and Brown, 2000). One of the reasons quoted for the low productivity is the poor stocking found in these plantations. The scientific basis of the presently existing density management schemes is also not well-founded. Although control of stand density is often profitable by itself, an optimum density level is not yet worked out for this important crop. This paper attempts to work out optimal density for teak plantations in the tropics. Also, the current management practices such as rotation age of 60 years are based on tradition with little scientific justification. Now when we have better data and modelling experience, it is time to develop a sound ground for management. The work has specific reference to southern India as the data set used for the analysis has been generated from Kerala in southern part of India but methods can be applied anywhere for problems of similar nature.

METHODS

A biologically meaningful stand level growth model, which predicts increment in mean tree diameter and volume as a function of stand density was developed first. Optimal density was sought analytically and by simulation using the estimated model. Later, a simplified economic analysis was carried out to find out the economic rotation age.

Growth model

Since the proposed growth model was a function of stand density, a satisfactory measure of density was required first. A proper measure of density should remain constant in equally dense stands, regardless of their diameter. Reineke (1933) had offered such an index based on number of trees and diameter. Reineke's index (S) is given by

$$S = N\left(\frac{D}{25.4}\right)^{r} \qquad (1)$$

where N = Number of trees per ha
D = Quadratic mean diameter of trees in cm
r is a parameter which is taken as 1.6 for all practical purposes.

Reineke's index lumps together two processes of self-thinning *viz.*, increasing average crown size expressed by diameter and diminishing crown closure. Zeide (2002a) further modified this index to describe both processes explicitly. The modified index was

$$S = N\left(\frac{D}{25.4}\right)^{b} e^{c(D-25.4)} \qquad (2)$$

However, for use in growth equations, the exponential part of the index was found unnecessary as this aspect could be taken care of by other growth parameters, thus reducing the modified index to a form similar to that of Reineke's index but with a smaller b which can be interpreted as a measure of self-tolerance of a species, i.e., the ability of trees to compete with or tolerate conspecifics (Zeide, 1985). This ability is measured by the proportion of trees eliminated during period dt by a certain increase in average diameter, dD/Ddt. Having got a satisfactory measure of stand density, it was possible to set up process-based growth models using the same.

Zeide (2002) had developed certain process-based models and procedures for projecting diameter and volume growth. For the present case, models proposed by Zeide (2002) were modified to suit the context of the data. The equation developed was,

$$\frac{dD}{dt} = Z = a_2 H^{b_3} D^{p} e^{-qt} e^{-S_t/c_2} e^{-S_m/c_3} \qquad (3)$$

where,
Z is the mean annual increment in diameter at breast-height (cm)
H is the top height at the base age of 50 years(M)
D is the quadratic mean diameter of teak (m)
t represents age (year)
S_t is the density of teak and S_m is the density of miscellaneous species including teak coppice.
a_2, b_3, c_2, c_3, p and q are parameters

The model consists of five modules: site index (H^{b_3}), unrestrained growth (D^p), aging (e^{-qt}), density of teak (e^{-S_t/c_2}) and density of miscellaneous species (e^{-S_m/c_3}). Site index as measured by height of trees will have an increasing effect on growth. Diameter represents the size of the tree and growth is generally proportional to the initial size raised to a power. Increasing age acts as a diminishing factor on growth and thus has a negative index. Higher density level of teak or miscellaneous species will have a negative effect on the growth of individual trees. However, higher density levels of teak trees leads to increase in total volume but the effect of miscellaneous species is one-sided.

Further, the following thinning impetus module (Zeide, 2002a) was included in equation (3) in multiplicative mode.

$$impetus = Z(m) = 1 + mMe^{-M} \qquad (4)$$

where $M = (S_b - S_a)/S_b$
S_b and S_a represent stand density before and after thinning.

The impetus module could indicate changes in growth associated with sudden changes in stand density due to thinning. When parameter $m > 0$, thinning increases growth of equally dense stands and *vice versa* for $m<0$. The maximum boost is m/e.

A volume growth model of the following form was also conceived which included the effect of miscellaneous species on growth of teak trees.

$$v' = a_1 b_1 D^{b_1-1} Z e^{S_t/c_1} e^{S_m/c_4} \qquad (5)$$

where v' is mean annual increment in tree volume (m^3)

Z, D, S_t and S_m as defined earlier

a_1, b_1, c_1 and c_4 are parameters

Data

Data were obtained from 31 permanent sample plots laid out in teak plantations in different parts of the State of Kerala (Latitude 10.00 N and Longitude 76.25 E), India. The plots were of size 50 m x 50 m except a few which were of size 20 m x 20 m. The plots belonged to age levels varying from 4 to 60 years. The plots were established during 1993-1994 and were remeasured twice during 1997 and 2001. Girth at breast-height (1.37 m above ground) was recorded on all the trees in the plots. Height was measured on a subsample of five trees covering the range of diameters in each plot. Crop diameter was obtained as the quadratic mean diameter of the stand. Top height was computed as the height corresponding to the quadratic mean diameter of the largest 250 trees (by diameter) per hectare as read from a local height diameter relation developed for each plot. Site index was calculated by using the equation reported by Jayaraman (1998). Volume was computed using the volume prediction equation reconstructed from Chaturvedi (1973).

The mean diameter in the 31 plots ranged from 4.5 cm to 41.9 cm. The number of trees varied from 76 to 1150 trees ha^{-1} and the basal area from 1.82 m^2 ha-1 to 33.10 m^2 ha^{-1}. The range of site index was from 11.8 m to 27.9 m.

The increment in mean diameter was obtained as the difference between quadratic means of diameter after thinning at the current measurement and that before thinning in the succeeding measurement. The increment thus obtained was divided by the interval between measurements to get the mean annual increment. The mean annual volume increment per tree was also obtained in similar lines but the mean volume per tree at any measurement instant was obtained as the arithmetic mean of the predicted volume for individual trees.

RESULTS

Diameter increment function

The parameters of equation (3) including the impetus module and equation (5) were estimated simultaneously using PROC MODEL of SAS, assuming an additive error term. Simultaneous estimation was considered because the endogenous variable Z in equation (3) appears in the right hand side of equation (5).

The estimate of parameter p was 0.250 (±0.040). In order to be consistent with certain theoretical expectations on the values of the different parameters involved, the value of b had to be fixed at the initial estimate of 1.25 obtained from the data before other parameters were estimated. The estimate of q was 0.029, which was a function of p and age at inflection point. The estimate of the site index parameter b_3 was 1.09 (±0.26) indicating an almost linear increase in the diameter growth with increase in the site index, keeping other factors constant. As diameter and site index are highly related, a separate module for site index was superfluous but its exclusion reduced the R^2. The parameters c_2 and c_3 were 769 (±379) and 348 (±114) respectively indicating a wide difference in how main crop and miscellaneous growth affect the growth of teak trees. The density of teak although has a depressing effect on individual tree growth, it has complementary positive effects on overall stand growth by the larger number of trees with higher density. On the contrary, the effect of miscellaneous species on teak growth is one-sided and is very serious as the coefficient $(1/c_3)$ is higher than $(1/c_2)$.

The estimate of impetus parameter was 0.14 (±0.64), nonsgnificant at P=0.05, which was probably due to the large gap between thinning and the measurement times. The parameter a_2 was 0.0813 (±0.059). The adjusted R_2 for the re-estimated model was 0.54. The residuals did not show any unsatisfactory pattern when plotted against predicted values of diameter increment.

Volume increment function

Equation (5) when simultaneously estimated with equation (3), produced the following estimates. The estimates were a_1= 0.1263 (±0.0081), b_1 = 2.7315(±0.0732), c_1 = 3443(±2666). As the parameter c_4 was nonsignificant, this had been dropped from the model. The parameter c_4 was nonsignificant as the miscellaneous density had no direct effect on volume increment. The miscellaneous species had high influence on diameter growth (Z) but as Z was already present in equation (5) as a predictor variable, the variable, miscellaneous density, became redundant. The value for a_1, the coefficient of proportionality and b_1 the power coefficient of tree volume equations was realistic. The adjusted R^2 for the fitted model was 0.96. The residuals did not show any distortion when plotted against the predicted values of volume increment except for a few outliers but this was ignored because of the high R^2.

Because of the repeated measurements in the sample plots, the residuals of the successive observations could be correlated which may introduce bias in the estimates. However, the observations when ordered by measurements, produced nonsignificant values for Durbin-Watson (DW) statistic for both equation (3) and equation (5).

Current Optimum

The optimal density for maximizing current volume growth was found from $S = 1/(1/c_2 - 1/c_1)$ as described by Zeide (2002). The value of S_C turned out to be 950. In order to have additional evidence on the value of S_C, equation (6) was fitted to data on mean diameter and number of trees per ha of teak trees in the three measurement occasions keeping the value of b at 1.25.

$$N=a\left[\frac{D}{25.4}\right]^b e^c (D-25.4) \qquad (6)$$

The estimate of a was 257 (±7) and that of c was 0.000991 (±0.002). Stand density index was computed substituting these estimates in equation (2) for 1170 sample plots of the Inventory of Teak Plantations in Kerala-1997 conducted to estimate productivity of teak plantations in Kerala, covering all the age groups available (KFRI, 1997). The stand density index ranged from 3 to 1102. The mean of five top ranking values was 911, which was very close to the estimate obtained from c_1 an c_2.

Long-term optimum

In order to find out the long-term optimum, a programme for growth simulation was developed in SAS with diameter as the driving variable. The programme was run for different density levels starting from 0.2 to 1 with a gap of 0.1 and the mean diameter and mean annual increment in accumulated volume were worked out for different age levels. As the change in diameter could occur also due to diameter jump as a consequence of thinning (Zeide, 2002a) other than due to growth, the following module for diameter jump was incorporated in the simulation.

$$D_a = D_b\left(1 + Z/D_b\right)^{b_4} \qquad (7)$$

where D_b and D_a refer to diameter before and after thinning

Z is the diameter increment

$b_4 = br$

The value for b was set to 1.25 as obtained earlier. The estimate for r came to 0.391 (±0.062). The density of miscellaneous species was set to 60, which was the mean density value for the data set used for estimation of parameters. The mean annual increment in volume was found to attain its maximum at a density level I of about 0.5, where I is $S/950$, regardless of site quality class. Next, the simulation runs were repeated for all the site quality classes by setting the miscellaneous density to 0. The long-term density was attained again at a density level I of about 0.5 in the absence of miscellaneous species, for all site quality classes. In effect, the long-term stand density index for maximizing cumulative volume of teak was found to be 475.

Economic analysis

Net Present Value (NPV) as shown in equation (8) was used as a financial criterion to arrive at economic rotation age.

$$V_0 = \sum_{t=0}^{n} C_t / (1+i)^t \tag{8}$$

where V_0 = present value of the cash flows
C_t = cash flow to be received at time t
n = number of periods
i = discount rate

Standing volume at any age was predicted from the accumulated volume computed by the simulator, using the following equation,

$$V_{st} = 1.073 V_{ac}^{0.4147} D^{0.7184} \tag{9}$$

where V_{st} refers to standing volume (m^3 ha^{-1})
V_{ac} refers to accumulated volume (m^3 ha^{-1})
D refers to mean diameter (cm)

The coefficients of equation (9) were obtained using data from yield table for teak (FRI and Colleges, 1970). The fitted model had an R^2 of 0.98. Thinned volume at any age was computed utilizing the successive differences of accumulated thinned volume. These quantities were further divided into quantity of timber and smallwood using equations (10) and (11).

$$R_{st} = 0.977\left(1 - e^{-0.16D}\right)^{16.078} \tag{10}$$

$$R_{st} = 0.939\left(1 - e^{-0.112D}\right)^{16.848} \tag{11}$$

where R_{st} indicates the proportion of timber in the standing volume
R_{th} indicates the proportion of timber in the thinned volume
D is diameter at breast-height (cm)

The parameters of equation (10) and (11) were estimated from data of yield table of teak (FRI and Colleges, 1970). The R^2 values were 0.99 and 0.96 respectively. Timber refers to round wood with 64 cm or higher girth over bark. Smallwood applies to round wood with girth between 64 and 16 cm girth over bark. Timber and smallwood roughly correspond to logs and poles. The volume figures were multiplied by price per m^3 taken from Mammen (2001). As the price varies with the size category of logs or poles, the median price was taken assuming that the conditional distribution of logs or poles for a given mean diameter of the stand is symmetrical. The median prices were USD 514 per m^3 for timber and USD 172 per m^3 for smallwood. The said prices are realized when the mean diameter of the stand is 55 cm. The constitution of timber and smallwood per m^3 and thus the price per m^3, changes linearly with the diameter. So, the unit price was allowed to change linearly with diameter at any age. Thus the price per m^3 at any age could be obtained by multiplying the unit price at diameter of 55 cm by the ratio of diameter at that age to 55 cm. Net Present Value (NPV) of timber and successive yield of thinning up to any particular age was found out by discounting the value at an inflation free interest rate of 5%.

Examination of the NPV revealed that it attains the maximum around 50 years for all site quality classes. The cost of input was disregarded as the thinning schedule pertains to an ideal strategy of long-term optimal density. More thorough economic analysis may be necessary for practical alternatives.

Effect of understory species

Miscellaneous species was found to have significant physical effect on growth of teak. In the absence of any miscellaneous species at long-term optimal density, the average diameter at 50 years was about 20 per cent higher than that of stands with miscellaneous species. The corresponding gain in the mean annual increment in volume was around 30 per cent. The miscellaneous species was dominated by *Terminalia paniculata*, a close associate of teak in natural forests.

DISCUSSION

The present study indicates that current volume growth of teak attains its maximum at a stand density index of 950 but this shall lead to greatly reduced diameter of individual trees and overall yield as well. The optimal long-term density which maximizes the accumulated volume however was found to be around 475. It is good to make an assessment of the impact of maintaining plantations under this density throughout the rotation period which is attempted in the following.

Comparison with yield table for teak

Any comparison requires a standard and in the case of teak, the only standard reference for density management in India is the All India Yield Table for teak established in 1959 (FRI and Colleges, 1970), which pertains to fully stocked stands. A comparison of the effect of keeping the stand density constant at its long-term optimal value over a rotation period of 50 years (with and without miscellaneous species) with that of the existing yield table is furnished in Table 1. A perusal of Table 1 will indicate that the mean annual increment (MAI) at 50 years corresponding to density at its long-term optimal value in the presence of miscellaneous species is lower than the yield table figures. When miscellaneous species is controlled, the MAI and the diameter are higher than the yield table figures. So, it turns out that if the density management is planned to be at its long-term optimal value, it is important to keep off the miscellaneous growth. The data used for generating the yield table were presumably obtained from well-maintained sample plots and the corresponding growth pattern is comparable only with conditions of no weed growth. The economic rotation age worked out based on the model output was fairly comparable with that based on yield table.

In the analysis phase, the self-tolerance values for teak and miscellaneous species were not found significantly different. However, the miscellaneous species had a greater coefficient in the diameter growth function implying that the competition is mainly for underground resources including soil moisture and nutrients. Removal of miscellaneous growth can bring in multiple benefits. Other than the positive effect on growth on teak trees, local inhabitants would be benefited by the availability of firewood by letting them utilize the same periodically, at no extra cost for cutting. The leaves and branches of small shrubs would add organic matter to the soil as well.

A value of 475 for long-term optimal density may not be directly meaningful to practicing foresters. Hence the number of trees to be retained in unit area in order to keep the density at 475 under different site quality classes was worked out. It could be seen that the number of trees required to keep the required density was almost double that of the numbers prescribed by the yield table. Number of trees below 10 years was not relevant as it takes time for the young seedlings to attain competition inducing density levels. However, the optimal density levels worked out practically implied initial planting at a spacing of 1.5 m x 1.5 m (4444 plants per ha) and first silvicultural thinning at 10 years to achieve the desired density levels. In better sites, a silvicultural thinning can be carried out at 5 years to avoid the sudden change in the number of trees.

Impact assessment

It would be interesting to assess the benefits of maintaining plantations under long-term optimal

Table 1. Comparison of the effect of maintaining plantations at long-term optimal density on diameter and mean annual increment in volume with that of yield table for teak at 50 years. Economic rotation age for each strategy is also indicated.

Site quality	Density level	DBH at 50 years(cm)	MAI at 50 years(m^3 ha^{-1})	Economic rotation age (year)
I	475 t + 60 m	46.3	9.7	50
	475 t	56.2	12.9	50
	Yield table	51.8	10.2	45
II	475 t + 60 m	35.3	65	50
	475 t	42.7	8.6	50
	Yield table	37.1	7.3	50
III	475 t + 60 m	25.1	4.0	50
	475 t	30.3	5.2	50
	Yield table	24.6	4.5	65
IV	475 t + 60 m	16.0	2.1	50
	475 t	19.2	2.7	50
	Yield table	16.0	2.2	40

Note : 475t + 60m = Density index of 475 for teak 60 for miscellaneous species.
DBH = Diameter at breast-height, MAI= Mean annual increment

density in contrast to the existing condition of the plantations. As part of a project to evaluate the productivity of teak plantations in Kerala, a survey had been conducted during 1997 using a stratified two stage sampling plan (KFRI 1997). The frequency distribution of the density was computed using equation (2) with $b = 1.25$ and $c = 0.000991$, in the 1170 sample plots used for the study. The said survey included plantations of age up to 60 years or even higher. The gain in MAI of volume at 60 years (current rotation age) for each density class was computed in comparison to the long-term optimum, for median site quality II/III. The weighted average gain came to 42%. A small bias on account of stratification could be present in this estimate. More important is the high gain in growth that can be attained if the density levels are raised to the optimum value.

The combined effect on returns

Bringing up the density of understocked stands (index less than 400) and reducing the index of overstocked stands will increase productivity by 42%. Economic analysis indicated that the net present value is maximized at 50 years. Bringing down the rotation age from the current 60 years to 50 years will increase the returns by 2.6% for site quality II/II without controlling understory species. Shortening the rotation age from 60 to 50 years will result in an increase in the harvest area by 20%. The combined effect of all these (1.42 x 1.026 x 1.2=1.75) would be an almost doubling of the returns from the existing plantations at no extra costs. Further, by controlling understory, the mean annual increment in volume can be increased by 30% leading to a total gain of the order of 1.75 x 1.3 = 2.3.

Limitations of the study

The small size of the data (31 plots and 2 remeasurements in 8 years) was probably a limitation of the present study. In order to keep consistency for the important parameter b (the exponent D in the modified Reineke's index), its value had to be fixed at 1.25 obtained from the diameter increment function, in some subsequent models. The R^2 value for the re-estimated diameter increment function, keeping the inflection point and the parameter b fixed, was low (0.54). This could be because diameter growth is very much affected by several extraneous factors. In teak, defoliation by teak defoliator has been found to cause depressive influence on growth. Teak defoliator is a migratory pest and its occurrence could not be recorded during the measurement time. The results of the present study are more general indicating general level of density at which long-term optimum in respect of growth is attained. Despite much effort to obtain data from several sources, no additional data to reconfirm the finding could be obtained.

It is to be noted that keeping density constant at its long-term optimal value need not be the best strategy available. The same may involve frequent thinning as well in order to keep the density constant. Density could be made progressively increasing or decreasing and the consequences in terms of stand structure require a thorough economic analysis, which would be attempted in due course. However, such economic optima would change with change in price levels and over regions.

CONCLUSIONS

This study has led to the following conclusions:

1. The stand density which maximizes current volume of teak growth is as high as 950 but the long-term optimal density is 475 which is 50% of the current optimum.
2. At current prices, the economic rotation age for teak in the region was found to be 50 years.
3. The mean diameter and mean annual increment in volume at 50 years for stands under long-term optimal density were higher or on par with the existing yield table values only when the undergrowth is controlled.
4. Understory species have a great influence on growth of teak trees. By controlling miscellaneous growth, the mean diameter of teak trees at 50 years can be enhanced by 20% and mean annual increment in volume at the corresponding age by 30%.
5. The overall gain in mean annual increment in volume in the State by keeping plantations at optimal density levels was assessed to be 42%, which can be attained by a simple change in the

thinning schedule at no extra cost.

6. The combined effect of maintaining plantations under optimal density, bringing down the rotation age from 60 years to 50 years and controlling understory was shown to result in more than doubling of the returns from the existing plantations at no extra costs.

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Stand Level Radial Growth Rate Pattern Reveals Growth Convergence in *Tectona grandis* L.f.

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ABSTRACT

Constant diameter increment of trees belonging to different diameter classes has been reported. It appears that, if the radial growth rates have to be constant across trees of different diameters, their initial growth rates must be varying, and at some point of time, the growth rate should converge. It is known that variations in anatomical properties of wood reduce during the transition from juvenile phase to the mature phase of the tree. The hypothesis was tested through stump analysis of teak (*Tectona grandis* L. f.), that radial growth rates of trees belonging to different radial classes converge towards the end of the juvenile phase. Growth patterns of 168 teak trees were analyzed after classifying them into four cohorts, based on the radial growth accumulated over the initial 20 years. Growth rates varied significantly among cohorts up to 15 years, but converged towards the end of the juvenile phase of tree growth (16- 20 years). Correlations show that growth up to 15 years had a significant impact on the cumulative growth. Trees that accrued larger growth during the initial 10 years, attained lesser growth during the period between 16-20 years and *vice versa*, showing a clear growth rate compensation. Growth beyond 20 years was relatively constant across the cohorts. It is also shown that competition affects trees that had slower growth initially and has little influence on fast growing ones. The paper discusses the implications of the findings in the management of teak trees.

Keywords: Tectona grandis, growth rings, tree growth, competition, growth convergence

INTRODUCTION

Growth, in the present context, is referred to the biological phenomenon of increase in size with time. The size / age relationship in trees, when represented with cumulative growth curve, is the accelerating rate of growth in the juvenile phase and a constant rate of growth during the maturity.

Although, the growth rate of trees during maturity is relatively constant, it may be different for different trees and may be conveniently assumed to be influenced by the amount of growth during juvenile growth phase. In contrast to this assumption, constant diameter increment for trees belonging to different diameter classes have been reported (Eyre and Zillligit, 1953, Gilbert *et al.*, 1955, Lundqvist, 1995). It appears that if the radial growth rates have to be constant across trees of different diameters, their initial growth rates must be varying, and at some point of time their growth rate should converge. It is also known that variations in the anatomical properties of wood reduce during the transition from juvenile phase to the mature phase of the tree (Bhat *et al.*, 2001). We tested the hypothesis that radial growth rates of trees belonging to different radial classes converge during this transition period through stump analysis of teak (*Tectona grandis* L.).

MATERIALS AND METHODS

Teak has distinct annual growth rings when viewed in a cross-section (Tewari, 1992), hereafter referred to as 'rings'. Width of each ring reflects the quantum of radial growth accrued by the tree in a year (Chowdhury, 1939). These rings could be used to analyze the patterns of growth rates through time and the variation in population (Assmann, 1970; Bhattacharya *et al.*, 1992).

Field data on rings of 168 teak trees from three sites (see Table 1 for sample sizes) viz., Virnoli, Bhagavati and Barchi were collected between March-April 1999 during the process of establishment of seed production area for teak. Each site is a managed plantation of known age located within a radius of 20 km from Dandeli (Haliyal Forest Division), Karnataka, India. Heartwood ring widths were measured using a ruler with a precision of 1 mm. Four measurements were taken radially from the pith in four directions approximately at 90^{0} from each other at stump height of each tree. Measurements were taken in units, hereafter called Measurement Units (MUs), with each MU consisting of five rings. The first set of five rings beginning from the pith formed the first MU (MU1); the next set of five rings beginning from MU1 formed the second MU (MU2) and so on. Since each ring represents one year of growth, each of the MUs comprising five rings represents five years of growth. Whenever the total number of heartwood rings was not in multiples of five, measurements were taken up to the maximum possible extent as units of five rings and the remaining number of rings were counted and their widths measured. Since the rings in the sapwood were not easily discernible, total sapwood width was measured. Thus, data were obtained on the total radius of the tree in four directions, excluding that of the bark. The average radial width (average of the four directions), of each MU for each of the trees, was calculated and used during the analysis. Analysis on growth pattern was restricted to four MUs corresponding to initial 20 years of growth. Also, a minimum of four MUs was available for all the trees across the three sites. Frequency distribution of total growth, i.e., radius from pith to the end of MU4, was plotted. From this frequency, trees were categorized into four size cohorts namely those with very small (C1), small (C2), medium (C3) and large (C4) radius, using the standard deviation (refer table 1 and fig. 2). The average growth rate, measured as cm/MU, of trees in each of the cohorts at every MU was plotted. Data from the individual sites and data that was pooled from all the sites were separately analyzed. Interpretations related to growth patterns made from the pooled data would be more meaningful as the year of planting varies between the plots and by pooling the data, any hidden interaction between stage of growth and prevailing environmental condition in a plot will be negated by the other plots that would be facing different conditions while passing through that particular stage of growth. Student's t-test was used to compare the growth pattern of cohorts with each other. Growth beyond MU4 was compared across individual cohorts separately in each of the plots as the age at culling differed between the plots (Student's t-test).

Contribution of growth during each of the MUs on the total growth was reflected through Pearson's product moment correlation. Correlations between growth up to initial 20 years and growth in each MU in each of the cohorts was expected to reveal the effect of competition on trees belonging to different radial classes across time.

One way ANOVA was performed to test the differences in the average growth rate at each of the sites. Data could not be pooled for the three sites as tree age and cohort size varied between sites.

RESULTS

The average growth rate decreased with age i.e. as we moved from MU1 towards MU4 (Fig. 1). It is also seen that the variance was highest during MU2 which later decreased. Growth rates of the cohorts

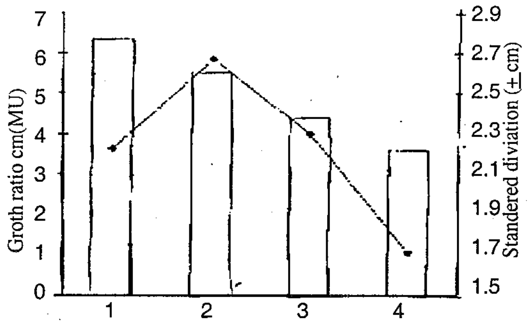

Figure 1. Mean growth rate (n) and standard deviation (-u) of 168 trees for each Measurement Unit (MU). Mean and standard deviation are plotted on separate scales.

Table 1. Sample sizes, location and other details of the teak plantations sampled in the study sites

Sites	Block/Compartment	Year of planting	Number sampled
Virnoli	11 – 12A	1958	72
Bhagavati	VIII – 1 – 13	1961	48
Barchi	VII – 3	1953	48

at different MUs for the pooled data (Fig. 3) show that the cohort with large radius (C4) had the highest growth rate and the cohort with very small radius (C1) had the lowest growth rate at MU1; the intermediary cohorts (C2 and C3) show a similar trend and were positioned between C1 and C4. The relative positions of growth rates of the cohorts remained the same at MU2 and MU3. The growth rates were significantly different at each of the first three MUs (Student's t-test; $p<0.05$). Interestingly, differences between the growth rates at MU4 was not significant (Student's t-test; $p>0.05$). Analysis of data from the individual sites (Fig. 4) also showed similar results. Differences in growth rates between tree cohorts were not significant at MU4 at all the three sites except between C2 and C4 at Virnoli. The differences in the growth rates of the cohorts at the first three MUs were significantly different from each other in all the sites except in a few cases.

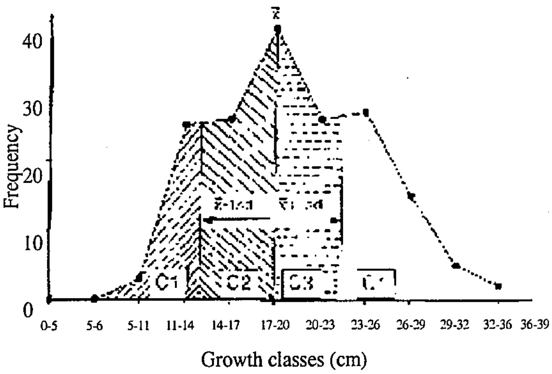

Figure 2. Frequency distribution of 168 trees based on the radius from pith to the end of MU4. Mean =19.91 cm; sd = ± 5.23 cm. C1, C2, C3 and C4 indicate cohorts with trees of very small, small, medium and large radius, respectively.

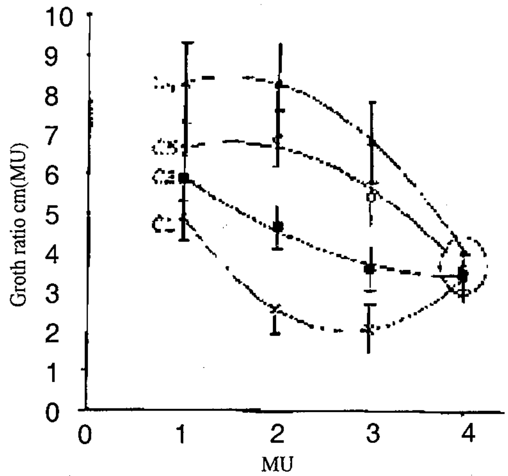

Figure 3. Growth rates of radial cohorts in different Measurement Units (MU) from the pooled data (points within the circle are not significantly different, the cohorts C1 (x), C2 (•), C3(o) and C4(•) contain35, 55, 46 and 32 trees, respectively

Table 2. Correlation matrix between growths in different Measurement Units (MU) and total growth from the pooled data

	MU1 (1 – 5 years)	MU2 (5 – 10 years)	MU3 (10 – 15 years)	MU4 (15 – 20 years)
MU1				
MU2	0.27*			
MU3	0.05	0.53*		
MU4	-0.16*	-0.26*	-0.04	
Total growth (1 – 20 years)	0.53	0.78*	0.75*	0.15

*p<0.05

Growth during each of MU1, MU2 and MU3 was positively and significantly correlated with that of total growth till 20 years whereas growth during MU4 was not correlated (Table 2). Also, there was a significant positive correlation between growth in MU1 and MU2; and MU2 and MU3. Noticeably, growth during MU1 and MU2 was negatively and significantly correlated with that during MU4. Another interesting finding was that growth during the initial years (MU1 and MU2) for trees in C1 and C2 was positively and significantly correlated with total growth till 20 years, while there was no such correlation for C3 and C4 (Table 3). Average growth of trees beyond MU4 in different tree cohorts at each individual sites was not significant (p>0.05) (Fig. 4).

DISCUSSION

Variations in tree growth are best expressed during their juvenile phase. Teak trees are known to complete their juvenile phase by ~20 years (Lamprecht, 1989, Bhat *et al.*, 2001). We find that the average growth rate decreases, as expected, as we move from MU1 to MU4. Also, the high variance during MU2 suggests that the progeny selection for any tree improvement program in teak is best done at 6 to 10 years.

A comparison of growth pattern across cohorts (Figs. 3 and 4) reveals two interesting patterns – a) cohorts with higher growth rates during their initial stages reduced their growth rates towards the end of their juvenile period while those with lower growth rates in initial stages increased their growth rates and b) all the cohorts converged towards a common growth rate at the end of the juvenile phase. These results indicate that convergence in growth rates occurs by 16-20 years in teak irrespective of the initial growth differences. This means that irrespective of age of the trees (Table 1) and size of the trees, growth rates converge towards the end of the juvenile phase.

The significant negative correlation between growth in MU1 with MU4, and MU2 with MU4 (Table 2) clearly shows that there is a compensation in growth rates towards the end of the juvenile phase of the trees. If this compensation continues for a long period it can be expected that beyond MU4, trees in C1 and C2 would accrue larger growths than the

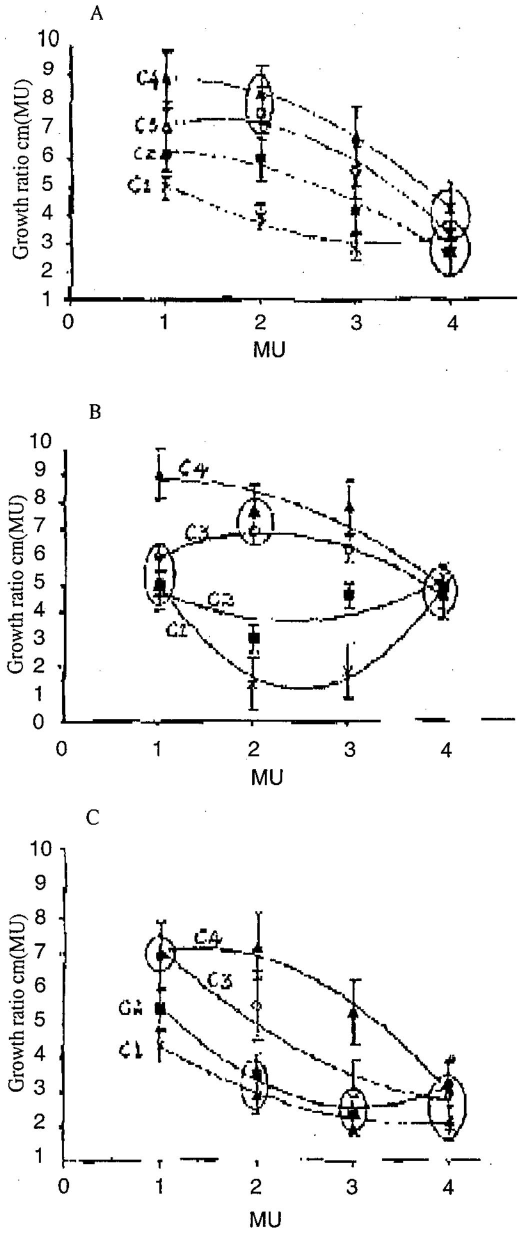

Figure 4. Growth rates of radial cohorts in different Measurement Units (MU) at A) Virnoli (C1 (x), C2 (?), C3 (o) and C4 (?) contain 14, 19, 28 and 11 trees, respectively) B) Bhagavati (C1 (x), C2 (?), C3 (o) and C4 (?) contain 13, 12, 15 and 8 trees, respectively) C) Barchi (C1 (x), C2 (?), C3 (o) and C4 (?) contain 9, 13, 17 and 9 trees, respectively) (points within the circle are not significantly different)

Table 3. Correlations between total growth (1 – 20 years) and growth in each Measurement Unit

(MU) in each of the cohorts(C)	MU1	MU2	MU3	MU4
C1 (n=35)	0.43*	0.25	0.05	0.18
C2 (n=55)	0.36*	0.46*	0.20	0.24
C3 (n=46)	0.06	0.25	0.24	-0.32*
C4 (n=32)	0.19	0.18	0.38*	0.16

indicates p<0.05 'n' indicates number of trees

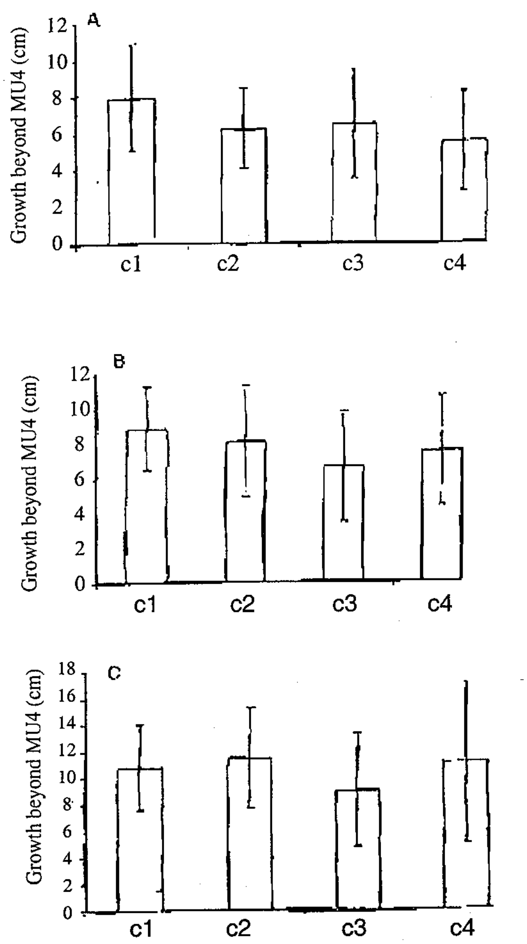

Figure 5. Average growth of trees beyond MU4 in different tree cohorts at Virnoli (A), Bhagavati (B) and Barchi (C). One-way ANOVA was performed to test the differences between cohorts. $p>0.05$ at each of the sites. Data from the three sites could not be pooled as tree age and cohort size varied between sites.

trees in C3 and C4. However, the differences in growth beyond MU4 among the cohorts were non-significant (Fig. 5). This shows that growth rate compensation may not extend beyond the juvenile stage of the tree. It also suggests that growth rates of similar aged trees are relatively constant across cohorts beyond their juvenile stage. Relatively constant diameter increment for all diameter size classes in managed hardwood stands has been reported (Eyre and Zilligit, 1953) Similar results are reported from experiments on Norway spruce wherein low correlations existed between mean annual diameter increment and tree diameter (Lundquist, 1993). Our study provides an explanation for their results. It also shows that this growth convergence coincides with the end of juvenile growth phase for teak trees.

The initial spacing given while planting provides opportunity for seedlings to grow without competition. Hence, it can be expected that differences in the initial growth rate of trees (beginning from their seedling stage up to the end of MU1) is more due to genetic factors or due to differences in resource availability and less due to competition. A mechanical thinning operation was carried out at the end of 10 years after planting (end of MU2) for trees in Virnoli and Barchi, and at the end of 8 years for trees in Bhagavati with an objective of increasing the growth rates of the retained trees. However, from Fig. 3 it is clear that the growth rates have not registered any increase at the end of MU3 from their previous point. It also appears that competition negatively influences the later growth rates of trees in lower cohorts resulting in significant contribution of initial growth to the total growth for C1 and C2 (Table 3). Competition does not seem to have a considerable impact on growth rate of trees in C3 and C4. Hence, thinning operation may be beneficial if carried out when competition for resources might have just set in as is evidenced by early thinning at Bhagavati wherein C1 and C2 registered a higher growth rate at the end of MU3 over MU2 (Fig. 4).

CONCLUSIONS

1. The transition period between juvenile and mature growth phase has always interested researchers. Our study adds another interesting dimension to this period. The convergence in growth rates, irrespective of the initial differences, appears to be an age (or time) dependent phenomenon rather than a growth dependent one.
2. Compensation in growth is a well-known phenomenon. However, we show that this compensatory growth in teak trees, like in annuals or animals, also appears to be age-dependent.
3. It is necessary to have a more cautious approach while predicting growth on the basis of data obtained from the initial few years.

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Effect of Soil-Leaf Nutritional Factors on the Productivity of Teak (*Tectona grandis* L.f.) in Kerala State, India

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ABSTRACT

A study was conducted at the College of Forestry, Kerala Agricultural University, Thrissur, India during 1994-96 to identify and assess the nutritional factors limiting productivity of teak plantations of different age groups. The sample set of 300 trees obtained from 20 sample plots laid out in different plots of Kerala was grouped into three age groups as <= 20 years (60 trees), > 20 and <= 40 years (135 trees) and > 40 years (105 trees) and the nature of relation between tree volume and the soil/leaf nutrient status and also current annual increment (CAI) in basal area per tree and soil/leaf nutrient status in each age group were investigated. The relation between leaf nutrient status and tree volume was feeble in all the three age groups. The models obtained through stepwise regression were all linear in nature and no quadratic terms were present. In all the age groups, the critical nutrient concentrations with respect to tree volume do not seem to be attained by the levels of nutrients covered by the data set considered for the study. This indicates that volume of trees for any particular age could be increased further by adequate supply of appropriate nutrient elements. The relation between tree growth and nutrient status of soil was stronger compared to the relation between the growth and nutrient status of leaves. In more specific terms, for the first two age groups selected, the models relating tree volume with soil nutrient levels were linear in nature. For the older plantations (age > 40 years), almost 50 % of the variation in tree volume was explained by the soil nutrient levels. For this age group, soil P had a quadratic term in the model and the point of maximal response for P was predicted at P = 26.66 ppm. The relation between CAI in basal area per tree and the nutrient status of leaves was also linear. The relation between CAI in basal area per tree and nutrient status of soil revealed that for any fixed age level, variation in CAI is positively correlated to soil N. This implies that effect of soil N on CAI need not remain same at all age levels. Alternatively, age related change on CAI is positively modified by the level of soil N.

Key words: teak, Tectona grandis, site quality, soil nutrient status, leaf nutrient status, current annual increment, growth , age groups.

INTRODUCTION

Teak (*Tectona grandis* L.f.) is a valuable timber in Kerala. As the demand for teak timber is ever increasing, further increase in the area under teak in the public sector is unlikely and productivity of the existing plantations is of utmost importance. One of the ways to achieve this goal is through proper nutrient management of the plantations. In a study on the degradation of tropical rain forests upon replacement with plantations in Andaman and Nicobar Islands in India, Dagar *et al.* (1995) concluded that nutrient cycling and water balance were negatively affected by monoculture of commercial teak plantations.

Teak is characterised by relatively high nutrient requirements and nutrient deficiencies can bring about reduced stand growth (Zech, 1990; Zech and Drechsel, 1991). The pattern of nutrient cycling in the plantations has revealed that nutrient deficiencies are essentially problems of young and old age trees (Miller, 1984). Gagnon (1964) showed that elemental composition of needles in black spruce have relation to the site index or site quality. Hence, to have a comprehensive idea about nutritional status of plantations, one has to consider plantations of different age groups belonging to different site qualities. In tree crops, foliage analysis is reasonably sensitive for detecting nutrient deficiencies and also has the advantage of being directly related to productivity as foliage is the site of photosynthesis (Mead, 1984). Also, in teak, leaves contribute to a major share of the nutrient budget (Pande and Sharma, 1988).

Nutritional diagnosis studies have been very much limited in tropical tree crops. Very few studies were conducted in India on teak nutrition and the results are by and large inconsistent. An assessment of nutritional factors limiting the productivity of teak plantations will give a lot of insight into better management strategy of future plantations. So the basic objective of the present study was to identify and assess the nutritional factors limiting productivity of teak plantations of different age groups belonging to different site qualities and to recommend possible corrective measures. The study also aimed to find out the influence of nutrient status of soil and leaf on the tree growth as represented through volume and current annual increment (CAI) in basal area (BA) per tree.

MATERIALS AND METHODS

Sample plots of size 50 m x 50 m belonging to different age groups and site quality classes retained as semi-permanent sample plots throughout Kerala State by Kerala Forest Research Institute, Peechi were utilized for the study. The selected plots belonged to the following age groups *viz.*, 0-9, 10-19, 20-29, 30-39 and 40-49 years. Fifteen representative trees were selected from each plot such that they included three trees each belonging to maximum, minimum, average and intermediate gbh (girth at breast height) classes. The intermediate dbh was selected on either shoulder of the average and their by six editional trees were selected.The height and gbh of all the selected trees were measured using clinometer and tape respectively.

Leaf samples were collected from the fifteen selected trees of each plot during the months of September to November as per the procedure standardised by Jayamadhavan and Sudhakara (2000). The second leaf rank from the bottom canopy was collected for the analysis. They were oven dried (70°C) and powdered using grinder and stored in polythene bags till analysis. Leaf samples were analysed for N, P, K, Ca, Mg, Fe, Mn and Zn concentration.

Representative soil samples were taken from 0-30 cm depth at a lateral distance of 1 m from the base of each of these trees. The soil samples were collected from three points and mixed to get the representative sample for each tree. Soil and leaf samples were collected simultaneously. Collected soil samples were air dried and sieved through 2 mm mesh and stored in polythene bags till analysis. Soil samples were analysed for pH, organic carbon, available P, total N and exchangeable K, Ca, Mg, Fe and Zn.

Relation between tree volumwe and soil attributes and foliar nutrient status

Tree volume, considered as an expression of growth, was computed for individual sample trees using the prediction equation reported by Chaturvedi (1973).

$$V = 0.1217 + 0.2257\,D^2H \qquad (1)$$

where, V = Volume of timber and small wood from the tree (m^3)
D = Diameter at breast-height of the tree (m)
H = Total height of the tree (m)

Since the trees were of different age levels, the effect due to age had to be eliminated first before regressing the volume on soil and foliar nutrient status directly. For this purpose, an equation of the following form was fitted first and the residuals were obtained.

$$\ln\ V = a + b\,X \qquad (2)$$

where, V is as defined earlier
X = Age of the tree (year)
ln indicates natural logarithm

a and b are constants to be estimated

The residuals of the above equation were then regressed on the soil and leaf attributes separately using the following model.

$$y = \beta_0 + \sum_{i=1}^{p} \beta_i x_i + \sum_{i=1}^{p} \beta_{ii} x_i^2 + \sum_{i<j}^{p} \beta_{ij} x_i x_j \quad (3)$$

where,

y = Residuals from the volume-age equation

x_i's are the set of soil or leaf attributes as the case may be

βs are the regression coefficients

p = number of variables

In particular, the soil attributes were pH, organic carbon and concentrations of N, P, K, Ca, Mg, Fe and Zn and the leaf attributes were concentrations of N, P, K, Ca, Mg, Fe, Mn and Zn.

Significant attributes from among the full set of attributes in the second order response function of (3) were identified through stepwise regression (Montgomery and Peck, 1982). The procedure was executed using SPSS software (Norusis, 1988). Before fitting the equation (3), the whole set of 300 trees was classified into three age groups as ≤ 20 years, >20 and ≤ 40 years and >40 years. These groups were formed based on the major differences found with respect to the pattern of RGR in these age groups as computed from the All India Yield Table (Fig.1 in results) for teak (Anon., 1970). There were 60 trees in the first age group, 135 trees in the second age group and 105 trees in the last age group. Stepwise regression was carried out for each age group separately. The resultant equations of stepwise regression were utilized to characterise the nature of response surface and to find out the optimum levels of soil attributes and foliar nutrient elements. The levels of $x_1, x_2, ..., x_p$ which maximize the predicted response were identified through the following equation (Montgomery, 1991).

$$\mathbf{x_0} = -\frac{1}{2}\mathbf{B}^{-1}\mathbf{b} \quad (4)$$

$$\text{where } \mathbf{b} = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \cdot \\ \cdot \\ \beta_p \end{bmatrix} \text{ and } \mathbf{B} = \begin{bmatrix} \beta_{11} & \beta_{1p}/2 & \cdot & \cdot & \cdot & \beta_{1p}/2 \\ \cdot & \beta_{11} & \cdot & \cdot & \cdot & \beta_{1p}/2 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \beta_{11} \end{bmatrix}$$

The predicted response at the stationary point is given by the following equation.

$$\hat{y}_0 = \hat{\beta}_o + \frac{1}{2}\mathbf{x}_0^1\mathbf{b} \quad (5)$$

To characterise the response surface, it was necessary to express the fitted model in canonical form.

$$\hat{y} = \hat{y}_0 + \lambda_1 w_1^2 + \lambda_2 w_2^2 + ... + \lambda_p w_p^2 \quad (6)$$

where w_i's are the transformed independent variables and the $\{\lambda_i\}$ are the eigen values or characteristic roots of matrix B.

The nature of the response surface can be determined from the stationary point and the sign and magnitude of the λ_i's. Suppose that the stationary point is within the region of exploration for fitting the second-order model. If the $\{\lambda_i\}$ are all positive, then x_o is a point of minimum response. If the $\{\lambda_i\}$ are all negative, then x_o is a point of maximum response and if the $\{\lambda_i\}$ have different signs, then x_o is a saddle point.

Relation between CAI in basal area per tree and soil attributes and foliar nutrient status

The nature of relationship between current annual increment in basal area per tree of each plot and the corresponding soil and leaf attributes was also foundout. Basal area per tree in each plot was calculated as follows :

$$\text{BA per tree} = \frac{\text{BA per plot}}{\text{Number of trees in the plot}} \quad (7)$$

CAI is calculated using the formula

$$CAI = \frac{BA_2 - BA_1}{(A_2) - (A_1)} \quad (8)$$

where $(BA)_1$ = Basal area per tree at the time of first measurement

$(BA)_2$ = Basal area per tree at the time of second measurement

$(A)_1$ = Age of the tree at the time of first measurement

$(A)_2$ = Age of the tree at the time of second measurement

The first measurement on the trees were taken in 1992-94. The second measurement was taken in 1997 (Jayaraman, 1998).

CAIs in basal area per tree were regressed on the different measurements made on soil and leaves along with age and initial basal area per ha included as independent variables in the regression model (3) using SPSS software. Age and initial basal area per ha were included in the model, so as to eliminate their influences from the effects of soil/leaf variables on the CAI. Significant variables from the soil/leaf variables in the second order response function were identified through stepwise regression. The resultant equations of stepwise regression were utilized to characterise the nature of response surface and to find out the optimum levels of soil/leaf attributes as described earlier.

RESULTS

The ranges of different tree, soil and leaf characteristics measured in this study are reported in Tables 1 and 2.

Relation between tree growth and soil attributes and foliar nutrient status

The whole set of 300 trees were grouped into three age groups as $\leq$ 20 years, >20 and $\leq$40 years and >40 years. Based on the pattern of RGR in these age groups as computed from the All India Yield Table for teak (Fig.1). Age below 20 years is a rapidly declining phase for RGR. Between 20 and 40 years the decline in RGR is slower and age greater than 40 years in a stable phase. Since the trees were of different age levels, the effect due to age had to be eliminated first before regressing the volume on soil attributes and leaf nutrient status directly. The volume-age equation fitted was of the following form:

$$\ln V = \underset{(0.1014)}{-1.743} + \underset{(0.0030)}{0.0251}\,A \qquad (9)$$

where, ln V = Natural logarithm of volume of timber and small wood from the tree (m^3)

A = Age of the tree (year)

The values in parentheses are standard errors of the coefficients. The adjusted R^2 for the above equation was 0.1886. The residuals of the above equation were then regressed on the different fertility attributes of soil and nutrient status of leaves separately using equation (3). The results are presented in the following sections.

Relation between volume and nutrient status of leaves

The resultant equations of the stepwise regression with respect to nutrient status of leaves of trees belonging to the three age groups are given in Table 3.

For the first age group ($\leq$ 20 years), the resultant model was linear and had an adjusted R^2 value of 0.1089. Nitrogen is the only element found to be related to volume growth. The negative coefficient of nitrogen indicates that the higher the volume growth, lesser the nitrogen concentration in leaf which could be explained on the basis of dilution effect.

For the trees having age > 20 and age $\leq$ 40, the model had an adjusted R^2 value of 0.2977. The absence of quadratic terms in the model indicates a linear surface subjected to interactions between nitrogen and calcium, phosphorus and calcium and magnesium and iron in the leaf. The first two interactions had positive coefficients while interaction between magnesium and iron had a negative coefficient.

The equation fitted with respect to nutrient status in leaves of trees having age > 40 years, through stepwise regression had an adjusted R^2 value of 0.3213. The model is linear and no quadratic terms were present. Phosphorus had a linear effect on the model. Also the interaction between nitrogen and calcium, nitrogen and magnesium and phosphorus and zinc contribute to the linear surface. The interaction between nitrogen and magnesium had a negative coefficient while others had positive coefficients.

Table 1. Range of soil fertility attributes and height and girth of trees for the three age groups of teak

Variable	Minimum	Maximum	Mean	Standard deviation	Unit
a. For age <=20 years (Number of trees observed = 60)					
N	0.08	0.32	0.22	0.04	%
P	7.00	48.00	19.22	15.15	µg g-1
K	0.0081	0.0356	0.02	0.01	%
Ca	0.023	0.315	0.19	0.09	%
Mg	0.005	0.025	0.02	0.00	%
Fe	13.070	288.46	136.64	118.08	µg g-1
Zn	0.770	15.46	7.11	4.73	µg g-1
OC	0.90	5.70	3.48	1.04	%
pH	4.8	5.7	4.14	0.16	
Height	1.20	18.30	13.06	3.23	m
Girth	9.00	97.00	57.91	2.31	cm
b. For age > 20 and age <=40 years (Number of trees observed = 135)					
N	0.07	0.36	0.22	0.06	%
P	6.00	37.00	14.59	7.06	µg g-1
K	0.0019	0.0413	0.01	0.01	%
Ca	0.007	0.318	0.08	0.06	%
Mg	0.001	0.027	0.01	0.01	%
Fe	5.88	46.04	19.34	8.49	µg g-1
Zn	0.34	18.96	1.99	1.94	µg g-1
OC	0.84	5.88	3.54	1.16	%
pH	3.5	5.6	4.95	0.32	
Height	2.80	28.50	16.71	5.97	m
Girth	21.00	155.00	79.53	30.69	cm
c. For >40 years (Number of trees observed = 105)					
N	0.08	0.41	0.24	0.08	%
P	8.00	40.00	15.61	9.13	µg g-1
K	0.0069	0.0469	0.02	0.01	%
Ca	0.017	0.206	0.10	0.06	%
Mg	0.004	0.026	0.02	0.01	%
Fe	7.23	199.25	32.83	38.02	µg g-1
Zn	0.390	6.890	2.09	1.40	µg g-1
OC	1.20	5.94	3.43	1.22	%
pH	3.9	5.7	4.91	0.39	
Height	2.60	31.10	19.78	6.53	m
Girth	31.00	200.00	95.68	37.26	cm

The critical nutrient concentrations with respect to tree volume do not seem to be attained by the levels of nutrients available in the present data set.

Relation between volume and soil attributes

The resultant equations of the stepwise regression with respect to fertility attributes in soils under trees belonging to the three age group are given in Table 4 In the first age group (age $\leq$20 years), the resultant equation had an adjusted R^2 value of 0.4731. The model was linear and no quadratic terms are present. The linear surface is subjected to interactions between phosphorus and potassium, phosphorus and magnesium, calcium and iron and zinc and soil pH. Zinc had also a linear effect having a positive coefficient. The interaction coefficients of phosphorus and magnesium and zinc and soil pH were negative while others had positive coefficients.

The equation fitted with respect to nutrient status in soils of trees having age > 20 and age $\leq$ 40 years,

Table 2. Range of leaf nutrient concentrations and height and girth of trees for the three age groups of teak

Variable	Minimum	Maximum	Mean	Standard deviation	Unit
a. For age <=20 years (Number of trees observed = 60)					
N	1.23	3.05	1.95	0.45	%
P	0.1613	0.2737	0.22	0.03	%
K	0.450	2.300	1.27	0.59	%
Ca	1.840	5.647	3.37	0.92	%
Mg	0.258	0.660	0.44	0.09	%
Fe	59.00	360.00	178.22	79.55	μg g-1
Zn	10.00	45.00	20.62	6.88	μg g-1
Mn	15.00	99.00	50.88	19.26	μg g-1
Height	1.20	18.30	13.06	3.23	m
Girth	9.00	97.00	57.91	22.31	cm
b. For age > 20 and age <=40 years (Number of trees observed = 135)					
N	1.04	2.51	1.56	0.28	%
P	0.0750	0.5737	0.23	0.10	%
K	0.100	2.050	0.66	0.40	%
Ca	1.728	6.785	3.59	1.04	%
Mg	0.198	1.198	0.52	0.15	%
Fe	54.00	569.00	222.74	100.73	μg g-1
Zn	7.00	34.00	17.47	5.53	μg g-1
Mn	21.00	147.00	67.82	26.03	μg g-1
Height	2.80	28.50	16.71	5.97	m
Girth	21.00	155.00	79.53	30.69	cm
c. For age >40 years (Number of trees observed = 105)					
N	0.95	2.52	1.66	0.30	%
P	0.1275	0.3563	0.21	0.05	%
K	0.200	2.050	0.79	0.43	%
Ca	2.297	5.675	3.66	0.74	%
Mg	0.203	0.875	0.50	0.14	%
Fe	84.00	902.00	244.58	166.70	μg g-1
Zn	7.00	42.00	20.25	6.56	μg g-1
Mn	29.00	148.00	59.23	21.62	μg g-1
Height	2.60	31.10	19.78	6.53	m
Girth	31.00	200.00	95.68	37.26	cm

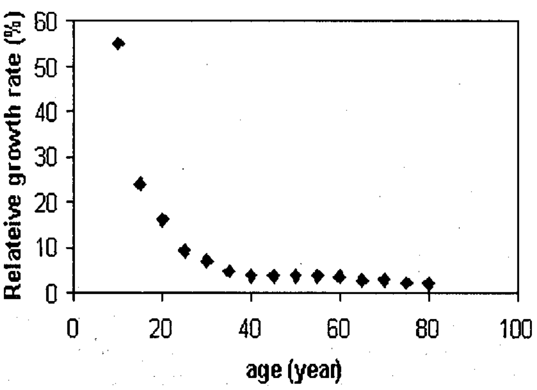

Figure 1. Pattern of relative growth rate over different years of age

had an adjusted R^2 value of 0.3476. Many components of the nutrient status in soils have significant influence on the volume growth of trees. However, the absence of quadratic terms in the model indicates a linear surface. Soil calcium had a linear effect with a positive coefficient. The linear surface is also subjected to interactions between nitrogen and zinc, phosphorus and organic carbon, magnesium and zinc and iron and organic carbon. The interaction between magnesium and zinc and iron and organic carbon were having negative coefficients while the other three had positive coefficients.

For the third age group (age > 40 years), the model had an adjusted R^2 value of 0.4997. The equation had one linear term (phosphorus), three interactions terms and a quadratic term. The interaction terms include interactions between nitrogen and calcium, nitrogen and zinc and organic carbon and pH. Phosphorus had a quadratic term in the equation. Exploration of the surface through the canonical form revealed the existence of a saddle point on the surface. But the point of maximal response of the phosphorus axis was attained. As there is no interaction term of phosphorus with the other variables in the model, the maximal response of phosphorus is predicted at 26.66 ppm, using differential equation (4).

Relation between CAI in basal area per tree and soil attributes and foliar nutrient status

Relation between CAI in basal area per tree and nutrient status of leaves. The equation fitted with respect to nutrient status in leaves, through stepwise regression was:

$$y = 0.0084 - 0.00003x_1 + 0.0330x_{10} - 0.000006x_2x_8 - 0.0005x_6x_7$$
$$(0.0022)\ (0.00004)\ \ (0.0132)\ \ (0.000002)\ \ (0.0002)$$

where, y = CAI in basal area per tree x_7 = leaf zinc
x_1 = age, x_8 = leaf iron
x_2 = leaf nitrogen x_{10} = initial basal area per ha.
x_6 = leaf magnesium

The model had an adjusted R^2 value of 0.4441. The absence of squared terms in the model indicates a linear surface subjected to interaction between nitrogen and iron and between magnesium and zinc. Both these interactions had negative coefficients. Age and basal area also had a linear effect on the model.

Relation between CAI in basal area per tree and soil attributes

The fitted equation with respect to nutrient status of soils, through stepwise regression was:

$$y = 0.0122 - 0.0004x_1 + 0.0534x_{11} + 0.0013x_1x_2 - 0.0076x_2x_{10}$$
$$(0.0039)\ (0.0001)\ \ (0.0126)\ \ (0.0004)\ \ (0.0032)$$

where, y = CAI in basal area per tree
x_1 = age, x_2 = soil nitrogen,
x_{10} = soil pH, x_{11} = initial basal area per ha

The adjusted R^2 value is 0.5618. Here also the model contained and no squared terms. The interaction between age and nitrogen and nitrogen and soil pH contribute to the linear surface. The age and initial basal area were also had a linear terms.

DISCUSSION

Relation between tree growth and nutrient status of leaves

For the first age group (<=20 years), the resultant model was linear and had a very low adjusted R^2 value of 0.1089. The leaf nitrogen concentration had a very meagre effect on the tree volume. The negative coefficient of the nitrogen indicates that with increasing volume growth, nitrogen concentration in the leaves deceased which may be due to the dilution effect. So there is scope for getting more volume growth by applying nitrogen fertilizers. This was the age group where RGR was maximum and hence one expects maximum influence of leaf nutrient status on growth of the tree. But the result does not show such influences by any element. At this phase of plantation development, the canopy is open and no distinctive microclimate and soil environment are developed. So the effect of other factors like soil physical properties, moisture availability and temperature might have masked the effect of leaf attributes on tree growth. Also the range of variation for all the macro elements and for most microelements was very narrow.

For the second age group, the tree volume was significantly influenced by leaf nutrient concentrations of N, P, Ca, Mg and Fe. Here the model contained interaction terms and had a higher adjusted R^2 value of 0.2977 compared to the first age group. Increase in the volume growth of tree was associated with in the leaf nutrient concentrations of N, P and Ca. The interaction between Mg and Fe in leaf had a negative effect on tree growth.

For the last age group, the model had an adjusted R^2 value of 0.3213. The model contained a few interaction terms but had no squaredterms. The phosphorus content in the leaf had a positive linear effect on tree volume indicating higher tree volume with increase in leaf phosphorus. Also there was

Table 3. Resultant equations of the stepwise regression with respect to nutrient status of leaves of trees in different age groups

Age group	The resultant equation of the stepwise regression	Adjusted R2
$\leq$20 years	y = 0.8277 - 0.4736 x1 (0.3302) (0.1652)	0.1089
>20 and $\leq$40 years	y = -1.0045 + 0.2604 x1x4 + 0.3113 x2x4 - 0.0055 x5x7 (0.3066) (0.0642) (0.1517) (0.0013)	0.2977
> 40 years	y = -3.6101 + 5.5133 x2 + 0.4917 x1x4 (0.6427) (2.4672) (0.9097) - 1.2684 x1 x5 + 0.1223 x2x6 (0.4772) (0.0681)	0.3213

The values in the parentheses are standard errors of the coefficients
where, y = Residuals from the volume-age equation; x1 = Leaf nitrogen; x2 = Leaf phosphorus ; x4 = Leaf calcium, x5 = Leaf magnesium; x6 = Leaf zinc; x7 = Leaf iron

Table 4. Resultant equations of the stepwise regression with respect to nutrient status of soil in different age groups

Age group	The resultant equation of the stepwise regression	Adjusted R2
$\leq$20 years	y = 0.0383 + 0.5526 x6 + 2.2434 x2x3 (0.2200) (0.2236) (0.6719) - 2.2142 x2x5 + 0.0194 x4x7 - 0.1283 x6x9 (0.9718) (0.0038) (0.0432)	0.4731
> 20 and $\leq$40 years	y = - 0.8121 + 7.7064 x4 + 1.2953 x1x6 (0.2132) (2.0081) (0.3407) + 0.0075 x2x8 - 15.8635 x5x6 - 0.0040 x7x8 - 0.0055 x5x7 (0.0033) (6.4587) (0.0018) (0.0013)	0.3476
> 40 years	y = - 6.2031 + 0.5546 x2 + 40.1271 x1x4 (0.9900) (0.0854) (7.6566) - 1.9066 x1x6 - 0.0104 x22 + 0.0483 x8x9 (0.4042) (0.0019) (0.0224)	0.4997

The values in the parentheses are standard errors of the coefficients
where, y = Residuals from the volume-age equation; x1 = Soil nitrogen; x2 = Soil phosphorus; x3 = Soil potassium, x4 = Soil calcium; x5 = Soil magnesium; x6 = Soil zinc; x7 = Soil iron; x8 = Organic carbon; x9 = Soil pH

significant positive interaction between nitrogen and calcium and also between phosphorus and zinc.

In all the three age groups, the critical nutrient concentrations with respect to tree volume do not seem to be attained by the levels of nutrients available in the present data set. Sudhakara *et al.* (2001) also reported that the critical nutrient levels for N, P and K could not be determined for the four site quality classes of teak plantation of Nilambur, since the basal area and volume increased linearly with increasing foliar nutrient concentrations.

The adjusted R^2 values increase from first age group to third age group. A possible explanation here could be that larger volume of a tree compared to that of its counterparts in lower age group would have been a result of continued better nourishment over a longer time span. Thus it is just natural that the leaf nutrient status of such trees reflect the higher attainment in the physical dimensions.

Relation between tree growth and soil fertility attributes

For the first age group, the resultant model had an adjusted R^2 value of 0.4731. The result indicated that Zn in the soil is linearly related to the tree volume. Also the interaction between soil phosphorus and potassium and also the interaction between calcium and iron were positive indicating the synergistic rather than antagonistic effects of these sets of elements on tree volume.

For the second age group, the model contained no quadratic terms. The adjusted R^2 value was 0.3476. The result indicated that calcium in the soil is having a significant positive effect on tree volume. In this age group coefficient of variation of soil characters were very small in most of the cases.

In the last age group, the model had an adjusted R^2 value of 0.4997. The interaction between organic carbon and pH of the soil had a positive effect on tree volume. Soil phosphorus had a quadratic term in the model. Exploration of response surface through canonical form revealed the existence of a saddle point on the surface. But the point of maximal response was attained in the phosphorus axis. As there was no interaction term of phosphorus with other nutrients in the model, using differential equation, the point of maximal response for phosphorus was predicted at P=26.66 ppm. Comparing soils under teak plantations and natural forests of Madhya Pradesh, Choubey *et al.* (1987) reported that phosphorus under teak plantations is higher than natural forests and also values tended to increase with the age of plantations. This also shows that response may not be obtained for further application of phosphorus fertilizers.

The present study was conducted on teak plantations widely distributed all over the State. No deliberate attempts were made to control the status of soil and leaf attributes. The natural variation was left uncontrolled except for the effect of age. The range of variation found in the values of each characteristics in a given age group is an important factor to be considered while judging the significance of their effect on tree growth. In many instances, the range of variation was found to be small. Even when an element has significant effect, the chance of getting it masked by uncontrolled factors related to microclimate and inter-tree competition is high in a study like this. Hence, many variables which might have influenced the tree growth may not appear in the final equation of the stepwise regression. Also, in some cases, by sheer chance, some variables may accidently get included in the final equation even when they have no significant effect on tree growth, although chances of such occurrence are low. Additionally, when there is high intercorrelation among the regression variables, the stepwise regression is likely to exclude many variables from the final model considering them as redundant. In spite of the limitation, certain broad indications are sure to be obtained by the use of the procedures.

Finally an important limitation of this approach was that the tree growth which is a manifestation of long years of complex interactions with soil and climate need not show good relationship with current soil fertility attributes or leaf nutrient status like in agricultural crops. The use of volume prediction equation would have also brought in some error in the assessment of volume. Nevertheless, the observation that almost 50 per cent of the variation in tree volumes in the older age group could be explained by soil nutrient levels is something remarkable.

Relation between CAI in basal area per tree and soil attributes and foliar nutrient status

Current annual increment in basal area per tree was computed through stand level values because records of increment of individual trees could not be obtained. Since the heights of all trees in the plots were not known, basal area was taken as an index of growth in this case.

In the case of relationship between CAI in basal area per tree and nutrient status of leaves, the model had an adjusted R^2 value of 0.4441. The model was linear and no quadratic terms were present in the model. The interaction between nitrogen and iron and also that between magnesium and zinc had negative effects on the CAI in basal area per tree. In a study on litter production and nutrient return in 20-23 years old teak plantations and adjoining natural forests in Madhya Pradesh, Chaubey *et al.* (1988) reported greater content of N, P, K and Ca in plantations than in forest litter indicating a greater nutrient return in the plantations.

Relation between CAI in basal area per tree and nutrient status of soil also followed a linear model, the adjusted R^2 value being 0.5618. The result revealed that interaction between age and soil nitrogen had a positive effect of CAI indicating that for any fixed age level, variation in CAI is positively related to soil nitrogen. This may also imply that effect of soil nitrogen on CAI need not remain the same at all age levels. Alternatively, age related change in CAI is positively modified by the level of soil nitrogen. The interaction between nitrogen and pH was negative. Alexander *et al.* (1987) found that soil variables accounted for 37 % of the variation in top height of teak and age 63 %.

CONCLUSION

The study conducted on the nature of relation between tree growth and the soil/leaf nutrient status using data from semi permenant sample plots in Kerala indicated the following.

The relation between leaf nutrient status and tree volume was generally feeble. The models obtained through stepwise regression were all linear in nature and no quadratic terms were present. In all the three age groups, the critical nutrient concentrations with respect to tree volume do not seem to be attained by the levels of nutrients available in the data set. It indicates that volume of tree could be increased further by adequate supply of the appropriate nutrient elements. The relation between tree growth and nutrient status of soil was stronger compared to the relation between the growth and nutrient status of leaves. For the first two age group selected (Age $\leq$40 years), the models were linear in nature. For the older plantations (Age >40 years), almost 50 per cent of the variation in tree volume was explained by the soil nutrient levels. For this age group, soil phosphorus had a quadratic term in the model and the point of maximal response for phosphorus was predicted at P = 26.66 ppm.

The relationship between CAI in basal area per tree and nutrient status of leaves was also linear. The relationship between CAI in basal area per tree and nutrient status of soil revealed that for any fixed age level, variation in CAI is positively correlated to soil nitrogen. This implies that effect of soil nitrogen on CAI need not remain same at all age levels. Alternatively, age related change in CAI is positively modified by the level of soil nitrogen.

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Quality Timber Products of Teak from Sustainable Forest Management pp 540-544

A Preliminary Study on Growing Teak in a Sandy Area in Malaysia : A Fertilizing Trial

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ABSTRACT

Planting of Teak *(Tectona grandis)* has been carried out mainly in marginal areas in Malaysia during the last decade. The present study reports the growth performance of this species at a site classified as sandy. Application of fertilizer was necessary and organic fertilizer was the best for promoting the growth of this species in this marginal area.

Keywords: Tectona grandis, marginal area, fertilizer application, Malaysia.

INTRODUCTION

Growing timber trees has been a trend among the planters in Malaysia recently. Teak is one of the high value species planted for furniture making and other purposes, covering approximately 3,000 hectares throughout Peninsular Malaysia (Krishna-pillay and Ong, 2003). Planting of Teak in Peninsular Malaysia, however, mainly takes place on idle land and marginal sites, i.e. steep slopes, areas with high water table, poor soil conditions etc.. It is due to the long gestation period involved in the plantation of forest species. Appropriate measures to overcome limitations at these sites are crucial for high productivity and wood quality, especially during the first few years of establishment (Akinsanmi, 1976; Zech and Drechsel, 1991).

MATERIAL AND METHODS

The experiment was carried out in Puncak Alam, Selangor, Malaysia. The site was 1.4 ha, slightly sloppy and belonged to a small holder. The land had been idle for several years and was covered by shrubs and grasses before the planting of *T. grandis*. For the purpose of growing this timber species, eradication of shrubs and grasses was carried out by the application of glyphosate. This area was then cleared and disc ploughed twice in two different directions. A total of five soil samples were collected randomly up to a depth of 50cm from the study site. These soil samples were analysed for wet pH and composition of sand, silt and clay.

Teak seedlings at the age of 6 month-old with an average height of 30cm were used as planting materials. The planting distance was 3x3m. An amount of 1kg organic fertilizer (3:6:4:2:10) and 100g Christmas Island Rock Phosphate, CIRP, was placed in each planting hole prior to planting. The seedlings were subjected to a fertilizing trial at six month-after-planting. The fertilizing treatments were application of 80g nitrophoska green, NPK green (15:15:15); 80g nitrophoska blue, NPK blue (12:12:17:2); 100g Basacote (15:8:12:2+TE); 200g organic fertilizer as in the planting hole and the untreated control (Table 1). The fertilizers were applied in 2 pockets at a depth of 10 cm and a distance of 50 cm from the seedlings. The application of NPK green and blue and organic fertilizer was carried out quarterly until the seedlings were one year-old. The application frequency was then reduced to four month-intervals for the subsequent years. The untreated control trees were also treated with NPK blue according to the same rate and frequency of four month-intervals from the age of 12 month-old onwards as they showed nutrient deficiency symptoms. Basacote, which is a slow release fertilizer, was only applied annually. All the trees in the areas were each subjected to application of 20g Aquastore in two holes at 24 month-after planting as they suffered from water stress and lost a lot of leaves, especially during the dry season. The holing was done by using an auger at a depth of 60cm and a distance of 60cm from the tree. This paper reported the results of the fertilizing trial for a period of up to 32 month-after planting. The cumulative quantity of nitrogen, N; phosphorus, P and potassium, K applied was shown in Table 2.

For the determination of growth performance in this trial, the seedlings were measured for survival rate, height and stem diameter at three month-intervals during the first year. The stem diameter was measured by using a caliper at a distance of 10cm above the ground. As the seedlings grew into trees, the stem diameter was measured by using a diameter tape at breast height of 1.3m from the age 12 month-old onwards. The growth parameters of survival rate, height and stem diameter, however, were measured at four month-intervals for these subsequent years followed by the applications of fertilizers according to their treatments. Sturdiness quotient was computed as the ratio of height (cm) to stem diameter (mm). The relative growth rates (RGR) of height and stem diameter were computed as below :

$$RGR = (\ln M_2 - \ln M_1)/t$$

Table 1. Fertilizing treatment

	6-12 month-old		>12-24 month-old		* >24-32 month-old	
	Amount(g)	Frequency	Amount(g)	Frequency	Amount(g)	Frequency
control	-	-	80	4 month-interval	80	4 month-interval
NPK green	80	Quarterly	80	4 month-interval	80	4 month-interval
NPK blue	80	Quarterly	80	4 month-interval	80	4 month-interval
Basacote	100	Annually	100	Annually	100	Annually
Organic fertilizer	200	Quarterly	200	4 month-interval	200	4 month-interval

*Application of 20g Aquastore in 2 holes at a depth of 60cm and a distance of 60cm from each tree was carried out.

Table 2. The cumulative quantity of N, P and K applied for a period of 32 months after planting

	Period (months after planting)							
	6	9	12	16	20	24	28	32
(a). The cumulative quantity of N applied								
control	-	-	9.6	19.2	28.8	38.4	48.0	57.6
NPK green	12.0	24.0	36.0	48.0	60.0	72.0	84.0	96.0
NPK blue	9.6	19.2	28.8	38.4	48.0	57.6	67.2	76.8
Basacote	15.0	-	-	-	30.0	-	-	45.0
Organic fertilizer	6.0	12.0	18.0	24.0	30.0	36.0	42.0	48.0
(b). The cumulative quantity of P applied								
control	-	-	9.6	19.2	28.8	38.4	48.0	57.6
NPK green	12.0	24.0	36.0	48.0	60.0	72.0	84.0	96.0
NPK blue	9.6	19.2	28.8	38.4	48.0	57.6	67.2	76.8
Basacote	8.0	-	-	-	16.0	-	-	24.0
Organic fertilizer	12.0	24.0	36.0	48.0	60.0	72.0	84.0	96.0
(c). The cumulative quantity of K applied								
control	-	-	13.6	27.2	40.8	54.4	68.0	81.6
NPK green	12.0	24.0	36.0	48.0	60.0	72.0	84.0	96.0
NPK blue	13.6	27.2	40.8	54.4	68.0	81.6	95.2	108.8
Basacote	12.0	-	-	-	24.0	-	-	36.0
Organic fertilizer	8.0	16.0	24.0	32.0	40.0	48.0	56.0	64.0

Where,

M_1 = the previous growth measurement
M_2 = the current growth measurement
t = period (day)

The study was a single factorial experiment based on a completely randomized design with 48 replicates, where a random tree from the planted area was used as a replicate. Analysis of variance was carried out for the relative growth rates of each period. Treatment means of the relative growth rates within the same growth period were compared using Tukey's Studentized Range Test.

RESULTS AND DISCUSSION

Based on analysis of soil samples, the area was found to have above 80% sand (Table 3). The soil pH of the site was also rather low (Table 3). It was considered as a marginal area for crop growing purposes. Teak grown at this experimental site, however, managed to maintain a survival rate of 80% for a period of up to 28 month-old (Figure 1). The survival rate reduced slightly to the range of 70-80% for most of the treatments as they grew older to 32 month-old (Figure 1). It was probably due to crown closure and competition for space among the trees.

Table 3. Analysis of soil samples

Coarse sand	41%
Fine sand	42%
Silt	3%
Clay	19%
Wet pH	4.02

Teak showed rapid growth in terms of height and stem diameter for a period of up to 12 month-old (Figures 2 and 3). The relative growth rate was, however, lower as the trees grew older (Tables 4 and 5). The control trees and those subjected to treatment with organic fertilizer were shorter and had smaller stem diameter during the beginning period of up to 12 month-old when compared to those treated with non-organic fertilizers of NPK blue and green and Basacote (Figures 2 and 3). The trees subjected to the application of organic fertilizer, however, recorded higher relative growth rate of height and stem diameter from the age of 24 month-old onwards following the application of Aquastore (Tables 4 and 5). The control trees exhibited the lowest growth performance (Figures 2 and 3) even though they were also subjected to the application of NPK blue from the age of 12 month-old onwards. The fertilizing treatment of applying 100g Basacote once a year, on the other hand, contributed the lowest total quantities of N, P and K to the trees among all the treatments under study (Tables 2a, 2b and 2c). These trees eventually showed the lowest relative growth rates of height and stem diameter from the age of 24 month-old onwards as the cumulative quantities of N, P and K in the control trees exceeded that with this treatment of 100g Basacote applied once a year (Tables 2a, 2b, 2c, 4 and 5).

All the trees in this study, however, did not show great differences in terms of sturdiness quotient due to fertilizing treatment (Figure 4). The rapid increment in height resulted in the increased sturdiness quotient as the trees grew from six month-old to nine month-old. Higher sturdiness quotients were observed for all the trees at the age of twelve month-old following the lower stem diameter measured at breast height.

Table 4. The relative growth rate of height of *T. grandis* following application of fertilizers

Treatment	Relative growth rate of height (cm cm^{-1} day^{-1}) for the period (day)						
	180-270	>270-360	>360-480	>480-600	>600-720	>720-840	>840-960
Control	0.0057	0.0030	0.0011	0.0011 ab	0.0007	0.0004 b	0.0008 a
NPK green	0.0058	0.0025	0.0007	0.0010 b	0.0005	0.0004 b	0.0005 ab
NPK blue	0.0060	0.0028	0.0010	0.0011 ab	0.0008	0.0003 b	0.0010 a
Basacote	0.0066	0.0026	0.0012	0.0017 a	0.0007	0.0003 b	0.0002 b
Organic	0.0063	0.0031	0.0009	0.0012 ab	0.0007	0.0007 a	0.0008 ab

Means with the same letters within the same column are not significantly different at 5% level of significance

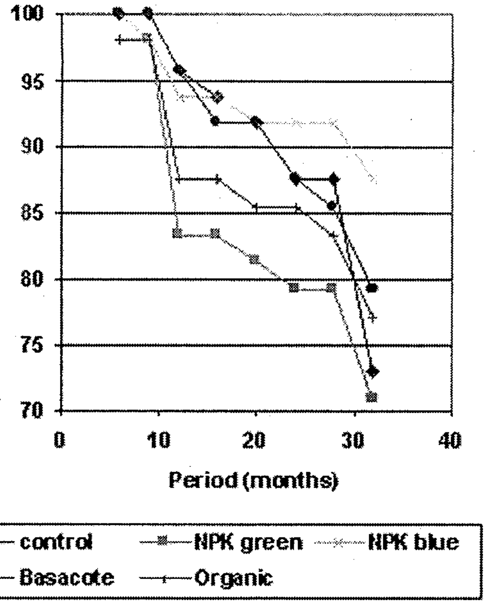

Fig. 1. Survival rate of teak trees planted in a sandy area

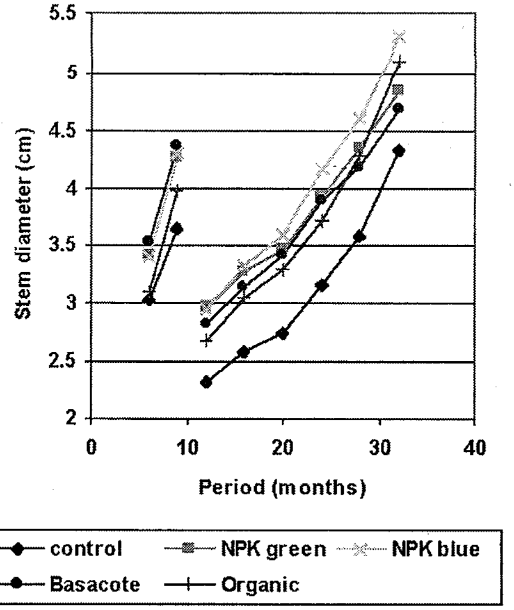

Fig. 3. Stem diameter of teak planted in a sandy area, measured at 10 cm above ground at 6 and 9 month-old and at breast height from 12 month-old onwards.

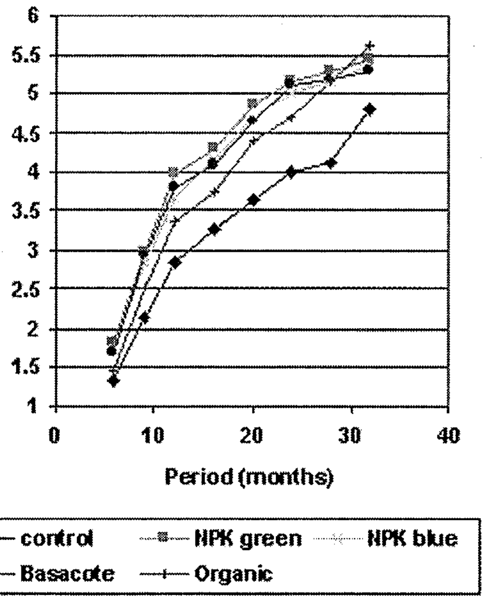

Fig. 2. Height of teak trees planted in a sandy area

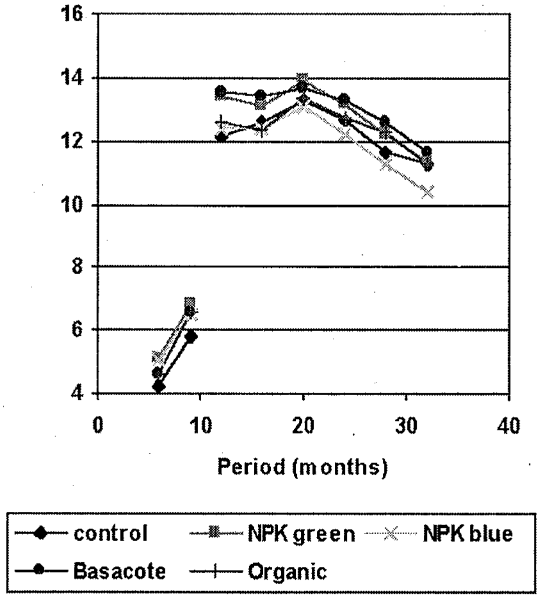

Fig. 4. Sturdiness quotient of teak planted in a sandy area

This parameter decreased from the age of 24 month-old onwards after the application of Aquastore that resulted in higher gain in the stem diameter growth.

The results indicated that the application of organic fertilizer was more beneficial for teak planted in a sandy area although the cumulative quantities of N, P and K were lower as compared to the non-organic

Table 5. The relative growth rate of stem diameter of *T. grandis* following application of fertilizers

Treatment	Relative growth rate of stem diameter (cm cm^{-1} day^{-1}) for the period (day)						
	180-270	>270-360	>360-480	>480-600	>600-720	>720-840	>840-960
Control	0.0020	-	0.0008	0.0004	0.0010 ab	0.0010 a	0.0010 ab
NPK green	0.0024	-	0.0008	0.0004	0.0010 ab	0.0008 ab	0.0009 ab
NPK blue	0.0025	-	0.0010	0.0006	0.0012 a	0.0009 a	0.0011 a
Basacote	0.0023	-	0.0009	0.0005	0.0009 b	0.0006 b	0.0007 b
Organic	0.0027	-	0.0010	0.0006	0.0009 b	0.0010 a	0.0012 a

Means with the same letters within the same column are not significantly different at 5% level of significance

fertilizer treatments (Tables 2a, 2b and 2c). The organic fertilizer was a soil conditioner that improved the water retention capacity and soil properties besides supplementing nutrients to the trees. Further studies on the cost effective application rate of organic fertilizer for the productivity of this species under such harsh condition are necessary.

CONCLUSION

Application of fertilizer is necessary for teak planting at a sandy site. Application of organic fertilizer is best for promoting the growth of this species in this marginal area.

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Influence of Water Stress on Teak (*Tectona grandis* L.f.) Seedlings

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ABSTRACT

A pot culture experiment was conducted to study the growth of teak (*Tectona grandis* L.f.) seedlings under soil moisture stress (water stress), at College of Forestry, Kerala Agricultural University, Vellanikkara. Uniform sized stump of teak, prepared from one year old seedling were transplanted in black polythene bags of size 40 x 20 cm, containing 5 kg potting mixture of sand, soil and farm yard manure (1:1:1). All the seedlings were irrigated daily with adequate quantity of water for six months. After six months growth, the plants were exposed to four levels of water stress, by withholding irrigation, so that the soil moisture tensions were approximately 0.3, 1.0, 5.0 and 10.0 bars respectively. To achieve this the seedlings were irrigated daily (No water stress), once in three days (mild stress), once in six days (moderate stress) and once in nine days (high stress), with equal quantities of water. The seedlings were grown under the above water stress cycle for four months and the plants were observed for changes in growth, morphological and physiological characters. The experiment was laid out in Completely Randomized Design with five replications. Seedling height, collar diameter, number of leaves, leaf area, leaf weight, specific leaf area and dry matter production decreased significantly due to water stress. High level of water stress (irrigated once in nine days) resulted in permanent wilting of all the plants. The relative growth rate (RGR) and net assimilation rate (NAR) were low in water stressed seedlings. The water stress increased the leaf diffusive resistance. The transpiration rate decreased in all the species with increasing levels of water stress. The leaf water potential and the net photosynthetic rate also decreased due to water stress. A mid-day closure of the stomata and dip in net photosynthetic rate was observed in all teak seedlings.

Keywords: *Tectona grandis*, Water stress, Seedlings growth, RGR, NAR, SLA, Leaf diffusive resistance, Leaf water potential, Net photosynthesis

INTRODUCTION

Water is considered as the most limiting factor for establishment and growth of trees in dry areas, which forms 75 per cent of the total cultivated area in India. Water deficits influence all phases of tree growth and are probably responsible for more growth loss than all other causes combined (Kramer, 1980). The water stress tolerance of plants varies with species and varieties/types. Water stress or water deficit refers to situations in which plant water potential and turgor are reduced to a level which interfere with normal physiological functioning and growth of the plants. The exact cell water potential at which this occurs depends on the kind of the plant, stage of development and the process under consideration (Kramer, 1983). Water deficits may vary in intensity from a small decrease in water potential, detectable only by instrumental measurements, through transient midday wilting, to permanent wilting and death by dehydration. Knowledge on the response of tree species to water stress is of great significance, especially in places were rainfall is limiting and/or poorly distributed. In most species the seedling phase is more sensitive to water stress. A lot of research has been done on the response of tree seedlings to water stress in temperate species but not much in tropical tree species (Zahner, 1968; Seiler, 1985; Kozlowski, 1982 and Kozlowski *et al.*, 1991).

Teak is the most important timber species of the tropics. In Kerala, during the recent years there has been a boom in planting teak, not only in forestlands but also in farmlands and public lands. Most of the areas planted with teak in Kerala are prone to water stress during the period from December to May, because of the restricted distribution and the seasonality of rainfall. The information on the effect of seasonal water stress on the growth of teak, both at seedling phase and adult phase is important for developing management strategies for growing teak. So an experiment was conducted to study the growth and physiological response of teak seedlings in response to different levels of water stress.

MATERIALS AND METHODS

A pot culture experiment was conducted at College of Forestry, Kerala Agricultural University, Thrissur, to study the growth response of the teak seedlings to different levels of water stress. The experiment was conducted during the rain-free period from December to May. The temperature during the period varied from 32.2 to 37.6° C (Maximum) and 22.2 to 24.9° C (Minimum). The relative humidity during the forenoon varied from 71-91 per cent and 45-65 per cent during the afternoon hours. From December to March there were no rainy days. During April and May there were 5 and 13 rainy days with a total rainfall of 119 and 371 mm respectively. Teak stumps were prepared from one year old seedlings showing apparently uniform growth characteristics and planted in polythene bags of size 40 x 20 cm filled with 5 kg potting mixture of composition 1:1:1, soil, farmyard manure and sand. The seedlings were irrigated daily to field capacity and allowed to establish well in the polythene bags. After six months of growth, the seedlings were exposed to varying intensity of soil moisture stress (water stress) by withholding irrigation for varying periods, so that different levels of soil moisture tension (SMT) is attained in the polybags. The water stress levels were:

S_0 – Control – Irrigating daily to field capacity (SMT –0.3 bars)
S_1 - Irrigating once in three days to field capacity (SMT – 1.0 bars)
S_2 – Irrigating once in six days to field capacity (SMT – 5.0 bars)
S_3 – Irrigating once in nine days to field capacity (SMT – 10.0 bars)

The soil moisture content of the potting mixture and the corresponding soil moisture tensions were estimated for progressive stages of drying of the potting media, from field capacity to wilting coefficient by using a pressure plate-membrane apparatus. From these values a soil moisture characterization curve was constructed by plotting the soil moisture percentage on 'y' axis and soil moisture tensions on 'x' axis. The average value of SMT under the four levels of irrigation were worked out from the curve, by estimating the gravimetric water content just before irrigation, in each pot. Every time irrigation was done with equal quantity of water and the water stress was imposed by varying the frequency of irrigation.

The experiment was laid out in Completely Randomized Design with four treatments and five replications. Each replication had 16 seedlings, three seedlings each used for the sampling at 30, 60, 90 and 120 days after imposing the water stress cycle. Seedlings as indicated by the peak in LDR observed during the midday. These results indicate that, as the water stress increases, teak seedlings try to reduce the water loss by stomatal regulation of transpiration. However, the stomatal response was slow in the teak The growth of the seedlings under water stress levels were monitored by recording the observations on seedling height, collar diameter, number of leaves and leaf area. At the time of destructive sampling, additional observations like dry weight of leaf, stem and roots were also recorded. The shoot, root and total dry matter production, relative growth rate, net assimilation rate and specific leaf area were calculated. Physiological parameters like relative water content of the leaves (Barrs and Weatherley, 1962), leaf water potential (using plant water status console, Soil moisture Equipment Corporation, USA), leaf diffusive resistance (using a steady state porometer, LI-COR, USA) were also recorded periodically. These observations were made on five plants per treatment, on the second or third leaf from the top, every day at 08 00 and 14 00 hours IST, after the beginning of the water stress cycle. The transpiration rate and the leaf temperature were recorded by using the steady state porometer. The net photosynthesis was measured with a portable infrared gas analyzer (IRGA) (Model LI 6200, Li-Cor, USA) using a one litre leaf chamber. Day time variations in these parameters were recorded at bihourly intervals. The data were statistically analyzed by ANOVA for completely randomized design and the means were compared by Least Significant Differences (LSD).

RESULTS AND DISCUSSION

Growth attributes

Height of seedling decreased significantly due to mild or moderate water stress (Table 1). The primary effect of water stress is the reduction in turgor which retards cell elongation which in turn affect the inter-node elongation. Reduction in stem elongation of water stressed seedlings was reported from temperate species like loblolly pine (Cannell *et al.*, 1978), *Picea rubens* (Robert and Cannon, 1992) and *Liriodendron tulipifera* (Cannon *et al.*, 1993) seedlings. Compared to tropical fast growing species like *Acacia mangium, Pterocarpus marsupium* and *Swetenia macrophylla,* the height of *Tectona grandis* was less influenced by mild and moderate water stress (Rajesh, 1996). Teak seedlings wilted and died when the seedlings were kept without watering for nine days. The soil moisture tension corresponding to this stress level was about 10 bars which indicates that the permanent wilting point for teak is much less than the general, average value of 15 bars suggested as permanent wilting point for most plants.

The collar diameter of the seedlings also showed significant reduction due to water stress. Several aspects of cambial activity, including division of fusiform cambial cells and xylem mother cells as well as its enlargement, differentiation of cambial derivatives are very sensitive to changes in internal water balance. The adverse interference of cambial growth of *Acacia auriculiformis* due to water stress was reported by Kallarakkal and Somen (1992).

The number of leaves, the leaf area and leaf dry weight showed significant decrease due to water stress. The moderate level of water stress resulted in about 75 per cent reduction in number of leaves. Zahner (1968) reported that water stress induces senescence and early abscission of leaves which when combined with reduced formation of leaf primordial, result in reduction in number of leaves per plant. A reduction in number of leaves in response to water stress was reported in eucalypts (Myers and Landsberg, 1989) and *Fagus sylvatica* (Cermak *et al.*, 1993). Rajesh (1996) observed that the number of leaves, leaf area and leaf dry weight of *Ailanthus tryphisa* and *Pterocarpus marsupium* seedlings were relatively less sensitive to water stress as compared to teak.

The leaf areas of the seedlings were reduced by 53 per cent even with moderate (S_2) level of water stress. The reduction in leaf area could be due to the reduced number of leaves in water stressed plants. This coupled with reduction in leaf -size and increased leaf abscission might have contributed to the decreased leaf area in water stressed plants. Boyer (1976) attributed the reduction in leaf size as the main reason for the reduction in leaf area of water stressed plants, whereas Ludlow and Muchow (1990) attributed the reduction in leaf area to increased leaf abscission. However, teak

Table 1. Influence of water stress on growth characteristics of teak seedlings

Water stress levels	Height (cm)	Collar diameter (cm)	No. of leaves	Leaf area (cm^2 $plant^{-1}$)	Leaf dry weight (g $plant^{-1}$)	Specific leaf area (m^2g^{-1})
S0	73.8	15.1	32.0	3706	23.2	1.6
S1	59.3	13.4	14.5	2912	20.4	1.4
S2	48.4	11.0	8.0	1753	13.1	1.4
S3	Wilted Dead	Wilted Dead	Wilted Dead	Wilted Dead	Wilted Dead	Wilted Dead
F test	*	*	**	**	**	**
LSD 0.05)	13.8	1.7	2.4	118	0.8	0.07
SEM ±	6.7	0.8	0.6	30	0.2	0.02

* Significant at 5 % level ** Significant at 1 % level

maintained relatively high leaf area in the water stressed seedlings resulting in higher transpiration and eventual wilting. The data on leaf diffusive resistance also corroborates this view. The leaf dry weight decreased considerably due to water stress. The specific leaf area of teak seedlings showed a significant decrease due to water stress (Table 1). However, the decrease was only moderate indicating that the partitioning of dry matter to the leaves were not seriously affected due to water stress.

The dry weight of shoot was not significantly influenced by mild water stress. Moderate water stress reduced the shoot weight. The total dry weight and the dry weight of root also decreased due to water stress. Mild water stress resulted in a steady and slow decrease in dry matter production. Moderate water stress appears to have drastic adverse effect on the dry matter production. The reduction in shoot dry weight could be the cumulative effect of reduction in plant height, collar diameter, number of leaves and leaf area due to water stress. There are a number of studies, which reports the decrease in shoot dry weight in response to water stress (Driessche, 1991; Roberts and Cannon, 1992). The root – shoot ratio of the seedlings did not vary significantly due to the water stress, which corroborates view that the dry matter partitioning in teak is not in favour of root as observed in many plant species in response to water stress.

Physiological parameters

The relative growth rate (RGR), during 30-60, 60-90 and 90-120 days showed significant decrease due to mild and moderate water stress (Table 3). The RGR of teak was relatively low even when there was no water stress. There were no significant differences in RGR between mild and moderate water stress. The net assimilation rate (NAR) showed significant decrease due to water stress (Table 3). A sharp decrease was observed even with

Table 2. Influence of water stress on dry matter production and root-shoot ratio of teak seedlings

Water stress levels	Dry weight of shoot (g plant^{-1})	Dry weight of root (g plant^{-1})	Root/shoot ratio	Total dry matter (g plant^{-1})
S0	43.9	58.1	2.7	102.0
S1	44.1	44.9	1.9	89.4
S2	28.5	32.1	2.1	60.6
S3	Wilted Dead	Wilted Dead	Wilted Dead	Wilted Dead
F test	*	**	NS	*
LSD (0.05)	11.9	10.9	—	21.7
SEM ±	3.0	2.8	0.3	5.5

* Significant at 5 % level ** Significant at 1 % level NS = Not significant

Table 3. Influence of water stress on relative growth rate, net assimilation rate and relative water content of teak seedlings

Water stress levels	Relative growth rate (mg g^{-1} week^{-1})			Net assimilation rate (mg cm^{-2} week^{-1})			Relative water content (%)	
	30-60 Days	60-90 days	90-120 days	30-60 Days	60-90 days	90-120 days	08 00 hours	14 00 hours
S0	0.77	0.60	0.65	0.15	0.10	0.07	91.8	81.5
S1	0.25	0.23	0.19	0.01	0.02	0.002	81.4	72.1
S2	0.19	0.22	0.16	0.01	0.01	0.002	79.0	60.9
S3	Wilted Dead	Wilted Dead	Wilted Dead	Wilted Dead	Wilted Dead	Wilted Dead	Wilted Dead	Wilted Dead
F test	**	**	**	**	**	**	**	**
LSD (0.05)	0.08	0.26	0.18	0.03	0.03	0.03	9.5	9.7
SEM ±	.02	0.07	0.05	0.01	.01	0.01	2.9	3.0

* Significant at 5 % level ** Significant at 1 % level NS = Not significant

mild water stress. On the other hand Rajesh (1996) observed that the NAR of *Ailanthus triphysa* increased under mild water stress, even though higher levels of water stress decreased the NAR.

The relative water content of the leaves decreased significantly due to water stress (Table 3). The decrease was observed during morning (FN) as well as the afternoon (AN) hours. However, the extend of decrease was more during the AN.

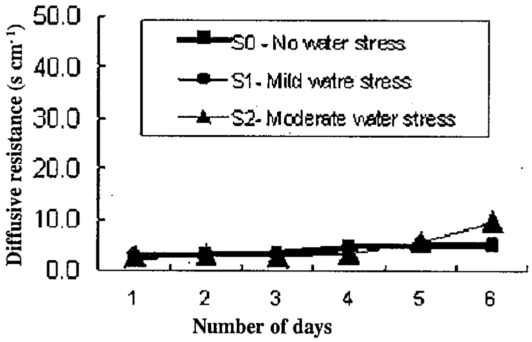

Fig.1 Leaf diffusive resistance of teak seedling as influenced by water stress (800 hours)

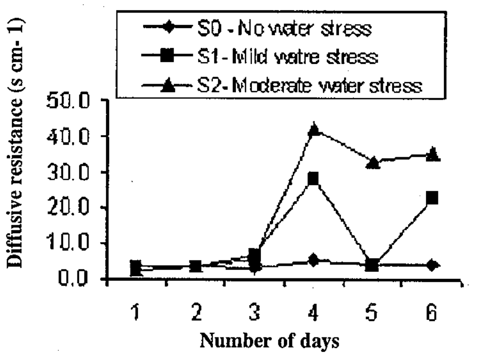

Fig.2 Leaf diffusive resistance of teak seedling as influenced by water stress (1400 hours)

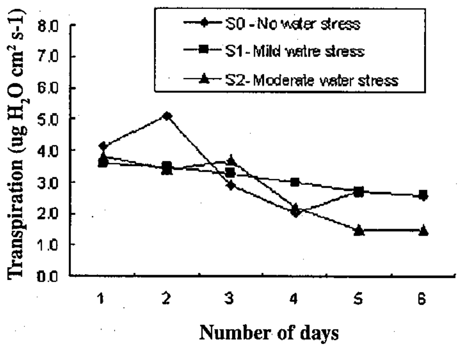

Fig 3. Transpiration rate of teak seedlings as influenced by water stress 800 hours.

The leaf diffusive resistance (LDR) increased due to increasing levels of water stress (Fig. 1 and 2). The LDR was high in the AN hours compared to the morning hour. The difference in the LDR due to water stress levels were also more prominent in the AN hours. During the FN hours the LDR did not vary much during initial four days of water stress. However, by sixth day of stress, there was a jump in LDR values. The stomatal closure and increase in LDR are usual when the turgor of guard cells decrease during relatively early stages of leaf water deficits, often long before the leaves wilt (Kramer, 1983). The increase in the LDR observed could be an indication of the internal water stress of the seedlings. There was a pronounced midday closure of stomata in the teak seedlings as compared to the values reported for mangium and mahagony (Rajesh, 1996).

During the morning hour, transpiration rate of the seedlings were not much influenced by the water stress (Fig. 3). Plants grown without water stress retained a steady and high transpiration rate both during FN and AN hours (Fig. 3 and 4). The transpiration rate of water stressed plants dropped to very low values as compared to seedlings grown without water stress. During the FN hours this distinction was not perceptible.

The water stressed plants showed a higher leaf temperature than the daily-irrigated plants, which could be due to decreased transpiration cooling when the seedlings were water stressed. During the FN hour the leaf temperature was not significantly influenced by water stress (Fig. 5). By AN the leaf temperature showed considerable increase and the difference between water stress levels were prominent (Fig. 6). The leaf temperature which increased due to the day time absorption of solar radiation might have cooled down during night hours and stabilized by morning.

The LDR in water stressed plants increased exponentially after 8 AM whereas the LDR in daily irrigated plants remained low and steady (Fig. 7). Between 4 PM and 6 PM the LDR increased steeply probably due to the closure of the stomata induced

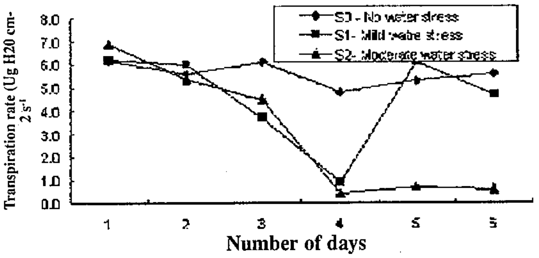

Fig 4. Transpiration rate of teak seedling as influenced by water stressat 1400 hours

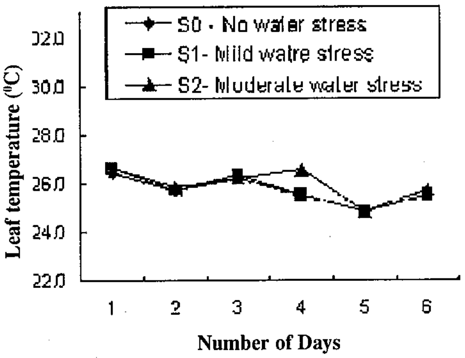

Fig. 5 Leaf temperature seedling as influenced by water stress at 800 hours

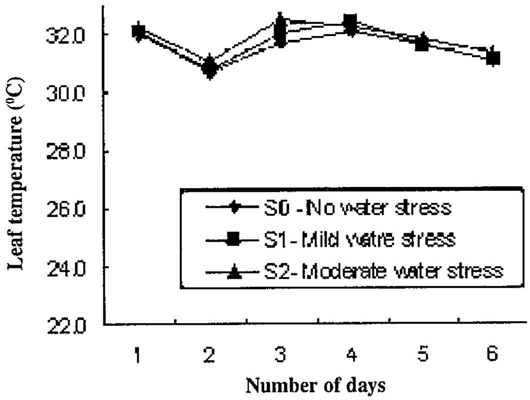

Fig. 6 Leaf temperature of teak as influenced by water stress 1400 hours

by low intensity of solar radiation. The leaf temperature was lowest at 6 AM and there was no significant difference between water stressed and daily-irrigated plants (Fig. 8). The leaf temperature, which was 24°C at 6 AM increased gradually with the progress of the day and reached the peak of 32°C between 12 noon

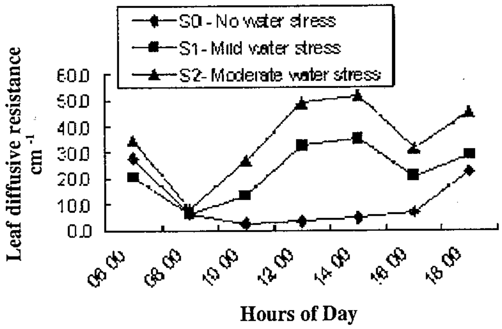

Fig. 7 Day time variations in leaf diffusive resistance of teak seedlings as influenced by water stress

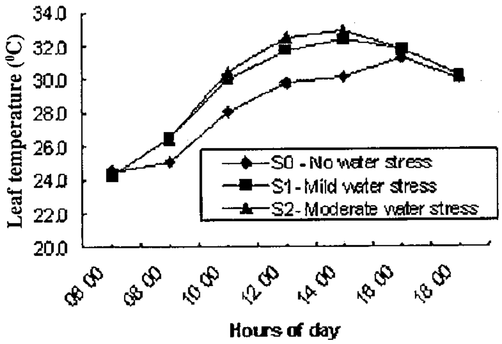

Fig. 8 Day time variations leaf temperature of teak seedlings as influenced by water stress

The LDR in water stressed plants increased exponentially after 8 AM whereas the LDR in daily irrigated plants remained low and steady (Fig. 7). Between 4 PM and 6 PM the LDR increased steeply probably due to the closure of the stomata induced by low intensity of solar radiation. The leaf temperature was lowest at 6 AM and there was no significant difference between water stressed and daily-irrigated plants (Fig. 8). The leaf temperature, which was 24°C at 6 AM increased gradually with the progress of the day and reached the peak of 32°C between 12 noon and 2 PM. The water stressed plants showed a higher leaf temperature through out the day as compared to the plants that were not water stressed.

There was no significant difference between the leaf water potential of seedlings irrigated daily and irrigated once in three days (mild water stress). However, further increase in water stress by withholding irrigation for more than three days

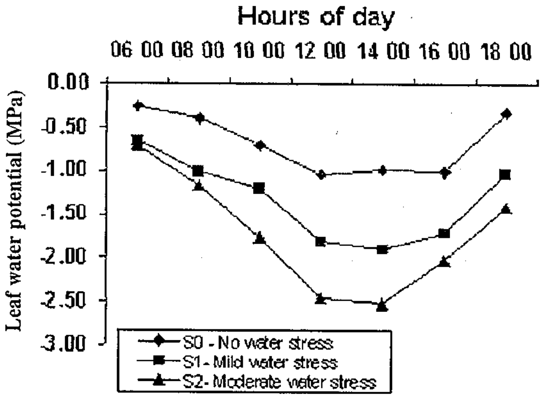

Fig. 9 Day time variations in leaf water potential of teak as influenced by water stress

resulted in low leaf water potential as compared to the daily-irrigated plants. Leaf water potential is considered, as a good indicator of the internal stress for water and a sudden decline in the potential may be an indication of the inability of the species to withstand water stress.

In the teak seedlings, leaf area decreased in response to mild water stress, however, the leaf water potential showed only a marginal decrease. When the water stress levels were increased, there was a steep decrease in leaf water potential, which indicated that at higher levels of water stress the leaves remaining on the seedlings were transpiring freely and decreasing the leaf water potential.

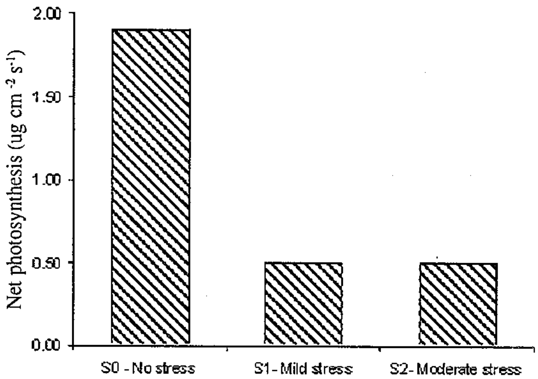

Fig. 10 Net photosynthesis of teak seedlings at 12.00 hours as influenced by water stress

The daytime variations in leaf water potential in teak seedlings decreased due to water stress (Fig. 9). Relatively higher leaf water potential was maintained throughout the day in plants grown without water stress. The daytime decrease in leaf water potential was almost proportional to water stress levels. There was a mid-day dip in leaf water potential and this decreases was more in water stressed plants. In spite of the slow stomatal response, resulting in high transpiration in teak seedlings it was able to maintain a high leaf water potential probably because of the efficient utilization of soil moisture.

The net photosynthesis of the seedlings was significantly reduced due to water stress (Fig. 10). Daily irrigated plants showed maximum net photosynthesis. The decline in net photosynthesis in response to water stress was very steep. This may be the reason for the sharp decrease observed in the net assimilation rates, in response to water stress (Table 3). The reduced net photosynthesis of the water stressed seedlings could be attributed, primarily to increased LDR and a reduction in the diffusion of carbon dioxide. Reduction in net photosynthesis in response to water stress was reported in several temperate tree species (Kozlowski, 1982 and Schulze, 1986). In teak seedlings, even though the LDR was low and the water potential high, net photosynthesis showed steep decrease even with mild water stress, indicating the high sensitivity of the species to water stress. The decrease in net photosynthesis observed in teak seedlings under water stress, among other reasons may also be attributed to the high chloroplast disintegration (as observed in the anatomical studies – data not shown). The stable relative growth rate and steep decrease in net assimilation rate in teak seedlings with increase in water stress indicate the poor efficiency of the leaves of the seedlings in assimilating carbon dioxide under water stressed environments.

In teak seedlings the relative water content (RWC) was also significantly reduced (Table 3), both at 08 00 and 14 00 hours. A rapid decrease in RWC is considered as a character of stress intolerant species, whereas stress tolerant species tend to have a slower decrease in RWC as the leaf water potential decreases (Cowan, 1981).

CONCLUSIONS

Teak seedlings are very sensitive to water stress. Both biometric characters and physiological parameters are adversely affected due to water stress. The photosynthetic rate in teak seedling is very sensitive to water stress that it dropped sharply even with mild water stress. The sensitiveness of the species is also evident from the low permanent wilting coefficient. Periods without irrigation up to three days were not creating much internal water stress. However, periods without irrigation for more than three days may cause problems in internal water balance and water stress for more than six to nine days may result in permanent wilting. Teak seedlings needs proper irrigation for its establishment and good growth in the field, in areas where rainfall is limited or its distribution is poor.

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Growth and Vigour of Nursery Seedlings of Teak in Response to Input of Organic Wastes

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ABSTRACT

A study was conducted to find out the effect of addition of fresh and decomposed municipal garbage and coir dust on establishment, survival, growth and vigour of *Tectona grandis* seedlings. The seedlings when raised using treatment T1 (soil: sand: cow dung in equal proportion), treatment T9 (garbage decomposed for 2 weeks) and T11 (soil: coir dust in equal proportion) recorded cent per cent success with regard to both initial establishment one week after planting and final survival after eight months. Generally, mortality was more when fresh garbage alone was used as the planting medium. With regard to growth and vigour in terms of shoot and root growth parameters and other physiological attributes like relative growth rate, leaf area, specific leaf area, specific leaf weight, leaf area ratio, leaf weight ratio, etc., potting mixtures of soil and cow dung with garbage decomposed for two or four weeks were found to be most promising. Growth and vigour were generally less when seedlings were grown in coir dust. The relative growth rate and other physiological attributes were also found to be less for this treatment. The study revealed significant differences between treatments with regard to biomass production. In most of the cases, growth attributes produced by decomposed garbage and cow dung were on par. Generally, the stomatal number and chlorophyll content were not found to be affected significantly by treatments. However, chlorophyll 'a' content was found to be slightly higher when compared to chlorophyll 'b'. Nutrient uptake, particularly nitrogen, was found to be more when partially decomposed garbage was used as a component of the potting medium. The potting medium did not affect the uptake of phosphorus and potassium.

Keywords: Coir dust, municipal garbage, decomposition, growth rate, chlorophyll production, biomass, stomatal distribution, nutrient uptake.

INTRODUCTION

Accumulation of wastes from a variety of sources have resulted in various forms of environmental threats and health hazards. Garbage and coir dust are the domestic wastes, which include the solid city waste generated by human dwellings, biodegradable and non-biodegradable components such as glass, paper, plastics, leather, rubber, metals, peelings of kitchen vegetables, egg shells, remnants of food materials, used tea leaves stubble, leaves of garden plants etc. Garbage is also known as city refuse, municipal waste or refuse, domestic refuse etc. Garbage has got many deleterious effects on the environment. It has been established beyond doubt that garbage problems transcend traditional environmental boundaries and contribute to serious air, water and land pollution. Disposal problems of these garbage becomes difficult with increase in population density. In Kerala, because of small holdings and land area, disposal of solid waste has become all the more serious. The character of garbage have altered in line with rising living standards. Because of large number of industrial units in Kerala, it is estimated that about 30 per cent of the area near various industrial units have become unsuitable for crop cultivation and even for afforestation. Some of these wastes, if supplemented with small quantities of fertilizers is said to be good for raising some selected vegetables.

The system of raising tree seedlings in containers is widely practiced in social and agroforestry planting programmes in most parts of India. It is a well known fact that the potting media has got tremendous influence on growth and vigour of seedlings in the nursery. Though the effect of various constituents like sand, farm yard manure etc. on the growth of plants have been studied, the effect of garbage on growth have not been studied, particularly with regard to tree seedlings like teak. Scientific information on the influence of waste materials on the growth behaviour, nutrient uptake, biomass production, chlorophyll production and physiological attributes will be extremely useful for the production of healthy seedlings of teak at low cost.

MATERIALS AND METHODS

Uniform sized seedlings of teak were planted in the following potting media containing waste materials.

1. Soil:Sand:Cowdung (1:1:1 ratio)

Table 1. Effect potting media on height (cm) and girth (mm) of Teak seedlings at monthly intervals

Treat No	Treatment details		Month								Total increment
			1	2	3	4	5	6	7	8	
T1	Soil:Sand:Cowdung	H	17.37	21.27	22.77	23.00	24.20	25.40	27.13	28.87	11.50
		G	2.27	3.47	3.73	4.03	4.30	4.43	4.58	4.73	2.46
T2	Soil:Fresh garbage	H	19.67	20.73	22.77	24.17	24.47	25.87	28.15	30.43	10.76
		G	2.07	3.07	3.20	3.60	3.90	4.20	4.28	4.37	2.30
T3	Soil:2weeks	H	9.10	16.13	17.70	18.40	18.57	18.77	20.22	21.67	12.57
	decomposed garbage	G	1.57	2.27	2.60	2.90	3.30	3.50	3.52	3.97	2.40
T4	Soil:4weeks	H	7.87	12.80	14.37	15.23	15.60	16.37	17.90	19.43	11.56
	decomposed garbage	G	1.33	2.13	2.43	2.67	2.83	3.00	2.98	2.97	1.64
T5	Soil:Fresh	H	11.73	13.67	16.20	17.17	18.27	19.10	20.45	21.80	10.07
	garbage:Cowdung	G	1.63	2.33	2.47	2.73	3.03	4.43	3.87	3.30	1.67
T6	Soil:2weeks										
	decomposed.	H	7.80	15.77	17.17	18.80	18.93	19.73	20.72	21.70	13.90
	garbage:Cow dung	G	1.33	2.47	2.70	2.97	3.43	3.43	3.42	3.80	2.47
T7	Soil:4weeks										
	decomposed.	H	9.07	12.73	14.67	15.80	16.07	16.67	18.00	19.33	10.26
	garbage.Cowdung	G	1.37	2.27	2.50	2.87	3.13	4.00	3.68	3.37	2.00
T8	Fresh garbage	H	11.43	14.53	15.97	17.47	17.80	18.50	19.45	20.40	8.97
		G	1.73	2.73	2.97	3.27	3.53	3.50	3.57	3.63	1.90
T9	2 weeks										
	decomposed.	H	10.97	16.23	17.77	18.47	19.47	20.00	22.00	24.00	13.03
	garbage	G	1.67	2.53	2.73	3.07	3.37	3.47	3.53	3.60	1.93
T10	4 weeks										
	decomposed.	H	10.83	15.00	16.80	17.73	18.47	18.60	20.33	22.07	11.24
	garbage	G	1.70	2.53	2.80	3.03	3.20	3.27	3.33	3.40	1.70
T11	Soil: Coir dust	H	12.63	13.03	14.33	15.47	16.23	17.97	19.12	20.27	7.64
		G	2.00	2.63	2.83	3.23	3.47	3.60	3.78	3.97	1.97
T12	Soil: Coirdust:	H	10.33	14.30	16.20	17.43	18.00	19.60	21.30	22.33	12.00
	Cow dung	G	1.40	2.37	2.63	3.07	3.47	3.42	3.42	3.50	2.07
T13	Coir dust	H	11.53	12.47	13.67	14.93	15.93	16.77	17.65	18.53	7.00
		G	1.63	2.13	2.33	2.57	2.70	2.87	2.98	3.10	1.47
F Test	H	**	**	**	**	**	**	**	**		
	G	**	**	**	**	**	NS	NS	**		
CD (0.05)		H	2.64	2.63	2.87	2.60	2.97	3.08	3.34	3.84	
	G	0.42	0.38	0.33	0.42	0.47	-	-	0.56		
S Em±	H	1.28	1.28	1.39	1.26	1.44	1.49	1.62	1.86		
	G	0.20	0.18	0.16	0.20	0.23	0.76	0.48	0.27		

H-height ; G-girth; ** Significant at 1% level; NS – Non- significant

2. Soil:Fresh municipal garbage (1:1 ratio)
3. Soil:Two weeks decomposed garbage (1:1 ratio)
4. Soil:Four weeks decomposed garbage (1:1 ratio)
5. Soil:Fresh municipal garbage: cow dung (1:1:1 ratio)
6. Soil:Two weeks decomoposed garbage: cow dung (1:1:1 ratio)
7. Soil:Four weeks decomoposed garbage: cow dung (1:1:1 ratio)
8. Fresh municipal garbage
9. Two weeks decomposed garbage
10. Four weeks decomposed garbage
11. Soil:Coir dust (1:1 ratio)
12. Soil:Coir dust:cow dung (1:1:1 ratio)
13. Coir dust

The study was conducted for a period of eight months. Initially, the seeds were sown in nursery beds. Uniform vigorous seedlings of 2-3 weeks old were planted in 200 gauge polythene covers of 30 x 40 cm size filled with different treatment media. The components were mixed on V/V basis. The experiment was done in CRD. The initial establishment and final survival rate of seedlings, shoot growth parameters (height and girth), total biomass production (shoot and root), root growth parameters (length and number), leaf growth parameters, physiological observations like chlorophyll, leaf area, relative growth rate, specific leaf area and weight, leaf area ratio, leaf weight ratio, stomatal number, etc. were recorded. The data were statistically analysed.

RESULTS AND DISCUSSION

Effect of potting media on initial establishment and final survival rate of seedlings

The observations indicate that the initial establishment recorded after one week of planting

Table 2. Effect of potting media on root growth parameters of teak seedlings at monthly intervals

Treatment Details	Root length (cm) Month								Root number Month							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
T_1 Soil:Sand: cowdung	20.83	24.92	25.00	26.67	26.33	25.17	25.33	27.33	17.33	19.33	21.33	25.00	28.67	28.50	26.33	28.00
T_2 Soil:Fresh garbage	21.67	22.17	22.67	25.33	26.00	26.17	26.33	28.00	16.67	17.17	17.67	17.33	18.00	18.67	18.33	18.67
T_3 Soil:2 weeks decomposed garbage	18.67	18.67	20.67	21.42	21.17	22.75	23.33	24.33	16.33	21.00	22.67	23.00	24.33	24.67	25.00	25.00
T_4 Soil: 4 weeks decomposed garbage	20.67	21.67	22.67	23.00	25.33	25.50	24.67	25.67	15.67	18.83	22.00	21.00	22.00	23.00	24.00	25.33
T_5 Soil:Fresh garbage: Cow dung	20.00	21.83	21.67	23.33	24.00	25.67	26.33	27.70	15.33	17.83	19.33	20.33	21.33	22.33	23.67	25.00
T_6 Soil:2 weeks decomposed garbage; Cow dung	11.50	15.58	19.67	21.67	23.67	24.83	26.00	27.67	11.00	15.17	18.33	18.00	18.67	18.17	18.67	19.33
T_7 Soil:4 weeks decomposed garbage: Cow dung	23.67	25.00	26.33	26.50	28.67	28.50	29.33	29.67	13.67	12.50	12.33	12.17	13.00	13.67	15.33	16.67
T_8 Fresh garbage	16.83	17.25	17.67	19.67	20.67	21.67	22.67	23.00	14.67	14.83	15.00	16.83	17.67	17.00	18.33	19.67
T_9 2 weeks decomposed garbage	11.33	13.83	14.33	15.33	16.33	17.17	18.00	19.00	15.33	15.17	15.00	14.50	15.00	15.83	19.67	16.73
T_{10} 4 weeks decomposed garbage	27.33	27.00	26.27	28.50	30.33	29.33	27.33	28.67	15.67	15.67	15.67	14.17	15.67	17.17	17.67	18.67
T_{11} Soil: Coir dust	18.67	20.33	18.00	18.83	18.67	21.33	22.00	20.67	22.67	24.00	25.33	25.17	25.00	26.33	28.67	27.00
T_{12} Soil: Coir dust: Cow dung	14.67	15.00	16.33	16.83	17.33	18.33	19.33	8.67	10.00	13.83	17.67	18.83	18.00	19.50	19.00	18.33
T_{13} Coir dust	20.33	20.00	18.67	18.50	19.33	19.67	19.00	18.00	19.67	19.33	19.00	18.67	18.33	19.33	19.33	20.00
- F Test	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	*	**	NS	**	**
CD (0.05)	-	-	-	-	-	-	-	10.94	-	-	-	7.09	7.23	-	8.73	7.11
S Em±	6.94	5.83	8.79	4.93	5.68	5.17	7.64	5.30	4.85	3.71	5.06	3.44	3.50	2.81	4.23	3.44

** Significant at 1% level; * Significant at 5% level; NS – Non-significant and final survival after eight months do not vary significantly with regard to potting media. However, the treatment T1 (Soil: sand: cow dung), T9 (2 weeks decomposed garbage) and T11(soil:coir dust) recorded 100 per cent initial establishment and final survival. It was also observed that when the seedlings planted in fresh garbage (Treatment T8), both the initial establishment and final survival were found to be very poor.

Waste materials, particularly decomposed materials, as component of potting media did not show any significant adverse affect on establishment and growth of seedlings. High mortality of seedlings when fresh garbage was used as a component of potting media in the present study, could be probably due to the low availability of nutrients in the media and also due to the infection of microorganisms present in the garbage (Wu-Weushi, 1997). Coir dust with about 30 per cent carbon and a C:N ratio of 112:1 which is presently available in abundance can be a good source of carbon especially under tropical climatic conditions (Joseph, 1995). Coir pith has low bulk density (0.1525 g cc-1), low particle density (0.49 g cc-1)and low thermal conductivity (Ravindranath, 1991). It is rich in lignin (30 per cent) and cellulose (26.5 per cent). Singaran and Pothiraj (1991) stated that raw coir pith has high lignin content, and may not be advantageous for the seedlings to establish. In the present study also, these are the reasons for poor establishment of seedlings in coir pith. Joseph (1995) observed that the simplest way to convert coir pith into organic manure is by composting. Coir pith decomposed for a period of four months were reported to have dual advantage of high moisture retention and good nutritional status (Moorthy *et al.*, 1996). According to Gaur *et al.* (1980), composting of coir pith could increase the availability of N and K, and hence, could be used as one of the potting media for raising nursery plants. Growth and vigour of *Ailanthus* and *Albizia* seedlings were not found to be affected significantly by the use of coir pith as one of the components in the nursery bed (Sudhakara, 1997).

Table 3. Effect of potting media on dry biomass (dry wt. in gms) of Teak seedlings at monthly intervals

Treat No	Treatment details	Month							
		1	2	3	4	5	6	7	8
1 – T_1	Soil:Sand:Cowdung	3.71	5.19	5.56	5.90	6.89	8.38	9.58	11.49
2 – T_2	Soil:Fresh garbage	0.83	1.02	1.32	1.54	1.93	2.25	2.53	3.39
3 – T_3	Soil:2 weeks decomposed garbage.	0.45	2.63	2.91	4.61	6.12	5.66	5.83	6.31
4 – T_4	Soil:4 weeks decomposed garbage.	0.77	1.32	1.17	1.42	1.84	1.89	2.14	3.17
5 – T_5	Soil:Fresh garbage: Cowdung	0.37	0.67	0.80	1.43	1.24	1.66	2.04	2.71
6 – T_6	Soil:2weeks decomposed garbage :Cowdung	0.50	2.67	3.47	4.44	5.32	5.29	5.51	6.64
7 – T_7	Soil:4weeks decomposed garbage :Cowdung	1.14	1.83	2.53	2.88	2.97	3.69	3.85	4.49
8 – T_8	Fresh garbage	0.39	0.91	1.33	1.67	2.07	2.22	2.42	2.76
9 – T_9	2 weeks decomposed garbage	1.63	2.07	2.88	3.81	5.05	7.43	9.11	10.69
10 –T_{10}	4 weeks decomposed garbage.	0.82	0.94	1.54	1.86	2.12	2.55	2.69	4.02
11 –T_{11}	Soil:Coir dust	0.73	0.93	1.02	1.52	1.77	2.28	2.39	3.28
12 –T_{12}	Soil:Coir dust: Cowdung	1.22	1.58	1.97	2.27	2.96	3.21	3.51	4.80
13 –T_{13}	Coir dust	0.58	0.63	0.91	0.98	1.12	1.26	1.56	1.63
-	F Test	NS	NS	**	**	**	**	**	**
	CD (0.05)	-	-	2.01	2.1	2.64	4.04	5.01	5.20
	S Em±	0.74	0.83	0.98	1.02	1.63	1.94	2.41	2.58

** Significant at 1% level ; NS – Non- significant

Effect of potting media on growth and vigour of seedlings

The data furnished in Table 1 indicate that the potting media significantly influenced the height and girth of teak seedlings.The observations recorded during the 8th month show that plants raised in treatment T2 (soil: Fresh garbage) and T1 (soil: Sand: Cowdung) recorded maximum heights of 30.43 cm and 28.87 cm, respectively. The difference between these two treatments were not significant. Seedlings raised in coir dust produced the least height of 18.53 cm at the end of 8 months of observation. However, the total growth increment was maximum (13.90cm), when the seedlings were grown in media consisting of soil: 2weeks decomposed garbage: cowdung (T6) and this was followed by treatments T9 (2 weeks decomposed garbage) and T3 (Soil: 2 weeks decomposed garbage) where the total height increment was respectively 13.03cm and 12.57 cm. This trend is clear from the beginning itself. When the seedlings grown in coir dust alone, the growth increment was found to be very poor (7.0cm). With regard to girth ,the observations related to 8th month revealed that the seedlings raised in treatment T1 (Soil: sand: Cowdung) and T2 (Soil: fresh garbage)have recorded a high value of 4.73mm and 4.37 mm respectively. The treatment T6 (Soil: 2 weeks decomposed garbage: cowdung), T1 (Soil: Sand: Cow dung) and T3 (soil: 2 weeks decomposed garbage) were found most promising with regard to total girth increment recording 2.47 mm, 2.46 mm and 2.40 mm, respectively. With regard to girth also the increment was very poor when grown in coir dust alone(1.47mm). The data reveal that the girth recorded during the 6th and 7th month was not significant. In most of the potting media, where garbage was used were found to produce good number of leaves. At the end of the study the lowest number of leaves was produced by the seedlings raised in potting media containing only coir dust. The other media with coir dust were also producing relatively less number of leaves. However, the differences between these treatments were not significant.

With regard to root growth parameters like length and number, there were no significant differences between various treatments during most of the periods of observation(Table 2). However, the 8th

Table 4. Effect of potting media on Chlorophyll content (mg g $^{-1}$) of Teak seedlings at periodic intervals

Sl. No.	Treat. No.	Treatment details	Month 2		4		6		8	
			Chl. A	Chl.B	Chl A	Chl B	Chl A	Chl B	Chl A	Chl B
1.	T_1	Soil:Sand:Cowdung	8.70	7.07	8.77	8.56	4.60	3.80	4.20	3.20
2.	T_2	Soil:Fresh garbage	9.60	7.04	5.87	5.72	4.90	3.60	5.31	3.94
3.	T_3	Soil:2 weeks decomposed garbage	7.10	5.40	11.99	10.11	4.20	3.50	4.68	3.38
4.	T_4	Soil: 4 weeks decomposed garbage	7.80	5.91	10.09	8.25	5.40	4.50	4.72	3.29
5.	T_5	Soil:Fresh garbage: Cowdung	10.11	7.50	10.67	8.97	4.31	3.72	6.47	4.66
6.	T_6	Soil:2 weeks decomposed garbage;Cowdung	7.50	5.92	12.33	9.64	7.00	5.04	5.85	3.98
7.	T_7	Soil:4 weeks decomposed garbage:Cowdung	8.90	6.20	8.66	7.45	5.91	4.32	6.09	3.98
8.	T_8	Fresh garbage	8.51	6.11	9.90	7.88	4.80	3.11	6.21	4.95
9.	T_9	2 weeks decomposed garbage	9.20	6.70	11.40	9.29	5.40	3.91	7.71	5.16
10.	T_{10}	4 weeks decomposed garbage	9.20	7.21	9.05	7.62	5.50	3.80	7.74	5.23
11.	T_{11}	Soil:Coir dust	7.30	5.40	10.69	8.93	5.90	4.30	6.22	4.29
12.	T_{12}	Soil:Coir dust: Cowdung	8.00	6.01	6.43	5.39	5.40	4.51	5.51	4.37
13.	T_{13}	Coir dust	5.41	4.11	9.07	8.21	4.70	3.60	7.81	5.72

month data reveals that the seedlings grown in treatment T7 (Soil: 4 weeks decomposed garbage: cow dung) recorded maximum length of roots (29.67 cm) while maximum number was produced by seedlings grown in treatment T1 (Soil: Sand: Cow dung).The coir dust was found to be poor with respect to this parameter. A perusal of the data furnished in Table 3 indicate that at the end of the study biomass production was maximum for the seedlings which were very vigorous. The dry biomass (shoot and root) of seedlings raised in potting media T9 (10.69) and T1 (11.49) were on par. The seedlings raised in T3 and T6 with two weeks decomposed garbage showed a biomass content of 6.64 and 6.31, respectively. The seedlings with coir dust as potting media were found to have lowest biomass (1.63). With regard to chlorophyll content, not much variation was observed between the treatments. Generally during all the months, chlorophyll A was found to be slightly higher compared to chlorophyll B. Seedlings grown in media with decomposed garbage generally recorded higher chlorophyll content (Table 4).The data furnished in Table 5 indicate the physiological attributes of seedlings at the end of eight month of the study as influenced by various potting media. The relative growth rate was found to be maximum (0.008gm/gm/day) in seedlings raised in treatment T4 (Soil: 4 weeks decomposed garbage) followed by T10 (4 weeks decomposed garbage) and T7 (Soil:4 weeks decomposed garbage:cow dung).The relative growth rate was found to be the least in seedlings potted in T13 (Coir dust) and T9(2 weeks decomposed garbage)where it was only 0.001 gm/gm/day. Treatment T6 recorded highest leaf area of 983 cm^2, followed by T9 and T1. The seedlings raised in coir dust recorded lowest leaf area of 150.3 cm^2. Generally, the other physiological attributes like specific leaf area, specific leaf weight, leaf area ratio and leaf weight ratio did not follow a systematic pattern with regard to treatments. However, the decomposed garbage and cow dung with soil were found highly promising. The stomatal number did not vary considerably between treatments. It was lowest in seedlings grown in treatment T13 (20256/cm^2) and highest in treatment T10 (31884/cm^2). The height, diameter and leaf area could be considered as important criteria for measuring vigour of seedlings as is reported by Hendromon (1988). In the present study, over all shoot growth performance of tree seedlings was influenced significantly by various types of potting media containing wastes, as is evident from the statistical analysis of the data. A positive correlation could be observed between the period of decomposition of garbage and coir dust and growth. Maximum height growth occurred in the medium containing cow dung may be due to the improved nutrient status and water retention capacity of the media. Similarly composting improves the nutrient status of the garbage as reported by many researchers and this may be the reason for the better performance of the media containing composted garbage. Khalilian and Sullivan (1997) reported that addition of composted garbage to soil reduce bulk density, increase porosity, water holding capacity and improve nutrient availability. This can be the probable reason for better performance of seedlings in media with composted garbage.

The results of the study revealed significant differences between treatments with regard to biomass production. In most of the cases, the treatment containing soil, sand, decomposed garbage and cow dung in equal proportions recorded maximum dry weight at the end of the study. Ward *et al.* (1981) noticed greater shoot weight of sugar maple seedlings when grown in green house medium. It is presumed that effective utilization of available solar energy and also the availability of ample nutrients especially nitrogen may be the reason for the better performance of seedlings grown in these treatments. Analysis of the data revealed that the treatments containing partially decomposed garbage were performing better compared to other treatments with regard to root growth parameters and physiological attributes. Similar trends were also reported by Radha and Panigrahi (1998).

Effect of potting media on nutrient uptake is illustrated in Figures 1 and 2.The observation revealed that the initial nitrogen content varied from 2.22 to 3.52 per cent while the final content from 2.10 to 3.92 per cents. Nitrogen uptake was maximum in treatment T7 (Soil:4week decomposed garbage: Cow dung) with a mean content of 3.92

per cent followed by treatments T4 and T6. Generally the potting media did not affect the uptake of phosphorus and potassium.

CONCLUSIONS

It is a well known fact that the potting media has got tremendous influence on growth and vigour of seedlings in the nursery. Though the effect of various constituents like sand, farm yard manure, etc. on the growth of plants have been studied, the effect of garbage on growth have not been studied, particularly with regard to tree seedlings like teak. In the present study partially decomposed garbage has resulted very high initial establishment and survival. Generally, mortality was more when fresh garbage alone was used as a planting medium. With regard to growth , vigour and biomass production potting mixtures of soil and cow dung with two weeks or four weeks decomposed garbage were found to be most promising. Growth and vigour was generally found to be less when seedlings were grown in coir dust. In most of the cases the growth attributes produced by decomposed garbage and cow dung were on par. Generally, the number of stomata and chlorophyll content were not found to be affected significantly by treatments. Nutrient uptake particularly nitrogen was found to be more when partially decomposed garbage was used as a component of potting media.

Table 5. Effect of potting media on physiological attributes of teak seedlings

Sl. No	Treat. No	Treatment details	Relative growth rate (gm.gm.day^{-1})	Leaf area (cm^2)	Specific Leaf area (cm^{2}gm^{-1})	Specific leafWeight (gm.cm^{-2})	Leaf arearatio (cm^2 gm^{-1})	Leaf weight Ratio (gm.gm^{-1})	Stomatal No.Per cm^2
1.	T_1	Soil:Sand: Cowdung	0.002	924.0	281.7	0.004	142.37	0.51	25498
2.	T_2	Soil:Fresh garbage	0.003	180.6	752.3	0.001	120.37	0.16	27834
3.	T_3	Soil:2 weeks decomposed garbage	0.002	355.3	136.7	0.007	84.40	0.62	21849
4.	T_4	Soil: 4 weeks decomposed garbage	0.008	405.0	470.9	0.002	197.57	0.42	31847
5.	T_5	Soil:Fresh garbage: Cowdung	0.003	335.5	372.8	0.003	223.67	0.60	25690
6.	T_6	Soil:2 weeks decompose d garbage; Cowdung	0.003	983.0	252.7	0.004	158.29	0.63	26752
7.	T_7	Soil:4 weeks decomposed garbage: Cowdung	0.005	574.0	700.0	0.001	198.62	0.28	25670
8.	T_8	Fresh garbage	0.003	229.7	433.3	0.002	153.10	0.35	29583
9.	T_9	2 weeks decomposed garbage	0.001	980.0	268.4	0.002	148.26	0.55	31449
10.	T_{10}	4 weeks decomposed garbage	0.007	493.0	503.1	0.002	188.89	0.38	31884
11.	T_{11}	Soil:Coir dust	0.004	250.0	290.7	0.003	132.28	0.46	25637
12.	T_{12}	Soil:Coir dust: Cowdung	0.004	634.0	621.6	0.002	235.69	0.38	28025
13.	T_{13}	Coir dust	0.001	150.3	375.8	0.003	140.49	0.37	20256

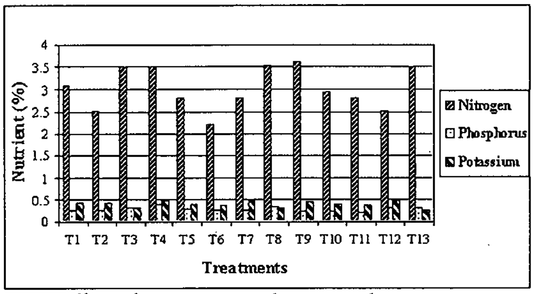

Fig 1. Effect of waste materials on initial nutrient content of teak seedlings

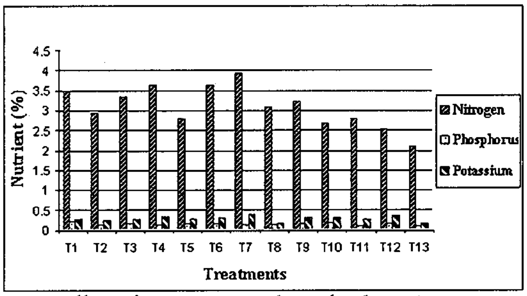

Fig 2. Effect of waste materials on final nutrient content of teak seedlings

Scientific information on the influence of waste materials on establishment and vigour is extremely useful for the production of healthy seedlings of teak at low cost. Production of healthy seedlings, same time using the waste materials is very important in thickly populated state like Kerala, where disposal of garbage is a serious problem.

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Economics of Teak Plantations and Policy Issues

Quality Timber Products of Teak from Sustainable Forest Management pp 561-570

Cultivation of Teak (*Tectona grandis* L. f.) in Farmlands of Different Agro-climatic Zones in Tamil Nadu: An Analysis of Ecological and Economic Factors

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ABSTRACT

During the last two decades, teak has attained maximum importance because of the entry of corporate sector in teak investment schemes in a big way, with attractive claim of unattainable returns. During the same period, many farmers started cultivating teak in their farmlands. Under a World Bank funded project, a study was carried out in seven agro climatic zones of Tamil Nadu, covering 427 plantations in age group varying from two to twelve years. Ecological factors which favour or limit the growth, yield and timber quality were analysed. Significant differences exist among the zones with respect to both mean girth and mean height of teak trees in farmlands. The result confirms that growth performance of teak varies greatly with changes in edapho-climatic conditions. The study also concludes that site selection remains as one of the important conditions for optimal growth of teak. Based on the observations made in the localities which are prone to strong winds, it was found that the mean height in plantation with wind barrier (vegetative barrier) was about three times more than that of plantations without wind barrier. Hence, the wind factor has to be taken in to consideration along with other important site factors, while matching the species with sites in any commercial plantation programme. The socio-economic factors of shifting to teak cultivation from conventional agricultural practices were also analysed and ranked according to Garrett ranking technique.

Keywords: Teak cultivation, farmland, agroclimatic zones, ecology, economics

INTRODUCTION

Teak (*Tectona grandis* L.f.), one of the world's premier timber species, has good potential as plantation species (Loke, 1996) for quality products. Private investment on teak plantations has begun as a response to the growing demand for housing and furniture grade timbers. Further, the constant demand and shortfall in its supply has hiked the price and made teak as one of the most preferred species among the farming community in Tamilnadu. This, in turn, has lead to raising teak plantations outside the forest areas, particularly in the farmer's field in the recent years. There are many records and references to find growth and yield of teak in forest lands (Chittranshi and Chitwatgi, 1971; Sharma, 1951; Chandrashekhar, 1983; Champion and Seth, 1968; Chaturvedi, 1973). In contrast, no information is available on growth performance of teak in farmlands, particularly under different agro-climatic zones. Hence, the present study was conducted to assess the growth performance of teak under different agro-climatic zones of Tamilnadu with an objective to identify the potential areas for optimum growth of teak in farmlands.

MATERIALS AND METHODS

Site descriptions

Based on rainfall, temperature, soil type and other ecological conditions, seven agro climatic zones

Table 1. Details on edapho-climatic parameters of five agro climatic zones of Tamilnadu

Zone	Rain Fall (mm) Winter (Dec -Feb)	Summer (Mar -May)	SW Monsoon (Jun -Aug)	NE Monsoon (Sep -Nov)	Total Annual Rainfall	Temp.° C Min	Max	Soil type	Ground Water Table depth (m)	Per cent of wells
Northeastern (NE)	55 (5.0)*	86 (7.8)	398 (36.0)	566 (51.2)	1105	21.0	38.4	Red sandy loam, Clayey loam, Saline coastal alluvium	12 – 15	62
Northwestern (NW)	39 (4.9)	104 (12.1)	379 (44.5)	327 (38.5)	849	19.0	37.0	Non Calcareous red, Brown & Calcareous black	18 – 25	78
Western (W)	59 (7.9)	144 (19.2)	216 (28.8)	331 (44.1)	750	19.0	35.0	Red and Black	18 – 22	40
Cauvery delta (C)	63 (6.4)	190 (19.3)	280 (28.5)	451 (45.8)	984	21.0	38.0	Alluvial, Red loamy, Lateritic	9 – 20	15
Southern (S)	28 (3.3)	100 (11.7)	290 (34.0)	435 (51.0)	853	21.0	38.0	Black, Red, Alluvial, Lateritic, Saline coastal alluvial	12 – 24	77

* Values in bracket indicate percentage of the total annual rainfall

have been identified in Tamilnadu (Anon 1993). Out of seven zones, teak is not being cultivated in two zones *viz.*, high altitude and high rainfall zones. Hence, the present study was carried out in the remaining five zones *viz.* Northeastern, Northwestern, Western, Cauvery delta and Southern zone. Edapho-climatic details of these five zones are presented in Table 1.

Plantation details

Many corporate companies launched teak investment schemes in a large scale with promises of unattainable returns, a decade ago. During this period, many farmers also started cultivating teak in their farm fields. Hence, most of the teak plantations, which exist in farmlands of Tamilnadu, under the age group of 5-10 years were selected for this study. Spacing ranged between 2.0 x 2.0 m and 2.5 x 2.5 m and all the plantations were irrigated for the first two years and then maintained under rain fed condition. All the other operations like pruning and weeding, practised by the farmers remained the same in all the zones. A total of 425 teak fields were visited and collected the biometrical data and socioeconomic information.

Observations

A random sample technique was used. Plantations belonging to the age groups 5, 6, 7, 8, 9 and 10 years were drawn from each zone and observations on growth variables measured. In the plantations, each tree was numbered and the girth at breast height measured. Total height of each tree was measured using Haga Altimeter (Chaturvedi and Khanna, 1982; Sudheendrakumar *et al.*, 1993).

Statistical methods

The reasons for opting teak cultivation by the farmers and the sources of information were ranked and analysed using 'Garrett Scoring Technique'. The ranks assigned by the respondents were calculated into percent position by using the formula.

Table 2. Range in growth characteristics of teak in farmlands under five different agro-climatic zones of Tamilnadu

Age	5 years at 95% CI		6 years at 95% CI		7 years at 95% CI		8 years at 95% CI		9 years at 95% CI		10 years at 95% CI	
	Girth at Breast Height (cm)											
Zone	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB
NE	22.3	23.6	27.5	29.4	26.9	29.9	28.7	32.8	31.1	34.2	39.9	42.6
NW	24.3	27.0	23.6	25.2	23.8	26.9	26.3	28.7	28.8	33.0	42.4	46.8
W	23.2	24.3	26.3	27.4	35.1	37.0	27.6	31.3	36.1	39.0	40.5	43.5
C	28.5	30.6	32.0	34.1	30.8	34.8	32.5	35.9	34.9	37.6	35.9	38.6
S	20.3	21.0	23.9	24.9	25.1	27.7	26.9	30.0	28.2	32.1	36.4	39.0
	Height (m)											
Zone	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB	LB	UB
NE	6.6	6.8	8.2	8.8	8.1	8.8	8.0	8.9	8.4	8.9	11.3	12.1
NW	7.7	8.2	8.1	8.3	8.4	8.7	9.7	9.8	9.3	9.9	12.0	12.0
W	7.0	7.1	8.0	8.1	8.5	8.7	8.3	9.0	12.0	12.3	13.7	13.8
C	7.2	7.5	8.2	8.4	9.0	9.4	10.4	10.7	12.7	13.1	12.3	12.6
S	6.8	7.2	7.4	7.6	8.0	8.6	7.5	8.2	8.2	8.9	8.9	9.2

LB – Lower Bound at 95% Confidential Level UB – Upper Bound at 95% Confidential Level CI – Confidential Level

$$\text{Per cent position} = \frac{100\,(R_{ij} - 0.5)}{N_j}$$

Where, Rj = rank given for the i[th] reason by the j[th] individual

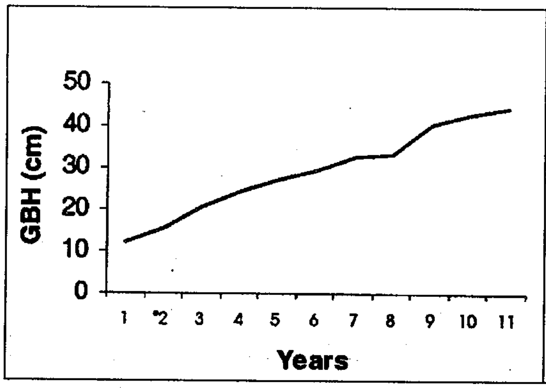
Nj = number of reasons ranked by j[th] individual.

By referring to the Garrett's table, the percent position estimates were converted in to scores. Then for each reason, the scores of various respondents were added and mean values calculated. The means of different reasons were arranged in descending order. The reason with the maximum mean value was considered to be the most important reason (Swaminathan *et al.* 1999).

Data obtained on biometrical traits pertaining to influence of zonal effect on growth were analysed for statistical significance. Analysis of variance (ANOVA) for one-way model was used to test the significance of the difference between zonal means for a particular age. Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984) was used to compare pairs of zones and group the means into homogeneous subsets. The software SPSS10.1 was used for statistical analysis.

RESULTS AND DISCUSSIONS

The range in growth characteristics observed in various zones at different ages are presented in Table 2 and the results revealed that there was a gradual



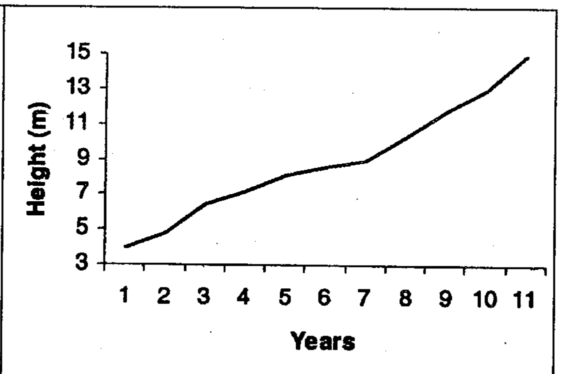


Figure 1. Mean girth at breast height (cm) and height (m) of teak trees at different ages in farmlands, Tamilnadu.

Table 3. Mean girth and height with standard error of teak plantations in farmlands under different agro-climatic zones in Tamilnadu

Zone	Age (years) 5	6	7	8	9	10
			Mean Girth at Breast Height (cm)			
NE	22.94 ± 0.33*	28.45 ± 0.46	28.37 ± 0.75	30.74 ± 1.0	32.66 ± 0.77	41.27 ± 0.67
NW	25.62 ± 0.69	24.37 ± 0.42	25.38 ± 0.77	27.48 ± 0.59	30.90 ± 1.1	44.50 ± 1.1
W	23.74 ± 0.29	26.85 ± 0.26	36.09 ± 0.47	29.43 ± 0.91	37.54 ± 0.70	42.02 ± 0.74
C	29.50 ± 0.52	32.02 ± 54	32.83 ± 0.99	34.20 ± 0.86	36.28 ± 0.66	37.32 ± 0.66
S	20.68 ± 0.18	24.40 ± 0.24	26.39 ± 0.63	28.44 ± 0.79	30.13 ± 0.97	37.74 ± 0.36
			Mean Height (m)			
NE	6.7 ± 0.1	8.5 ± 0.2	8.0 ± 0.18	8.4 ± 0.23	8.7 ± 0.12	11.7 ± 0.21
NW	7.9 ± 0.1	8.2 ± 0.01	8.6 ± 0.08	9.6 ± 0.04	9.6 ± 0.16	12.0 ± 0.00
W	7.1 ± 0.1	8.1 ± 0.03	8.6 ± 0.03	8.7 ± 0.18	12.2 ± 0.09	13.8 ± 0.04
C	7.3 ± 0.1	8.3 ± 0.03	9.2 ± 0.09	10.5 ± 0.07	12.9 ± 0.08	12.6 ± 0.08
S	7.0 ± 0.9	7.5 ± 0.07	8.3 ± 0.17	7.8 ± 0.18	8.6 ± 0.15	9.1 ± 0.09

* Mean value ± Standard error.

increase in minimum and maximum girth as well as height in all the zones with increase in age. Grand mean girth and height worked out for different ages, irrespective of zones, were depicted in Fig. 1. The results showed that both girth and height increased with age. The increase was from 12.3 cm girth and 3.9 m height at the age of two years to 44.7 cm girth and 15 m height in 12th year (Fig. 1). In the present study, the maximum girth and height observed in the upper bound at 95% confidence interval was 47 cm and 14 m respectively at the age of 10 years. Being a light demander, teak will attain greater height growth of 14 m in short period (10-12 years) and hence, it can be maintained in alley cropping agroforestry system. Teak crown can be manipulated (by reducing shade effect) through pruning and make compatible with annual crops.

Table 3 presents mean girth and height recorded at different ages in various agro-climatic zones. The highest average girth and height registered was 45 cm and 14 m at the age of 10 years.

Table 4. ANOVA for girth variations at six age groups of teak plantations in farmlands under different agro-climatic zones in Tamilnadu

Age (years)	Sources of Variation	Sum of Squares	df	Mean square	F	Sig.
5	Girth between zones	15603.371	4	3900.84	90.67	.000
	Within zones	67927.957	1579	43.02		
	Total	83533.325	1583			
6	Girth between zones	12315.998	4	3078.999	87.33	.000
	Within zones	46608.255	1322	35.256		
	Total	8924.247	1326			
7	Girth between zones	8923.907	4	2230.975	86.294	.000
	Within zones	16494.255	638	25.853		
	Total	25418.156	642			
8	Girth between zones	1092.658	4	273.164	9.605	.000
	Within zones	5545.737	195	28.44		
	`Total	6638.395	199	1339.858		
9	Girth between zones	5359.431	4	31.315	42.786	.000
	Within zones	15876.842	507			
	Total	21236.273	511			
10	Girth between zones	1552.323	4	388.081	13.445	.000
	Within zones	7533.851	261	28.865		
	Total	9086.174	265			

Table 5. ANOVA tables for height growth variations at six age groups of teak plantations in farmlands under different agro-climatic zones in Tamilnadu

Age (years)	Sources of Variation	Sum of Squares	df	Mean square	F	Sig.
5	Height between zones	219.223	4	54.806	12.65	.000
	Within zones	6840.614	1579	4.332		
	Total	7059.839	1583			
6	Height between zones	169.309	4	42.327	31.41	.000
	Within zones	1781.493	1322	1.348		
	Total	1950.802	1326			
7	Height between zones	69.459	4	17.365	23.66	.000
	Within zones	468.18	638	0.734		
	Total	537.639	642			
8	Height between zones	183.869	4	45.967	46.197	.000
	Within zones	194.048	195	0.995		
	Total	377.915	199			
9	Height between zones	1449.688	4	362.422	36.962	.000
	Within zones	4971.267	507	9.805		
	Total	6420.955	511			
10	Height between zones	772.632	4	193.158	184.97	.000
	Within zones	272.553	261	1.044		
	Total	1045.175	265			

Statistical analysis through ANOVA revealed that there existed significant difference among the zones with reference to both mean girth and mean height of teak trees in farmlands (Tables 4 and 5). These differences among the growth traits existed in all the six age groups and thus it is confirmed that growth performance of teak greatly varied with variation in edapho-climatic conditions. Duncan's Multiple Range Test results to group the zones into homogenous sub sets and the results are presented in Table 6. With regard to mean girth, Northwestern and South zones registered values among the five zones in all the age groups and farm as one sub set. Northeastern zone was found to have intermediate girth and formed another sub set. Cauvery delta and Western zone recorded greater mean girth and identified as the third group.

With reference to mean height, there was lesser difference among the zones (varied only from 7 to 9 m) at early ages of 5 to 7 years. However, there existed greater variation in height growth among zones from

Table 6. Grouping of agro-climatic zones of Tamilnadu in to homogenous subsets using DMRT on the basis of mean girth and height of teak plantations in farmlands

Zone	Age (years) 5	6	7	8	9	10
			Girth at Breast Height (cm)			
NW	25.62^{c}	24.37^{a}	24.85^{a}	27.58^{a}	30.99^{a}	30.1^{a}
S	20.63^{a}	24.40^{a}	26.12^{a}	28.40^{a}	29.99^{a}	30.1^{a}
NE	22.94^{b}	28.45^{c}	28.53^{b}	31.15^{b}	31.63^{a}	31.6^{a}
C	29.56^{d}	33.02^{d}	33.12^{c}	33.91^{c}	36.82^{b}	36.8^{b}
W	23.74^{b}	26.85^{b}	34.55^{d}	43.13^{d}	37.60^{b}	37.8^{b}
			Height (m)			
S	7.0^{ab}	7.5^{a}	8.3^{a}	7.9^{a}	8.8^{a}	9.1^{a}
NE	6.7^{a}	8.5^{c}	8.3^{a}	8.4^{b}	8.8^{a}	11.7^{b}
NW	7.9^{c}	8.2^{b}	8.5^{ab}	9.8^{c}	9.6^{a}	12.0^{b}
W	7.1^{ab}	8.1^{b}	8.6^{b}	8.6^{b}	12.2^{b}	13.8^{d}
CD	7.3^{b}	8.3^{bc}	9.1^{c}	10.4^{d}	12.8^{b}	12.5^{c}

Values sharing same alphabet (s) do not differ significantly.

were analysed through Garrett scoring technique. The results showed that 'less risk' involved in teak cultivation, as compared to agricultural crops, was registered as *first rank* with greater mean score of 54.33. *'Less attention need'* and the *'higher income'* anticipated from teak cultivation were the second and third reasons for the shifting to tree farming by registering mean scores of 52.6 and 51.2 respectively. Other reasons such as labour scarcity, low input costs and inadequate of water for agricultural crops were also pointed out by the farmers for the shift to teak cultivation.

Sources of information

Using the same Garrett scoring technique, sources of information for teak cultivation were analysed and ranked. The results revealed that, 'mass media' plays a vital role in transfer of information on teak cultivation to farmers and ranked as first source. Next to mass media, 'newspapers and magazines' were ranked as second and third important sources in transfer of information on teak cultivation to farmers. It can be inferred that there existed less chance for getting adequate and required technical inputs specific to the particular farm through such mass media, news papers and magazines.

Farmer's anticipation on harvest age of teak

The teak growers were asked to express their anticipation on economic harvest age of teak. The response of the teak-growing farmers was such that almost half of the respondents (45.9%) were ready to wait for a period of up to 40 years to harvest the trees. Only 12.7 percent of teak growers wanted to fell in 20 years as short rotation crop. Interestingly, more than one third of the teak growers (37.4%) showed their willingness to wait for a longer period (over 40 years) to harvest teak from their field.

CONCLUSION AND RECOMMENDATIONS

Teak – a long rotation species is being cultivated in farmlands of Tamilnadu. Investigations on growth performance of teak in farmlands in various agroclimatic zones revealed that, with regard to girth and height, western and Cauvery delta zones were the best suitable zones for teak cultivation. Further, greater variations were observed in girth and height of teak in farmland within an agro-climatic zone. Apart from major site factors, special attention should be given to velocity of wind speed (35 km/hr), which acts as an unfavorable factor for teak growth.

This study also showed that farmers are lacking knowledge in technical aspects of teak cultivation such as site selection, selection of quality planting stock, silvicultural operations including spacing, seeding, pruning, thinning etc. It is also observed from the socioeconomic survey that three fourth of the teak growing farmers belonged to the age group of less than 35 years. It infers that, rate of adoption of new things, willingness to take risks and acceptance of teak as a promising species for quick returns are high among the younger age group of farmers. It can, thus, be suggested that farmers of younger age group can be identified as potential target group for effective future extension programmes concerned with promotion of tree farming. With regard to teak cultivation by different categories of farmers, almost 78 per cent were of large and marginal farmer category, and only 22 per cent were of small farmer category. As small farmers solely depend on subsistence farming, they were not able to opt block plantations. Hence, teak can be promoted as an agroforestry component in the farm fields of small farmers and appropriate agroforestry technologies need to be developed and demonstrated.

With reference to category of lands that are brought under teak cultivation, it was observed that almost 90per cent of lands were of low (with total annual income of less than Rs. 25,000) and medium productivity (up to Rs. 50,000). This in turn suggests that appropriate teak cultivation technologies related to such low and medium productive lands need to be developed to obtain optimum yield and increase the farmland areas under teak cultivation. Results of the survey showed that, there is a need to establish linkage between research organizations and farmers. As such there is little effective mechanisms involved to transfer the technologies from lab to field (extension) and failure in sharing technical information for mutual benefits. Effective extension strategies like 'man to man' contact like in agriculture are yet to be established in forestry sector. Also, there is a need to develop a mechanism to provide information on technical, financial, economic and environmental aspects of teak to farmers in regional and national levels. With regard to farmers' anticipation on harvest age of teak, more than 80 per cent of the teak-growing farmers expressed their willingness to wait over 20 years and even up to 40 years, which can be a sufficient period to produce wood from farmland. This, in turn, revealed that, there is a greater scope for introduction of teak in farmlands to meet the local demands and cottage industries. Teak can also act as a wind barrier in agriculture field in alley cropping in zig - zag planting of two rows. Also, crown pruning is possible to avoid the shade effect on annual crops and any reduction in the crop yield can be compensated from interim returns from teak. Teak is an ideal species as a short rotation of 12-15 years under agroforestry system owing to the following facts.

1. It can fulfill the farmer's needs especially for small timber suitable for door and window frames, furniture, agricultural implements, etc. in village conditions.
2. Pruned and thinned materials can be used for scaffolding support to hybrid vegetables like tomato. Farmers can save approximately Rs. 5,000/ ha/annum.
3. It can be grown as alley cropping or as bund planting in farm fields. Since, there will not be any extra expenditure for separate irrigation, fertilizer etc.
4. In village conditions, the whole teak tree (12-15 years) can be used for construction purposes like small houses huts, tents, pens etc.
5. Teak in farmlands get the benefit of intensive land management practices and grows faster and produces more volume of stem wood (more than twice) in 12 years when compared to 20 year forest grown teak (Buvaneswaran *et al.* 2001). The volume of 12-year-old teak in farmland is more than two and a half times when compared to 11 year old irrigated teak under block plantation (Murugesh *et al.* 1997)
6. With regard to wood quality, it is not always inferior to mature wood, in properties like density and strength (Sanwo 1987; Bhat 1995) except colour due to less accumulation of phenolic compounds at the age of 13-20 years.
7. Teak wood from farm condition, is useful for making handicrafts and development of cottage industries for artisans.

To recapitulate, though teak can be grown in most parts of southern peninsular India, still identification of suitable and potential regions within southern India remains as an important silvicultural aspect for obtaining optimum growth. Further, there exists an imperative need for research programmes to develop suitable site-specific technologies for low and marginally productive lands. Appropriate extension programmes are also needed to transfer the technical information to the targeted farmers and cottage industries. More research, monitoring and evaluation of teak in farmland should be encouraged to develop technology for teak in short rotation of 12-15 years under agroforestry system.

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Prospects and Potential of Growing Teak in Punjab State, India

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ABSTRACT

Teak (*Tectona grandis* L.f.) is known for its excellent wood quality and is taken as a standard for comparing other tropical timbers. It is generally preferred in India for house construction, panelling and furniture making. The price of good quality teak logs of more than 120 cm girth, exceeds Rs 1425-1450 per cubic foot in timber depots. The timber quality and higher cost prompt farmers to grow teak in agricultural lands, as they have already successfully experimented with *Eucalyptus tereticornis* and *Populus deltoides* in early eighties and late nineties, respectively. However, its long rotation holds them back. Sometime back, many plantation companies sprang up and duped the public and the farmers in the name of prized and high return teak plantations. All these companies had to wind up and are in deep waters. State forest departments in Punjab and Haryana States are also planting teak in avenues, along roadsides, railway tracks and canal bunds, even though they usually suffer from neglect. Some isolated old teak plants (with 50-60 cm DBH) can be seen along the State highways which flower and set viable seeds, as well. Teak trees planted in early 1980's in the Punjab Agricultural University Campus were measured for the growth performance parameters and the timber volume was assessed. The information derived prompts for the successful cultivation of teak in some parts of Punjab State. Teak trees grow better and faster when planted along water courses and field boundaries. Plantation strategies on farm border rows and farm steads in agri-silviculture systems, as in the case of *Dalbergia sissoo*, for the benefit of farmers are discussed in the paper. The aftercare and management strategies to protect teak trees from frost damage in early stages, fire and wind damage are also given. Future scope and suitable extension strategies for quality teak plantaions in the North- western States of India are elaborated in the paper.

Keywords: Teak in Punjab, frost damage, management strategies

INTRODUCTION

The Punjab state is quite small covering a total area of 50,362 km^2, which is only 1.53 % of the total geographical area of the country, and lies in the northwest of India. The economy of the State is agriculture based as about 83 - 84 per cent of its total geographical area is under cultivation with a cropping intensity of 187 per cent. The recorded forest cover in the State is only 5.7 per cent out of which only 2.8 per cent forest area has a crown density of more than 40 per cent. Rest of the forest area is of open forests covered with degraded forests mostly in the foothills of Shivaliks in the northeast of the State. Natural forests in the State are of 'Tropical Dry Deciduous Forests' situated in the foothills of Shivaliks to 'Tropical Thorn Forests' in the southwest part of the State, as per classification of Forest Types by Champion and Seth (1968). Naturally occurring forest tree species in the State are *Shisham* (*Dalbergia sissoo*), *Babool* (*Acacia nilotica* sub sp. *incida*), Mulberry (*Morus alba* and *M. nigra*), *Neem* (*Azadirachta indica*), other less important tree species are *Dek / Dhrek* (*Melia azedarach*), *Bakain* (*M. compacta*), *Siris* (*Albizia lebek*), *Phulahi* (*Acacia modesta*), *Rheunja* (*Acacia leucophloea*), *Palah* (*Butea monosperma*), *Simal* (*Bombax ceiba*), and now almost rarely seen tree species are *Jandi / Khejri* (*Prosopis cineraria*), *Pharwanh* (*Tamarix articulata*), Barmer teak (*Tecomella undulata*), *Vana* (*Salvadora oleoides*) etc. (Sharma and Bir, 1978).

The State has become quite poor in the diversity of forest flora, which started with the consolidation of land holdings under the agricultural reforms (people uprooted or sold the trees for fear of transfer of ownership), followed by the extensive and intensive agriculture development leading to the introduction of high yielding crop varieties especially of rice and wheat for "Green Revolution" to contribute significantly in achieving self sufficiency in food grains in the country.

The state forest department had introduced *Eucalyptus tereticornis* in a big way in early 1960's to drain the low-lying areas along the National and State highways in the State. The farmers also picked up the plantation of *Eucalyptus* trees on their farm and field boundaries, water channels and paths. Seeing the success of *Eucalyptus* trees, the eucalypt trees were further planted in agroforestry systems on their field /farm boundaries, or in block plantations on marginal lands as well as on cultivated lands. As a result the State started exporting eucalypt timber as pulpwood and firewood within a decade to neighbouring state Haryana and as fruit packing cases for apples to Himachal Pradesh and Jammu and Kashmir. The State had become surplus in eucalypt timber from a deficit state (Dhanda, 1989). As the State did not have any large scale consuming unit like paper mill, consequently there was a sharp fall in sale price of farm grown eucalypt timber and the farmers got disappointed and uprooted the eucalypt plantations, which were planted originally to have 2-3 rotations. With the development of clonal propagation technique, eucalypt is again becoming popular among the farmers. Next exotic plant taken up in agroforestry was *Populus deltoides* (clones G-3, IC, D - 121, G - 48) from mid eighties to early years of the present century. Now, we can see poplar plantations (Clones G-3, G-48, Uday and Kranti clones of WIMCO) everywhere, mostly as solid block plantations. The sale price of poplar timber of more than 90 cm girth trees dropped from Rs. 480 - 520 a quintal to Rs. 200 - 210 a quintal now within a couple of years. These two agroforestry tree species have shown their potential and made Punjab as an exporter of farm grown timbers.

The state forest department had introduced teak through seeds and planted along the national highway near Kharar and Ropar towns and along state roads near Morinda town. The long rotation of teak discourages the farmers to plant teak trees in block plantations as they can not afford to spare cultivated lands for a long period more than forty years. Occasionally farmers have been trying to plant some non-native trees as well. Some farmers have planted few teak plants on their farmsteads or homesteads depending upon the availability of teak seedlings. Keeping in mind the interest of the farmers, the Department of Forestry & Natural Resources at the Punjab Agricultural University introduced teak plants in 1982 through set - planting material obtained from the Forest Research Institute, Dehradun. This paper deals with the performance of teak trees with respect wood production in central region of Punjab

MATERIAL AND METHODS

Forty stumps were planted in the experimental area at 5 m x 4.5 m spacing to study their growth performance. They were watered and weeded at regular intervals for three years; thereafter, occasional irrigation was given in hot and dry season. These trees were left to grow in natural conditions except for watch and ward. The site is situated at 245 m above the mean sea level and lies at 30°45'N latitude and 75° 44' E longitudes. It is situated in the central plains zone of the State. The climate is subtropical to tropical with long dry season stretching from September to June each year with rainy season from July to mid September. The pH of the site ranged from 8.2 at the surface layer to 7.4 -7.7 at 120 to 150 cm deep, with EC (ds / m) ranged from 0.1 to 0.2, organic carbon (%) ranged from 0.15 to 0.33 at different depths and soil texture ranged from sandy-loam to loamy sand at 90 to 150 cm depth. Some trees got uprooted due to storm and some were top broken by strong winds.

Subsequently we had planted teak plants in a farmer's field along the water course in July 1992 and these have grown more than 10 year-old. Teak plants were also planted in the demonstration area (arboretum) about 7 years before. All these categories of trees are now more than 20-, 10- and 7-year- old. It was planned to record the survival and growth performance of these teak plants after a growth period of 21 years. The observations were recorded on these trees for DBH (cm), total tree height (m), clear bole height (m), and estimated timber volume (standard and small timber). Timber volume (o. b) of standing teak trees was estimated by measuring diameter at breast height (DBH), total tree height (m) and clear bole height (m) by using diameter tape and Speigel Relaskop (metric). Outline sketch of each tree was drawn and the tree stem was divided into optical sections. The length of each section (si, sii .... sn) was measured by Relaskop, and basal diameter (di), middle (dm), and upper diameter (dii) of each section was measured either by Wheeler Pentaprism caliper or by Speigel Relaskop by coinciding the thickness of stem (diameter) with four narrow bands. Mean diameter of each section was calculated either by (di + dm+ dii)/ 3 or by Newtons' formula i.e., (di + dm*4 + dii)/ 6, where the middle diameter was significantly more over larger length. Timber volume of each section (vi, vii .... and vn) was calculated by $(D^2/4) * l$. The sum total of all sections in a tree up to diameter more than 20 cm over bark gave the standard timber volume (o b.), while timber portion less than 20 cm to 10 cm was calculated as small timber in that tree.

For single – entry timber volume only DBH was taken as an independent variable, while for multi – entry regression equation the diameter (DBH) squared times tree height ($D^2 H$) was used as an independent variable as described by Spurr (1952) in "combined variable" method. For regression equations, following forms were used:

Multi entry table: $V = a + b * (D^2 H)$
Single entry table: • $V = a + b * D$,

Where, V = dependent variable such as timber volume or timber yield, D = diameter at breast height (DBH) in meter, H = total height of trees in meters, and 'a' and 'b' are regression constant and regression coefficient, respectively.

RESULTS AND DISCUSSION

The survival percent was 60 in all the three categories of teak plantations, as 24 plants survived out of 40, and 6 survived out of 10 planted at each of the other two locations. The DBH in more than 20-year-old trees ranged from 17.3 to 40.8 cm, total tree height ranged from 11.3 m to 19.3 m, and clear bole height from 4.0 to 8.7 m. Seventeen trees were with DBH more than 25 cm and 7 with less than 25 cm. The mean DBH and total tree height of these better growing trees came out 33.49 cm $\pm$ 5.56 and 14.98 m $\pm$ 3.59, while the DBH and total tree height in case of poorly growing trees ranged from 20.81 cm $\pm$ 3.88 and 12.51m $\pm$ 1.51, respectively. The mean annual increment (MAI) for DBH (cm) and tree height (m) for vigorously growing trees came out 1.67 cm and 0.75 m /annum, while it was 1.04 cm and 0.625 m / annum for poorly growing trees. Timber volume was estimated in 24 trees with age more than twenty years. Growth parameters and estimated timber volume of standing teak trees are given in Annexure I.

Newton's formula gives accurate results for all sections of the tree except for butt logs with excessive butt swell (Husch *et al.*, 1982). The timber volume estimation is based on measurement of diameter and length of logs or sections (Chaturvedi and Khanna, 1982). Analysis of variance (ANOVA) of timber volume (ob) of teak trees for DBH alone and for DBH and total tree height was calculated, (Tables 1 and 2). The regression equations of timber volume (ob) were developed with DBH alone for

Table 1. Analysis of variance (ANOVA) of DBH (o.b.) with timber volume (o.b.) in teak Trees grown in Punjab

Source of Variation	df	Sum of Squares	Variance	Variance ratio (F)		Coeff. of det. (r^2)
				Observed	Exp. 0.1%	
Linear Regression	1	0.997	0.997	164.188***	7.94	0.939
Residual	22	0.134	0.00609			
Total	23	1.131				

***Significant at 0.1% level of probability. Regression equation of Timber Volume (o. b.) with DBH alone came out as: $\sqrt{V} = -0.372 + 2.862 * DBH$

Table 2. Analysis of variance (ANOVA) of (DBH)² and tree height with timber volume (over bark) in Teak Trees grown in Punjab

Source of Variation	df	Sum of Squares	Variance	Variance ratio (F) Observed	Exp. 0.1%	Coeff. of det. (r^2)
Linear Regression	1	0.947	0.947	113.094***	7.94	0.915
Residual	22	0.184	0.00836			
Total	23	1.131				

***Significant at 0.1% level of probability.
Regression equation of timber volume (o. b) with Diameter and Tree height came out as: $V = 0.107 + 0.259 * (DBH^2 * Ht)$

local timber volume, and with DBH and total tree height both for regional timber volume. The local timber volume based on a single variable (DBH alone) and regional timber volume based on two variables (DBH and tree height in m have been prepared (Tables 3 and 4). Chaturvedi and Khanna (1982) also mentioned that timber volume could be estimated from diameter and length of logs or sections. Philip (1994) mentioned that the timber volume can be estimated either felled or standing trees. He further recommended that when climbing is impracticable and the outline of tree is clearly visible then diameters might be measured optically using Spiegel Relaskop or the newer Tele-relaskop (Philip, 1994).

ANOVA has been done to know the timber volume of teak trees with different DBH and total tree height and also to compare them to calculate the timber out put of tree (per tree basis) in vigorously or

Table 3. Local Timber Volume (over bark) of Teak *Tectona grandis* tree grown in Punjab. Based on equation Ö V = - 0.372 + 2.862* DBH

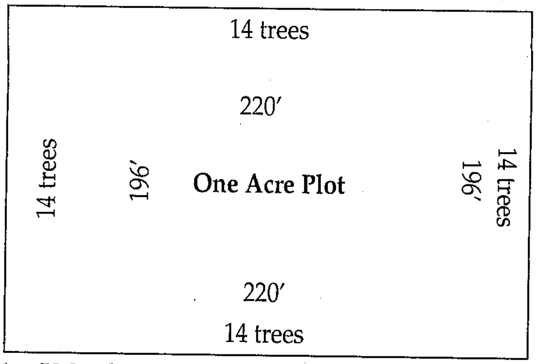
DBH (cm)	Timber vol. (o. b.) m³	DBH (cm)	Timber vol. (o. b.) m³
15	0.0033	36	0.433
18	0.0205	38	0.512
20	0.040	40	0.597
22	0.066	42	0.689
24	0.099	44	**0.782**
26	0.138	46	**0.892**
28	0.184	48	1.004
30	0.237	50	1.121
32	0.296	52	1.246
34	0.361	54	1.377

Where, V = Timber volume over bark, DBH = diameter of trees in m.

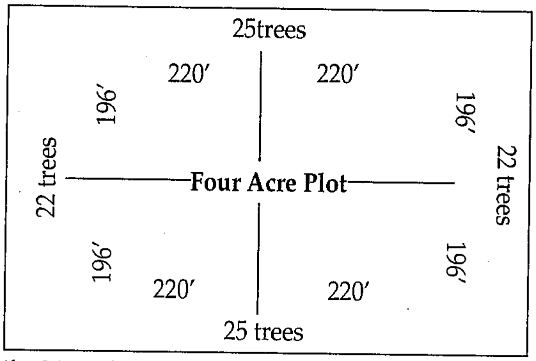
otherwise growing trees. The results show that the co-efficient of determination (r^2) is higher in case of single entry (DBH) ANOVA test (Table1). It is, thus, obvious that for timber volume estimation DBH alone of teak trees can be relied upon since the DBH and tree height both combined explain 91.5 percent of timber volume in teak trees, whereas DBH alone accounts for 93.9 % in timber volume estimation. Thus the arduous task of measuring the total tree height of teak trees can be safely dispensed with in estimating timber volume in teak trees.

Prospects and potential of teak cultivation in Punjab

The growth performance data of teak trees grown in Punjab (Tables 3, 4, and Annexure I) show a lot of variation in the growth of DBH, tree height, and timber volume (ob) production /tree. No doubt, teak cultivation is also possible in Punjab. Success of *Populus* and *Eucalyptus* as short rotation agroforestry plantations is largely credited to clonal propagation of elite trees. Use of such a venture for high production of teak trees will be highly useful to reduce the rotation age and will encourage the farmers for adoption. Even a small farmer with less than 2 ha agricultural land holding can plant teak trees on one–acre plot boundary and accommodate 50 trees (Figure 1), whereas the farmers with larger land holding can accommodate 100 teak trees on the outer boundary of 4 -acre plot. These teak plants on water channels /borders will benefit from irrigation, fertilizer and soil working give to the associated crops. At a rotation of 20 - 25 years the farmers can grow teak trees with DBH 45 -50 cm and obtain 0.6 to 0.8 m³ teak timber per tree. Taking an average, 80 % survival of originally planted teak



1a. 50 Teak trees as border row around one acre plot



1b. 96 Teak trees as border row around one acre plot

Figure 1. Proposed teak planting arrangement as single border row around 1-acre and 4-acre agricultural plot in agri-silviculture in Punjab

trees, the farmer can produce 28 m^3 and 56 m^3 of teak timber from 1-acre and 4-acre plot, respectively. This teak timber production will be an additional bonus in addition to agricultural crops like *rabi* and *kharif* fodder crops for dairy animals from one-acre plot. The remaining agricultural holding can be used to grow other normal crops. The farmers can grow normal routine crops in the 4 - acre plot with teak trees on boundary.

The farmers have already gained experience in growing trees in association with crops. They are very progressive and receptive to new crop combinations, and can plant teak trees on farm / field boundaries along with cultivation of traditional and cash crops. They cannot, of course, spare their arable land for teak solid block plantation as it is of quite a long rotation (> 40 years). The main limiting factor is the quality planting material of teak from elite trees, which can be a stimulating factor in pushing forward the incorporation of teak in agroforestry plantations in the State for 'Diversification of Agriculture' and 'environment amelioration'. The agricultural fields will then have border rows of teak trees around agricultural crops or as teak windbreaks around orchards, providing cleaner environment and carbon sequestration to reduce the carbon level in the atmosphere. The State will be able to produce farm grown teak for plywood and constructional timber requirement.

Table 4. Regional Timber Volume (o.b.) Table of teak trees grown in Punjab.

(Based on equation $V = 0.107 + 0.259^* D^2H$)

	Tree Height (m)									
DBH (m)	5	7	10	12	14	16	18	20	22	24
0.15	0.136	0.148	0.165	0.177						
0.18	0.149	0.166	0.191	0.208	0.224	0.241				
0.20	0.159	0.180	0.211	0.231	0.252	0.273				
0.22	0.170	0.195	0.232	0.257	0.282	0.308	0.333			
0.24		0.211	0.256	0.286	0.316	0.346	0.376	0.405		
0.26			0.282	0.317	0.352	0.387	0.422	0.457		
0.28			0.310	0.351	0.391	0.432	0.473	0.513		
0.30				0.387	0.433	0.480	0.527	0.573	0.620	
0.32				0.425	0.478	0.531	0.584	0.637	0.690	
0.34				0.466	0.526	0.586	0.646	0.706	0.766	0.826
0.36					0.577	0.644	0.711	0.778	0.845	0.913
0.38					0.631	0.705	0.780	0.855	0.930	1.005
0.40						0.770	0.853	0.936	1.019	1.102
0.42							0.929	1.021	1.112	1.204

ANNEXURE I:

Growth parameters and estimated timber volume in Teak trees grown in Agroforestry system in Punjab

Tree No.	DBH (cm)	Total Tree height (m)	Clear bole height (m)	**Standard timber vol.(m^3)	** Small timber vol.(m^3)	Total timber (ob) (m^3)
1	36.6	19.3	7.0	0.545	0.1646	0.7096
2	32.8	18.25	7.0	0.4862	0.0607	0.5469
3	38.8	17.25	8.25	0.5645	0.0425	0.607
4	17.3*	11.3	4.5	_	0.1	0.1
5	32.9	12.8	5.3	0.4571	0.1421	0.5992
6	32.9	18.8	8.3	0.6660	_	0.6660
7	21.1*	14.3	6.0	_	0.2113	0.2113
8	27.9	16.0	7.0	0.3491	0.0846	0.4337
9	34.7	13.3	6.3	0.4152	0.0567	0.4713
10	23.0*	12.8	5.0	0.1759	0.0201	0.1960
11	24.8*	13.3	6.0	0.2566	0.0760	0.3326
12	40.8	17.3	8,3	0.6675	0.1584	0.8259
13	33.0	17.8	6.7	0.562	0.081	0.643
14	31.0	16.0	5.0	0.295	0.080	0.375
15	38.0	15.5	8.5	0.650	0.076	0.726
16	17.5*	9.5	4.0	_	0.094	0.094
17	31.5	12.0	5.0	0.531	0.080	0.611
18	28.5	15.0	8.5	0.439	_	0.439
19	18.0*	13.7	5.7	_	0.319	0.319
20	27.0	13.7	6.7	0.327	0.083	0.410
21	38.0	13.7	7.7	0.592	0.155	0.757
22	25.0	12.7	4.7	0.255	0.050	0.316
23	24.0*	12.7	5.7	0.232	0.065	0.297
24	40.0	15.7	8.7	0.727	0.126	0.853

* Teak trees with DBH less than 25 cm, Mean DBH (cm) of trees with diameter > 25 cm = 33.49 + 5.56., Mean DBH (cm) of trees with diameter < 25 cm = 20.81 + 3.88, Mean tree height (m) of tree with DBH > 25 cm = 14.98 m + 3.59, Mean tree height (m) of trees with DBH < 25 cm = 12.5 m + 1.51. ** Standard timber = diameter > 20 cm (o.b)., ** Small timber = diameter 10 to 20 cm (o.b.)

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Economics of Teak Plantations in Kerala State, India

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ABSTRACT

A study on teak plantations in Kerala was undertaken to evaluate the present business economics of the plantations in the State under government ownership. The total cost of one hectare of plantation, spread over the rotation period of 60 years was estimated as Rs. 1,59,385 of which 3.83 per cent was invested during the establishment period. The amount of investment varied from Rs. 1,47,809 in Central Circle to Rs.1, 66,734 in the Olavakkod Circle. The study revealed that the expenditure on thinnings forms a sizeable proportion of total cost, even though the returns from first thinning was enough to realize the cost incurred until then. When *Taungya* system was practised in the State, the revenue exceeded the cost in the first year itself. The returns included the sale proceeds of poles, firewood, logs and timber, obtained through thinnings and the final felling. The average revenue from the plantations over the rotation period is estimated as Rs. 24,71,599 per hectare, using auction price of timber in the respective sales depots. Teak plantations of all circles proved to be financially sound. Plantations in the Olavakkod Circle were the most profitable ones with respect to the NPW and Benefit-Cost ratio (5%). The IRR was maximum for Southern Circle followed by Olavakkod. At higher level of discount rate, the profitability of Central and High Range Circles were most adversely affected. The situation of a 20 per cent increase in cost or 20 per cent decline in benefit, while other factors remaining the same, does not make the plantation non-profitable. But the profitability of plantations was more sensitive to a decline in benefit rather than an increase in the cost. Market analysis showed a bright price prospect for this tropical timber. So, the focus should be on timely scientific management to ensure maximum yield, as the average yields in many plantations are below the site potential. Proper management even at a higher cost can be justified for ensuring maximum production and economic efficiency.

Keywords: Market analysis, timber prices, returns from thinning, plantation management

INTRODUCTION

Teak (*Tectona grandis* L.f.) belonging to the family *Verbenaceae* is indigenous to peninsular India and it is considered as the paragon among tropical timbers. From very ancient times, due to the unique combination of properties like strength, durability, termite resistance, workability and attractiveness of its timber, teak has been used for a variety of purposes ranging from furniture making to shipbuilding. Teak is proved as one of the best-known timbers, which has performed well even outside its centre of origin, in south East Asia, Africa and Latin America. The total area under teak plantation in the world is estimated to exceed 3 million hectares (Centeno, 1997).

India enjoys the special privilege of raising teak plantation in Nilambur in Kerala in 1842. Of the total area under forest in the state, 6.8 per cent is with teak plantations. The extent of area under teak in the state has been distributed as plantations under government ownership, private individuals, institutions, companies and as component in home gardens.

Though Kerala has a long history in raising teak plantations, till now very few scientific studies have been conducted in the economics of these plantations This paper analyses the financial performance of teak plantations in Kerala under government ownership.

METHODOLOGY

Based on the details of teak plantations under the territorial divisions, a Circle wise / age group wise stratification was effected. The age groups formed were 0-5, 6-10, 11-15 and so on up to 60 years and above 60 years. Sample selection was done categorising the plantations into 13 x 4 categories based on age group and site quality. From each category, one plantation each was selected at random as sample. Thus, from each Circle the total sample size was 52 and total sample size in the study was 52 x 5 = 260.

Financial analysis

The yield from teak plantations starts with thinning and continues at definite intervals till final felling. The type of output varies from teak billets to quality timber. They are :

1. *Timber* : For the purpose of auction and sale, teak timber and poles are classified as follows.
   I class – 150 cm and above in girth, 3 m and above in length
   II class – 100 cm to 149 in girth, 3 m and above in length
   III class – 76 cm to 99 in girth, 3 m and above in length
   IV class – 60 cm to 75 in girth, 3 m and above in length
2. *Teak firewood*: Branch wood with girth 30 – 60 cm over the bark.
3. *Logs*: The logs are grouped based on these standards into lots of not more than 5 m^3.
4. *Poles*: Poles are classified as follows
   I class – 65 to 75 cm girth at 3 m from butt end
   IA – above 12 m in length
   IB – Between 9 and 11.99 meter in length
   IC – Between 6 and 8.99 meter in length
   ID – Below 6 meter in length
   II class – 53 to 64 cm in girth, 3 m from butt end
   IIA- above 12 m in length
   IIB – Between 9 and 11.99 m in length
   IIC – Between 6 and 8.99 m in length
   IID – Below 6 m in length
   III class – 41 to 52 cm in girth, 3 m from butt end: Minimum length 6.99 m and above
   IV class – 28 to 40 cm in girth, 3 m from butt end
   V class – 15 cm to 27 cm in girth
5. *Teak billets*: Small pieces of teak with a length less than or equal to one m.

The prices in timber depots are arrived at through auction. The sale is effected after grading according to length, girth and quality. These are sold in monthly auctions and records are maintained. The price data (1999) of these logs/timber firewood / poles for various quality standards are collected from respective depots. The total financial return was arrived at by multiplying the yield of each category of out put with respective prices. The same was also converted to per ha basis.

The financial feasibility of the plantations was worked out following the procedure suggested by Gittinger (1982). The tools followed are:

1. *Pay Back Period*

The pay back period of a project is the time required to earn back the expenses in the project. It is an undiscounted measure, which measures the period within which the returns offset the expenditure. It is estimated by comparing progressive total returns with progressive total of costs. However it is to be remembered that it does not consider the earnings after this period and the difference in the timings of earnings during the pay back period. Three measures of economic worthiness widely used are Net Present Worth (NPW), Benefit Cost Ratio (BCR) and Internal Rate of Return (IRR) (Table 1).

2. *Net Present Worth (NPW)*

$$NPW = \frac{å\,(B_t - C_t)}{(1 + i)^n}$$

Where B_t = benefits in t^{th} year
C_t = costs in the t^{th} year
i = rate of discount
n = number of years

3. *Benefit Cost Ratio (BCR)*

$$BCR = \frac{\text{å}\, B_t\, (1+1)^{-n}}{\text{å}\, C_t\, (1+1)^{-n}}$$

4. *Internal Rate of Return*

IRR is the rate of discount at which NPW is equal to zero. It is the returns or yields of the investment. The results of this analysis were obtained by using the package in Lotus 1-2-3 computer programme.

5. *Soil Expectation Value*

The Soil Expectation Value (SEV) gives an estimate of the present value of land if it were put to forestry and produced an infinite number of net returns (Rs. 'R') every 'r' years; where 'r' is the rotation length. To estimate SEV, the net benefit of forestry production at the end of rotation is calculated without taking actual land cost into account and then NPW of the future periodic series of net benefits of Rs. 'R' is computed beginning with Rs. 'R' received at the end of the first rotation.

SEV is used to determine what amount could be paid for the land to breakeven, i.e. have present value of costs equal to present value of benefits, using a discount rate 'i'. More generally it indicates the present value of the productive capacity of the land, given the values assumed and the assumption that the land could continue to produce timber in perpetuity at the given rate.

$SEV = [NPV\,(1+i)^t]/[(1+i)^t - 1]$

SEV = Soil Expectation value

t = rotation age

i = discount

Annualised land rent (ALR) is obtained by multiplying SEV with 'r' which gives the annual returns from forest land in addition to 100 x r% annual returns from capital (Sharma *et al.* 1991).

RESULTS AND DISCUSSION

The cost stream in plantations consists of the materials and labour associated with proportionate cost of nursery, slash burning and land preparation of main field, aligning and stalking, planting of stumps in crowbar holes, maintenance / intercultural operations, weeding, tending, climber cutting, thinning and final felling. The returns include the sale proceeds of poles, firewood, logs and timber, obtained through thinnings and final felling.

The total cost of a hectare of plantation spread over the rotation period (60 years) is estimated to Rs. 1,59,385 of which 3.83 per cent is to be invested during the establishment period. The amount of investment varies from Rs. 1,47,809 in Central Circle to Rs.1,66,734 in the Olavakkod Circle (Table 2). The expenditure on thinnings forms a sizeable proportion of cost. However, the invested amount is realised by the sales from the first thinning itself and the year of thinning varies according to the management practices followed in each case. So the delayed returns on account of the long gestation period of the crop is somewhat taken care of. When taungya system was practised in the state, the revenue exceeded the cost in the first year itself. The returns from thinning were Rs. 35,513 per hectare in the first mechanical thinning (ranging from Rs.2,180 in Central Circle to 40,975 in Olavakkod Circle). Average revenue from the final felling was estimated to Rs. 24,71,599.

At 5 per cent discount rate, the plantations in the Olavakkod Circle were the most profitable ones with respect to the NPW and Benefit-Cost ratio. The

Table 1. Results of financial analysis of teak plantations in Kerala State

Circle	IRR (%)	5%		10%		15%		20%	
		NPW	BCR	NPW	BCR	NPW	BCR	NPW	BCR
Southern	29	253245	6.88	58000	3.24	23110	2.15	10207	1.59
High range	20	139237	4.08	25346	1.94	7106	1.34	228	1.10
Central	21	164248	5.16	22826	1.97	5650	1.31	398	1.03
Olavakkode	26	260047	7.15	53302	3.16	19254	2.00	7279	1.45
Northern	23	127373	4.24	21790	1.94	7171	1.40	1941	1.13
State	25	197561	5.74	39727	2.61	16162	1.74	4988	1.30

NPW at 5 per cent discount rate was Rs.2, 60,047 per ha, which reduced to Rs.7279 per ha at 20 per cent discount rate, while the BCR fell from 7.15 to 1.45. Even if the discount rate is raised to 20 per cent the plantations remained to be profitable, which is true even the least profitable Circles (Northern Circle with lowest NPW and High range Circle with lowest BCR). However, as the discount rate increased the plantations in the Central Circle and the High range Circle show the lowest BCR and NPW respectively.

The IRR, which depicts the yield on investment, assess the southern Circle as the most profitable one, followed by the Olavakkod Circle. It tells us the maximum limit of the cost of capital that can be invested. It will be interesting to make a comparison of relative profitability of teak with other plantation crops, which are generally grown in the state. At 10 per cent discount rate, BCR of teak was found to be better than any other plantation crop in the state. But plantation crops like areca nut and cardamom are having higher NPW than teak. Especially in Northern Circle, the NPW of teak is Rs. 21,790 ha^{-1} where as the NPW of areca nut is Rs. 95,506 ha^{-1}. Areca nut is a major plantation crop in Northern Kerala. In high ranges, the major plantation crop like cardamom is proved to be financially more attractive with an NPW of Rs. 41,294 ha^{-1} against that of Rs. 25,346 ha^{-1} in teak. However the BCR is higher for teak.

With respect to yield on investments in pepper (Idukki and Kannur) and coconuts (Kozhikkode) were having a lower IRR than teak. Rubber and teak were on par in this respect.

Though financial analysis proves some crops more attractive than teak, the economic analysis (with the ecological and environmental impact on forest due to timber extraction) may yield results which are different. All biological systems face different types of risk, which may be due to technological, climatic, economic or policy factors. To test the shock absorbing capacity of the investment the sensitivity analysis was carried out, as detailed in the methodology

The situation of a 20 per cent increase in cost or 20 per cent decline in benefit, other things remaining the same did not make the plantation non-profitable. Hence the recent decision to enhance the wage rate is not going to adversely affect the performance of teak plantations to the negative side. But one point worth highlighting is that the profitability of plantations is more sensitive to a decline in benefit rather than an increase in the cost. For a 20 per cent increase in cost, the average decline in NPW was to the tune of only 4.22 per cent while the corresponding figure on account of a decline (at 5 per cent discount rate) in benefit was 24.22 per cent. Benefit from plantations is a function of yield and price of timber. Based on the projections of supply and demand for teak timber, the chance of decline in price is remote. But then comes the importance of yield from the plantations. The findings of Chundamannil (1998) on the declining tendency in Mean Annual Increment (MAI) in the Nilambur teak plantations over the years are to be reviewed in this context. He has also highlighted that the variability in yield was more pronounced during the period 1982-1994 than in 1967-1981. In this background the policy may be to adopt appropriate scientific management practices even at a higher cost, to guard against a possible decline

Table 2. Results of sensitivity analysis

Circle	10% increase in cost		20% increase in cost		10% decrease in benefit		20% decrease in benefit	
	NPW	BCR	NPW	BCR	NPW	BCR	NPW	BCR
Southern	248941	6.26	244636	5.74	223616	6.20	193987	5.50
High range	134717	3.71	130198	3.40	120794	3.67	102350	3.26
Central	160302	4.69	156355	4.30	143877	4.65	123505	4.13
Olavakkod	255822	6.50	251597	5.96	229818	6.44	199588	5.70
Northern	123443	3.86	119513	3.53	110706	3.82	94038	3.39
State	193389	5.21	189219	4.78	173634	5.16	149707	4.59

in the yield. Moreover, this study revealed that the realised yield from the plantations is below the site potential, which warrants more attention in the management of teak in the state. Owing to the special status as well as unique properties of tropical timber, teak will continue to be a profitable enterprise. However, lack of proper care and management of the plantations may lead to a situation of declining profitability.

The soil expectation value (Land expectation value) is a measure of present value of productive capacity of the land. It is used to determine what amount could be paid for land to break even. ALR gives the rate of annual returns from forestland in addition to 100 r per cent annual returns from the capital.

On an average the SEV (5 per cent) was estimated to be Rs. 2,08,736 ha^{-1}(Table 3). In the existing conditions it is highest (Rs. 2,74,756) for Olavakkod Circle, obviously due to a higher level of productivity, profitability and shorter rotation. The estimate was lowest for the northern Circle. At a higher level of discount rate (10 per cent), southern Circle was having the highest value and the northern Circle the lowest. The indication is that, if the cost of capital is 10 per cent, investment on land for teak can go up to Rs. 58,191 ha^{-1} where as it can be only up to Rs. 21,862 ha^{-1} in northern circle, for the project to break even. Similarly, at higher levels of cost of capital, the investment limit lowers.

The ALR (5 per cent discount rate) was estimated at an average of Rs. 10,437 ha^{-1} $year^{-1}$ from the teak plantations in the state. It shows wide inter-circle variability from Rs.6729 (northern) to Rs.13, 738 (Olavakkod). The interpretation is that, after ensuring a return of 5 per cent per annum on capital invested, teak ensures Rs. 10,437 ha^{-1} $year^{-1}$ from the land, if the land is used for teak production in perpetuity. When the rate of return on capital is increased to 10 per cent the annual land rent declines to Rs. 3986 ha^{-1} $year^{-1}$ for the state as a whole. In the case of plantations in the southern Circle, it ensured a higher annual return than the High range circle where it was the least.

SUMMARY AND CONCLUSIONS

1. The total cost of raising one ha of teak plantation in the state, spread over the rotation period (60 years) was estimated to Rs. 1,59,385 of which 3.8 per cent is the establishment cost.
2. The returns from first thinning are enough to cover the investment till then.
3. The average revenue from the plantations over the rotation period is Rs. 24,71,599 ha^{-1}.
4. The teak plantations in all Circles proved to be financially sound. Plantations in Olavakkod Circle were most profitable at 5 per cent level of discount rate, when NPW and BCR criteria are considered.
5. Yield on investment (IRR) was the maximum for the Southern Circle, followed by Olavakkod.
6. At higher level of discount rate, the profitability of Central and High range Circles are most adversely affected.
7. The estimation of SEV at Rs. 2,08,736 ha^{-1} for the teak plantations in state indicated that, if the cost of capital is 5 per cent, investment on land for teak growing can go up to this level, for the project to break even.
8. The annualised land returns were estimated as Rs. 10437 ha^{-1} (at 5 per cent discount rate). After ensuring a 5 per cent return on capital, the project ensures this amount ha^{-1} $year^{-1}$.
9. The profitability of plantations was found to be more sensitive to a decline in benefit than an

Table 3. Soil Expectation value and Annualised Land Rent, in the teak plantations.

Circle	SEV (5%)	ALR (5%)	SEV (10%)	ALR (10%)	SEV (15%)	ALR (15%)	SEV (20%)	ALR (20%)
Southern	267569	13378	58191	5819	31468	4720	17613	3523
High range	147113	7356	25429	2543	7107	1066	228	46.00
Central	173539	8677	22901	2290	5652	848	398	80.00
Olavakkod	274756	13738	53477	5348	19258	2889	7279	1456
Northern	134578	6729	21862	2186	7172	1076	1941	388
State	208736	10437	39858	3987	14165	2125	4989	999

Appendix 1

Cash flow statement of teak plantations in Kerala state (Rs. ha^{-1})

Year	Operations	Cost	Benefit	Net benefit	Year	Operations	Cost	Benefit	Net benefit
0	Establishment costs	6107.2	0	-6107.2	31	Weeding	1484.2	0	-1484.2
1	Maintenance	3158.6	0	-3158.6	32	Maintenance	819	0	-819
2	Maintenance	2650.6	0	-2650.6	33	Maintenance	819	0	-819
3	Maintenance	2123.2	0	-2123.2	34	Maintenance	819	0	-819
4	Maintenance	1126	0	-1126	35	Maintenance	819	0	-819
5	Maintenance	1045	0	-1045	36	Maintenance	819	0	-819
6	1st Mech. Thinning	3823.2	35513	31689.8	37	Maintenance	819	0	-819
7	Maintenance	819	0	-819	38	Maintenance	819	0	-819
8	Maintenance	819	0	-819	39	Maintenance	819	0	-819
9	Maintenance	819	0	-819	40	Maintenance	819	0	-819
10	2nd Mech. Thinning	4115.6	26428	22312.4	41	4th Silvi. Thinning	15037	170677	155640
11	Maintenance	819	0	-819	42	Weeding	1283.6	0	-1283.6
12	Maintenance	819	0	-819	43	Maintenance	819	0	-819
13	1st Silvi. Thinning	4238	39073	34835	44	Maintenance	819	0	-819
14	Maintenance	819	0	-819	45	Maintenance	819	0	-819
15	Maintenance	819	0	-819	46	Maintenance	819	0	-819
16	Maintenance	819	0	-819	47	Maintenance	819	0	-819
17	Maintenance	819	0	-819	48	Maintenance	819	0	-819
18	Maintenance	819	0	-819	49	Maintenance	819	0	-819
19	Maintenance	819	0	-819	50	Maintenance	819	0	-819
20	2nd Silvi. Thinning	4667.8	34307	29639.2	51	Maintenance	819	0	-819
21	Maintenance	819	0	-819	52	Maintenance	819	0	-819
22	Maintenance	819	0	-819	53	Maintenance	819	0	-819
23	Maintenance	819	0	-819	54	Maintenance	819	0	-819
24	Maintenance	819	0	-819	55	Maintenance	819	0	-819
25	Maintenance	819	0	-819	56	Maintenance	819	0	-819
26	Maintenance	819	0	-819	57	Maintenance	819	0	-819
27	Maintenance	819	0	-819	58	Maintenance	819	0	-819
28	Maintenance	819	0	-819	59	Maintenance	819	0	-819
29	Maintenance	819	0	-819	60	Final felling	62774.2	2031378	1968604
30	3d Silvi. Thinning	8077.2	134223	126145.8					

increase in cost. Market analysis shows bright price prospects for this tropical timber, that the concentration should be on timely scientific management to ensure maximum yield. The average yields in many plantations are below the site potential. Proper management even at a higher cost can be justified for ensuring potential production and maximum economic efficiency.

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Quality Timber Products of Teak from Sustainable Forest Management pp 583-588

Current Status, Future Prospects, Economics and Policy Issues for Teak (*Tectona grandis)* Investments by NABARD

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ABSTRACT

National Bank for Agriculture and Rural Development (NABARD) is a developmental bank, which provides credit for promotion of sustainable agriculture including forestry, for integrated rural development. Teak (*Tectona grandis* L. f.) is one tree which has great potential in rehabilitation of India's degraded forests and also raising farm forestry on wastelands, on a sustainable basis. Earlier, teak was believed to be slow growing. But, nowadays, with the availability of improved planting stock, advanced nursery and plantation technologies and intensive management, it is found to be suitable as a short rotation forestry / farm forestry crop. Many state-owned Forest Development Corporations (FDCs) have already raised excellent teak plantations, after availing of credit from NABARD/banks on long term basis. Today, FDCs are proposing short rotation, intensive, irrigated teak plantations and have already submitted few projects to NABARD. During the last decade, many private entrepreneurs floated companies, calling for investments in Teak equity with promise of high returns. Many people invested in such equities, although the promised returns were not available to them. However, it is felt that, teak is really a potential tree for investment and is strongly recommended for raising commercial plantations by the farmers and the FDCs on their lands. As per NABARD scheme for teak under farm forestry, the recommended number of trees per hectare is 2500 and the unit cost is Rs. 40,000 in four years. Thinning is recommended in 7 and 13 years, from which, sizable income will be available and the entire bank loan with interest can be repaid with that. Such teak plantations on wastelands are both technically feasible and financially viable. The IRR of the scheme is 28.69 per cent. Teak plantations on degraded forest lands are also viable and the IRR varies from 17 to 18 per cent. The major problems faced by teak farmers is lack of quality planting stock and the strict transit rules which need immediate attention of the planners, policy makers, forest departments and the scientists.

Keywords: NABARD, teak investments, economics, policy issues

INTRODUCTION

Teak is the most prized timber in India. The best quality teak wood is coming from the central parts of the country grown in states of Madhya Pradesh and Chhattisgarh with a brand name *CP(central proveince) Teak.* Because, teak was known as a commercial timber in India, NABARD has been associated with teak investments before it's establishment in 1982 i.e since the days of Agricultural Refinance Development Corporation (ARDC) of Reserve Bank of INDIA(RBI) through FDCs.

Current status of NABARD's investments in teak

In the forestry sector, teak plantation activity was the first to be funded by NABARD and other Banks. Madhya Pradesh FDC has been raising commercial teak plantations since 1976 from the Phase I to Phase V through institutional credits.The corporation raised excellent plantations in the Districts of Mandla, Seoni, Balaghat and Jabalpur with a total area of 118,703 ha and has created assets worth Rs.748 crores as on Mach 2003. A collection of data on growth from several MPFDC plantations indicated average height of 15.57 m and girth of 56.9 cm in 20 years age.These plantations were properly managed and raised in in areas of Site Quality ranging from I/II to II/III. Of course, these plantations were without any irrigation or fertiliser treatment but were properly protected, weeded and thinned according to silvicultural principles.

Ever since it's inception in 1974, the Forest Development Corporation of Maharashtra (FDCM) has been engaged in conversion of mixed forests into high quality commercial forests.To fulfil this main objective, large scale teak plantations have been raised since 1970 when Forest Development Board existed. In the initial years of FDCM, Govt. of Maharashtra has provided the entire finance for raising teak plantations in the form of loan and share capital till 1980-81. From 1981-82 and onwards, the Phase-I and Phase-I extension activities of teak plantation programme were carried out with NABARD/Bank loans. Further, the wasteland development programme was implemented under the Bank finance with refinancial assistance from NABARD. The details of the loan borrowed from the Banks are as follows:

Teak plantation Phase I	:	Rs.1272.90 lakhs
Teak plantation Phase I extension	:	Rs.2605.86 lakhs
Wasteland Development Zone II project	:	Rs.970.58
Wasteland Development Zone III project	:	Rs.1070.50 lakhs.

The entire Bank loan of Rs.4646.94 lakhs along with accrued interest have been repaid to the Banks as per repayment schedule by 31 March 2000. So far, the corporation's successful teak plantations have spread over an area of 97,333 ha with a growing stock of 24.21 lakh m^3., the value of which has been estimated at Rs.1415 crores.

Gujarat State FDC had also raised mixed teak plantations after availing of NABARD/ Bank loan; however the plantations were not very successful because of wrong site selection. In spite of some problems faced by the FDCs, they have repaid the bank loans regularly and till date no FDC is a defaulter. After 1990s, the FDCs stopped availing of bank credit for raising forestry plantations because of the deregulation of interest rates by RBI, which went up to 18% in some cases, making forestry projects nonviable with bank credit.

Future prospects of Teak investments

After intervation and regulation effected by RBI, interest rates were drastically reduced during the last 5 years and now stabilised. NABARD has now started negotiatiations with the financially strong FDCs for promoting new teak plantation projects for rehablitation of degraded forest lands.We have already received a teak plantation project from MPFDC which is under evaluation by NABARD.The capital outlay of the project is Rs.10,859.11 lakhs and the Bank loan is Rs.2880.86 lakhs.The remaining cost will be met by the company from it's internal resources including equity contribution.The project is for 15 years starting from 2002-03.

The new project

The major objectives of the project were: a. to convert low valued, degraded, poor site quality forests into high valued man-made forests to obtain quality produce for commercial, industrial and domestic use; b. to realise maximum production and financial returns in minimum possible time period by adopting intensive management practices; c. to improve the economic status of the area by enrichment to forest cover and to improve socio-economic condition of local people by employment generation. The project area will cover 8 project divisions, viz.Chhindwara, Balaghat, Lamta, Mohgaon, Rampur Bhatodi, Kundam, Umaria and Sishi.The project proposes to raise teak plantations over an area of 9761 ha.There are 3 types of teak plantations to be raised viz. commercial rainfed (9012ha), commercial high input rainfed (400ha) and hi-tech irrigated (259ha). The corporation proposes to plant teak under 2x2 m espacement accomodating 2500 plants per ha with mortality replacement at 20%. It was proposed to use quality seeds obtained from clonal seed orchards or plus trees. The cost per unit of 1 ha is Rs.28,666 for commercial rainfed, Rs.49,940 for commercial rainfed high input and Rs.146,237 for hi- tech irrigated plantations with I thinning starting at 11th, 8th and 6th year in respective plantations.The IRR of the plantatioms varied from 17.2 to 18.5 per cent. The repayment schedule varied from 16th year to 24th year with earliest return in hi-tech irrigated plantations. The various models of the project were found to be technically feasible and financially viable.The project is likely to be sanctioned soon by NABARD/ UCO Bank.

Potential for teak plantation forestry

In India, there are 31 million ha degraded forest lands, out of which 25 million ha need to be reforested immediately and urgently. If this is done over a period of 15 years at an annual target of 1.7 million ha, which is considered realistic and achievable, then the financial requirements would be to the tune of Rs.3740 crores based on a reasonable estimate of Rs.22,000/- per ha. This requirement of huge fund is neither available to Centre nor to state Govts. Hence there is tremendous scope to channelise institutional credit for development of India's degraded forest lands on sustainable basis.There are 23 FDCs in the country which were primarily set up for rehabilitation of degraded forests through institutional credit, as per recommendations of National Commission on Agriculture. Many of the FDCs are not doing well, however, if these can be revitalised, a substantial portion of our degraded forests can be rehabilitated with institutional credit. NABARD is now negotiating with potential FDCs for raising commercial teak plantations.We are expecting big projects from Chhattisgarh FDC, Karnataka FDC, Tamilnadu Forest Plantation Corporation, Andhra Pradesh FDC and FDCM besides some more projects from MPFDC. NABARD has so far disbursed Rs.286.80 crores under Forestry, a major portion has gone to FDCs for raising teak plantations on degraded forest lands. NABARD has recently sanctioned 2 Forestry projects to Andhra Pradesh FDC with capital outlay of Rs.5277.67 lakhs for raising clonal Eucalyptus and intensive Bamboo plantations in 10,830 ha degraded forest area under co-financing with Bank of Maharashtra.

NABARD'S new scheme

Realising the importance of teak under farm forestry/ agroforestry, NABARD formulated a model scheme for the benefit of farmers and banks. It can be raised either in block plantations on wastelands or on bunds or boundaries of agricultural lands in multiple rows.The number of plants to be planted by each farmer will depend upon extent of area and type of planting e.g. block or bund planting. The optimum spacing for block planting is 2 x 2 m accommodating 2500 plants per ha. The minimum planting area for block plantation should be 0.2 ha or 500 trees per unit. Only good quality planting stocks obtained from Forest Department may be used. It can also be raised along with agricultural crops at a spacing of 4 m x 4 m or 5 m x 1 m. Weeding may be carried out @ 3 operations in the 1st year, 2 operations in 2nd year and 1 operation in 3rd year. Irrigation should be followed by weeding (3,2,1) and adequate soil working. Two doses of fertiliser @ 50 gm per plant of NPK (15:15:15) may be provided every year upto three years.

Cost of cultivation

The cost of cultivation will depend upon the objectives, intensity, rotational age and the extent of the area to be planted. The cost of cultivation for an unit area of one ha at an espacement of 2 x 2 m. i.e. 2500 plants/ ha. has been worked out at Rs. 40000 which is shown in the Annexure- I.

Harvesting, yield and return

It takes roughly 20-30 years to produce reasonably good quality timber.However, due to large market demand, even the poles and small timber fetch good price. First thinning in 7th year and second thinning in 13th year may provide good number of poles and small timber to pay back the entire bank loan with accrued interest. In the final harvest by 20th year, each tree can produce quality timber ranging from 7-10 cft. The yield and income are based on a conservative estimate. Even after 20 years the farmers can retain some trees if they so desire.

Economics and repayment schedule

The financial analysis with the above cost and yields, gives IRR of 28.69percent. A detailed economics along with repayment schedule was worked out taking into consideration of 12% interest which is shown in Annexure- II. The entire loan with accrued interest can be repaid in 14 years from planting with a moratorium of 7 years.

Margin money, interest rates

NABARD stipulates beneficiary's contribution to the project cost in order to ensure his stake in the involvement. Such margin money varies from 5% to 25% depending upon the type of investment and the class of borrowers. The rate of interest to the ultimate borrowers will be decided by the financing banks which are subjected to revise by RBI / NABARD from time to time. At present NABARD's rate of refinance for wasteland development projects with teak is 6.75%. This means that a farmer can get bank loan approximately at 10% interest rate.

Marketing of timber

Teak is the most important commercial timber in India especially for furniture making. The very name of the tree translates into Carpenter's pride and is one of the most sought after timbers in Indian market, hence no problem is envisaged in marketing by the farmers.

DISCUSSION AND CONCLUSION

A study was undertaken in a 20-year-old teak in Thanjavur Cauvery canal plantation of Tamil Nadu (MOEF, 1997), because the yield of this plantation was often quoted by the private teak plantation companies in 1990s supporting their projections of high yield. The plantation was raised by Tamil Nadu Forest Department in the year 1976 in strips on the banks of Cauvery canal at an espacement of 3 m x4 m. The soil on the canal bank was deep, alluvium providing exeptionally good growth conditions and water was retained in the canal for 8 months in a year. The trees were not given any input but the dbh ranged from 18 to 42 cm with an average height of 22.7 m giving site quality III. The average timber volume found out from yield table was 16.6 cft. per tree corresponding to 31.5 cm average diameter.This is the best growth ever achieved in teak in India. However, the growth in strip plantation can never be compared with that in a block plantation.

Another study by F.R.I.(Sanyal et. al. 1987) indicated that 20-year-old teak logs of Cauvery canal strip plantation in Thanjavur District showed comparable strength properties to standard teak. The findings are that in green condition the plantation grown timber was stronger than standard teak on the average by 16% in case of 16 properties, while in case of 9 properties the species was weaker on an average by 8%. In air dry condition the timber was stronger by 9%. According to this study, it can be safely inferred that plantation grown teak showed better physical and mechanical properties than standard teak. However, it is a fact that in fast grown plantations, the grain and colour of timber will not be as attractive as that of a naturally grown teak and it will also fetch lower price. The fast grown teak of Nilambur in Kerala fetches lower price than the slower grown teak of central provinces and Maharashtra. The rates obtained from sale results of Thanjavur depots showed a lower rate as compared to standard market rate of t eak in south India. Thus, the promised returns of private teak plantation companies of Rs.50,000 per tree in 20 years and also investment of Rs.1000 per tree was not only unrealistic but also disproportionate to the actual planting cost (Chaturvedi, 1995).

The major issues hampering the growth of teak cultivation especially with farm forestry practices are: non-availability of of quality planting stocks to the farmers; strict transit rules for teak; non-incentives from Centre/State Govts and lukewarm approach of Banks for funding in view of long gestation period.

Although research on teak is age old, no real breakthrough has been achieved so far as has been achieved in case of *Eucalyptus* and Poplar *(Populus deltoides)*. Hence it is essential to select fast growing clones of teak for raising in farm lands (Haque, 1996). The Forest Research Institutes and Agricultural Universities may initiate research on this line. Although many trees have been exempted from transit rules of state Govts., teak is still kept under this rule. How can this be exempted may be debated among the policy makers. This is one reason why Planning Commission (2001) did not recommend teak as an agroforestry species. If the researchers can evolve genetically improved, fast growing and high yielding clones, then the tag of slow growith assigned to teak can be removed and sufficient credit can be channelised to teak plantations. Regarding incentives, the Investment Promotion Scheme (IPS) of Ministry of Rural Development, GOI can be used, which provides subsidy for wasteland development projects under agroforestry including teak. Under the scheme, subsidy ranging between 25% to 50% of the cost of development of wasteland, subject to a maximum of Rs.25 lakhs is provided by Govt. of India, depending upon the category of the farmers. The Agri-silviculture or Agri-horticulture and other models initiated in the IPS can also be covered under the programme and will be eligible for concessional refinance from NABARD.

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Annexure I

Cost of Teak Cultivation in One Hectare Wasteland

SL. NO.	PARTICULARS OF WORKS	UNIT	Cost(Rs.)per year 1	2	3	4	TOTAL (RS.)
1.	Site preparation	12MD	600				600
2.	Initial ploughing for six hours	Rs.150/Hr	900				900
3.	Alignment & staking	5 MD	250				250
4.	Digging of pits (45x45x45 Cm) and refilling of pits after mixing FYM, Fertiliser & insecticides @ (30 pits/MD & 100 pits/MD)	108 MD & 22 MD	5400	1100		6500	
5.	Cost of FYM @3 Kg/pit	Rs.150/ton.	1125				1125
6.	Cost of fertiliser @100 Gm/plant	Rs.4/Kg	1000	1000	1000		3000
7.	Cost of insecticides / pesticides	LS	500	500	500		1500
8.	Cost of plants including transport(2500,500)	Rs.2.50/ plant	6250	1250			7500
9.	Planting & replanting @100 plants per MD.	25 & 5MD	1250	250			1500
10.	Weeding(3,2,1)	16 MD per Weeding	2400	1600	800		4800
11.	Soil working (1 working in the Ist year and 2 workings upto 4th year)	16 MD per working	800	1600	1600	1600	5600
12.	Irrigation during dry months	LS	1000	1000	1000		3000
13.	Sub Total	RS.	21475	8300	4900	1600	36275
14.	Contingency 10 %	RS.	2147.5	830	490	160	3628
15.	Grand Total	RS.	23623	9130	5390	1760	39903

Yield and Rotation

Year	No.of trees surviving	No.of trees removed	No. of saleable trees or vol (cum)	Rate/Unit (Rs.)	Income (Rs.)
7th/8th	2000	1000	1000 POLES	125	125000
13th/14th	1000	500	500 POLES	300	150000
20th	500	250	56 Cum.*	7500	420000
30th	250	250	105 Cum.**	15000	1575000

Fuelwood in the form of lops & tops will be consumed locally by the farmer.
* Assumed Girth - 60cm & Height - 13 Mtr. ** Assumed Girth - 75 cm & Height - 14 Mtr.
Espacement: 2m x 2m; no.of trees/ha.:2500; wage rate:Rs.25/md; casualty replacement:20 %; survival/ha.:2000

Annexure II
Financial analysis and Repayment Schedule

ITEMS	Years												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
Capital Cost	23623	9130	5390	1760	0	0	0	0	0	0	0	0	0
Recurring Cost*	23623	2834.76	8504.28	8504.28	8504.28	8504.28	8504.28	0	0	0	0	0	8504.28
Total Cost	47246	11964.76	13894.28	10264.28	8504.28	8504.28	8504.28						8504.28
Total Income	0	0	0	0	0	0	125000	0	0	0	0	0	150000
Net Income	-47246	-11964.76	-13894.28	-10264.28	-8504.28	-8504.28	116495.7	0	0	0	0	0	141495.7
Discount Factor	0.15												
NPV	-6247.6045												
IRR	0.135413												
NPV of benefits	71371.32												
NPV of costs	77618.93												
BCR	0.919509												

Repayment schedule

	Term loan	Int	Acc.Int	Income	Int. repayment	Principal repay	TL O/S	Net surplus
1.	23623	2834.76	2834.76	0	0	0	23623	0
2.	23623	2834.76	5669.52	0	0	0	23623	0
3.	23623	2834.76	8504.28	0	0	0	23623	0
4.	23623	2834.76	11339.04	0	0	0	23623	0
5.	23623	2834.76	14173.8	0	0	0	23623	0
6.	23623	2834.76	17008.56	0	0	0	23623	0
7.	23623	2834.76	19843.32	125000	19843.32	0	23623	105156.7
8.	23623	2834.76	2834.76	0	0	0	23623	0
9.	23623	2834.76	5669.52	0	0	0	23623	0
10.	23623	2834.76	8504.28	0	0	0	23623	0
11.	23623	2834.76	11339.04	0	0	0	23623	0
12.	23623	2834.76	14173.8	0	0	0	23623	0
13.	23623	2834.76	17008.56	150000	17008.56	23623	0	109368.4

Optimal Rotation of Teak Production: Tools for Economic Analysis

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ABSTRACT

Bangladesh has a century-long history of teak plantations, like many other tropical countries. Management is one of the most important problems, besides budgetary constraints. It is one of the most important timbers in the world trade, used chiefly for shipbuilding and constructional puposes. Teak plantation is set for 60 years rotation for all sites in Bangladesh, which is not compatible with the economics of forestry. Based on assessment of economic and silvicultural aspects, teak rotation practice is going to be reduced everywhere to achieve viable balance between financial returns and production of market quality timber. Considering the economic importance and long-term nature of investment, the crucial policy is to determine the rotation age of teak plantations. The study attempted to determine the optimal rotation of teak plantations in order to make management efficient and long-term investment financially remunerative and attractive. The study, under current management practices and based on certain assumptions, found that ideal rotation for teak plantations would be 20-21 years. In the study, it is recommended for further research to arrive at more realistic and accurate estimates of rotation age for appropriate management and felling policy prescriptions.

Keywords: Teak, Bangladesh, rotation, management

INTRODUCTION

Teak (*Tectona grandis* L f..) has been cultivated in the tropics for centuries. It is believed that teak has been introduced to Java in the 14th century. There are references to plantations established in India in the early 1800s and in tropical America about 100 years later. The objective of such establishment is for utilization of high-quality teak timber, which has constant demand for domestic use, for export and financial gains. The causes of failure of teak plantations in countries like Bangladesh, Myanmar and India are unsuitable sites, inadequate allotment of funds, failure of timely implementation of tending operations in different stages of development, irregular thinning, most of which are beyond the control of the Forest Department (Chacko, 1995). Research indicated that site quality declines with age (Jayaraman, 1995) and that site deterioration between and within rotation poses a threat to potential yield and sustainable management (Chacko, 1995)

Studies by Kaosa-ard (1995) revealed that the proportion of teak in the overall plantation area in the tropics had declined sharply, from 11% in 1980 to 5% in 1990. Furthermore, India had reduced teak rotation to 30 years (Nair, 1995) while Thailand had reduced it to 16 years (Kaosa-ard, 1995) and Malaysia is practicing a 15-year rotation (Zakaria and Lokmal, 1995). These reductions in rotations are in line with modern research findings of site deterioration within and between rotations (Chacko, 1995) and the prevalence of insects and borer attacks as well as low yield obtained from plantations being far below expectation (KFRI, 1979).

Against this backdrop, some countries began to question the benefit of teak plantation establishment and some have discontinued teak as a promising species for plantation establishment (Keogh, 1979). Some have shortened the rotation of teak plantations to 30, 25 or 15 years (Keh, 1995) so as to make their investments more remunerative and also to lessen the extent of soil erosion and site degradation due to teak plantation (Nair, 1995).

Teak plantation has been the principal species in the plantation program in Bangladesh till early eighties. More than 70% of total plantation in the hill forest was t of teak (White, 1979).The rotation period was planned for 60 years in all sites. The consideration of shortening of rotation did not take place in the working plan. The rotation was determined in the absence of proper management and economic analysis.

The plantation program of the country should have been consistent with and harmonized with the growth process of the other sectors in order to generate maximum contribution to the society. But the teak plantation has been made without paying proper economic consideration of the country. In order to examine economic viability of teak plantation the present study set the objectives to: (i) review the existing teak plantation in Bangladesh (ii) identify the needs for economic analysis for determination of optimal rotation of teak plantation and (iii) suggest the tools and information needed for economic analysis and policy prescriptions.

Teak Plantation

The high commercial value of teak timber has prompted its introduction as a plantation tree in a number of countries. Teak is moderately hard and heavy, extremely durable, resistant to insect and fungi, easy to work with good finish, straight grained, good appearance and has a golden–brown hardwood. The timber has world-wide reputation mainly for shipbuilding, constructional work in general and bridge building in particular.

Considering the economic importance of teak, Bangladesh has also initiated plantation programme . Slavicky (1978) reported that plantation in Bangladesh till 1981 was about 89,500 ha, 54% of which was established in 1960s and 70s and about 8,500 ha during 1979-81 (Douglas,1981). ALIFF gave a figure of 76,080 ha up to 1976-77 (Douglas,1981). The distribution areas of teak plantations up to 1978 include Cox's Bazar 28.7%, Chittangong 19.8%, Chittangong Hill Tracts (North)14%, Chittangong Hill Tracts (South)14%, Jhum Control Board 11.5 % and Sylhet 12%. The earliest teak plantation took place in Chittangong Hill Tracts (South) Division in 1873. Chittagong and Cox's bazaar Division started plantation in 1921, in Sylhet in 1922 and Chittangong Hill Tracts (North) in 1941. But against the competition with high growth and quick yielding species, teak plantation is declining very rapidly overtime in Bangladesh. The Forest Resource Management Project (FRMP) study reported that teak plantation in Cox's Bazar Division declined from 173 ha in 1980-84 to 74 ha in 1992-93 (Forest Inventory 1998).

Teak Productivity in Bangladesh

Information on teak productivity in Bangladesh is limited. Winter (1956) classified teak sites into three classes, SQ I, SQ II and SQ III. This classification was based on only a few plots. The systematic records of these plots were not available, his estimate of mean annual increment (MAI) and his assumption of thinning practices were not compared with field conditions. Kingston (1979) reviewed and examined age-height relationship and found the existence of six types of sites which has been described as site index (SI) 15, 20, 25, 30, 35 and 40 on the basis of average height of tree in meters at the age of 50 years and found the productivity of different age groups in different sites. In case of 40-year-rotation scenario, production in SI 15 SI 20 and SI 25 is likely to enhance by 38%, 29% and 36% respectively over the production of 60-year-rotation scenario (Rahman, 1982).

Keogh (1979) made a comparison by identifying five site qualities of teak for tropical American region based on top height of trees at 30 years. The study found that MAI in different sites of Bangladesh was substantially lower than that of the tropical countries. Against these circumstances, the teak plantation in Bangladesh does not seem to be feasible below SI 30 and other consideration that teak substantially damages site quality is also important. Under the condition of timber famine it is urgently needed to carry out economic analysis in growing teak especially of suitable rotation.

Rotation

Based on the assessment of economic and

silvicultural considerations, shortening the rotation to 25 years from 40 years may be considered as the optimum cycle to achieve a viable balance between financial returns and the production of market quality timber. During this rotation period, thinning operations will provide financial returns at intermediate stages easing the economic burden related to the long-term nature of the operation and making the investment financially attractive.

Teak plantation in Bangladesh was set 60 year rotation in all sites. The argument behind this is the greatest volume of production that requires longer rotation period when marginal volume growth rate is negative. This argument is not compatible with the economics of forestry. In forestry economics, there are considerations that need to be taken into account are growth rate of resources, regeneration cost, land expectation value, and appropriate discount rate.

The problems that are very crucial to take care are thinning schedules that leave the growing stock as to maximize the net flow of value productivity over time. The existing thinning schedule in Bangladesh is more or less similar to all sites and object of management that needs to be addressed urgently.

Various definitions have been introduced by the foresters in determining the optimum rotation. Davis and Johnson (1987) explained that rotation length is the interval between one-generation harvest and next generation harvest whether by planting or by natural regenerations and it's final felling. Other definition is the "right time to cut" establishes the length of rotation for a tree or a cohort of trees in stand of the same age (Near, 1990).

Rotation is an important tool for determining the economic profitability of forest plantation regeneration methods. Forester has identified different conditions for rotation. There is physical rotation that is determined by the site or other environmental factors, which may prevent a stand reaching maturity. Silvicultural rotation, which is commonly applied where natural regeneration process is followed and species set seed freely and relatively early. Technical rotation is planned to maximize the yield of specified size and type to meet a particular end use. Rotation of maximum value is the one that gives the greatest average annual out-turns of timber. In terms of wood yield, it reaches the full growth potential of a species on a site. Financial rotation is the one that refers to a period of time over which the plantation yields the highest financial return under a particular set of circumstances (Rosnani, 1998; Fenton, 1967).

Economics of Rotation

The determination of rotation is a very complex issue that differs by species, site and other ecological and environmental factors. The answer depends basically on the purpose of management in reality. Neher (1990) described several economic models to determine the optimal rotation length in forestry. The models are maximum sustained yield (MSY), the single crop (one cycle or plant-harvest model) and ongoing forest (sustained yield management or plant harvest model). Maximizing present value of timber production from silvicultural efforts and time is also of interest to the forest owner. In felling trees the number of trees or stand is selected, so that some trees or stands are cut each year in regular way and the yield or the forest is sustained. The objective of the forester is traditionally to select the rotation period in such a manner that sustained yield is maintained from regular forest. The MSY refers to the rotation period where marginal yield equals average yield. This means marginal product of time equal to average product of time. In forestry economics, marginal yield is known as current annual increment (CAI) and the average is called mean annual increment (MAI). Thus, the maximum sustained yield can also be written as MAI=CAI where the MAI is maximum. The other models of optimum rotation are founded on economic and financial consideration. Neher (1990) described two economic models of optimum rotation length as Fisher and Faustmann Models.

Fisher Model

The Fisher model is suitable for economic analysis of single crop where there is no opportunity cost for land. The objective of this model is to maximize the present stumpage value, Q(0), by determining an appropriate rotation age (T). This concept is presented in Fig. 1.

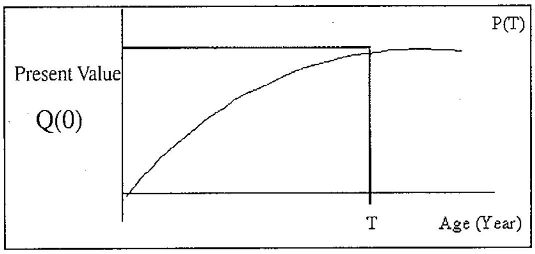

Figure 1. Optimal rotation length of a single crop

Interest rate plays a very important role in the estimation of desired optimal rotation period that has been explained by Neher (1990). Assuming a stand of tree with the same age group, and the land has got no alternative use in the industry or on the commerce and the existing trees going to be replaced with another rotation after the existing stand is felled (and got zero opportunity cost) in view of other alternatives uses. The economic horizon is taken to extend precisely to the date of contemplated harvest. According to Fisher Model, the present value of tree can be estimated as follows:

$$Q(0) = 1/(1+r)^{t} * Q(t)$$

The present value of tree begins with growth of tree Q(t), the value of net harvesting cost as its value at harvest time when the trees T years old and r is the annual compound rate of interest. It is more convenient to assume that interest rate paid and compounded continually, where t=T and t=o, when r indicates to discrete time intervals. The discount factor $(1+r)^{t}$, where r is interpreted as the "instantaneous rate of interest" comparable to e^{-rt} and r is annual rate of interest. Thus the formula can be rewritten as follows:

$Q(0) = e^{-rt}\ Q(T)$, where Q stands for stumpage value, P. Thus the equation can be formulated as follows:

$$Q(0) = e^{-rt}\ P(T)$$

The stumpage value, P is calculated using this formula as:
P = Logging price –Logging cost (variable)-Profit Margin
For single species through differentiation and manipulation the interest rate or opportunity cost is estimated as follows:

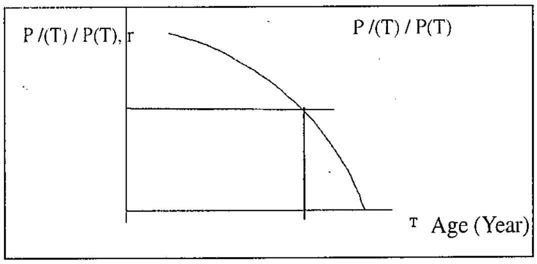

Figure 2. Optimal rotation length where marginal stumpage equals interest rate

$$P'(T) / P(T) = r$$

Where $P'(T)$ is the marginal stumpage, which states that timber should be harvested when the value of timber growth $[P'(T) / P(T)]$ equals interest rate or opportunity cost. This can be presented graphically as follows:

The Faustmann Model

This model is applied to an ongoing (sustained yield management) forest where the objective is to maximize land expectation value, i.e. Q(0), of a sequence of tree or stands associated with land. The concept of the model can be illustrated diagrammatically in Fig. 3.

The model can be written mathematically as follows:

$$\text{Max}_{T}\ Q(0) = P(T) * \frac{1}{e^{-rt} - 1}$$

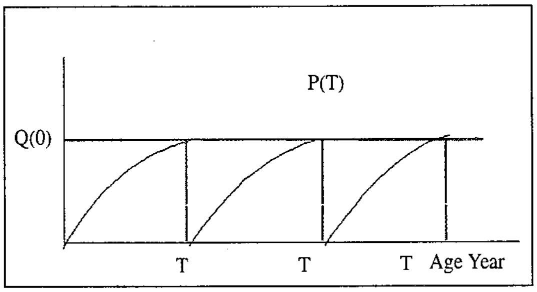

Figure 3. Optimal rotation for on growing crop

Where Q(0) = Land Expectation Value (LEV)
P(T) = Stumpage Value
r = Discount factor and
T = Age in years

Optimal Rotation Model Adopted in Malaysia

In order to determine the optimal rotation of teak both models of Fisher and Faustmann are used (Rosnani 1998). The models are described as follows;

i. $PNW = P(T)\, e^{-rt}$
ii. $LEV = P(T) * 1/ e^{-rt} - 1$

Where PNW = Present Net worth
LEV = Land Expectation Value
P(T) = Stumpage value at rotation age
e^{rt} = Discount factor for single rotation
$1/e^{rt} - 1$ = Discount factor for on going rotation
t = rotation age
r = interest rate.

The choice of optimal rotation for teak is determined based on the following conditions.

i Fisher Model $P^{/}$ (T) = r P T)
ii. Faustmann $P^{/}$ (T) = r [P (T) + LEV]

The study found that maximum physical yield for teak stand was attained at age 21 years, where mean annual increment (MAI) equals current annual increment (CAI). Applying Fisher model the Present Net Worth (PNW) of teak stumpage value, the optimal rotation of length is achieved when $P^{/}$ (T) = r* P (T), where at this point PNW is maximized.

In adopting Faustmann model, the optimal rotation length was achieved at age 19 years. At this age the maximum land expectation value (LEV) is achieved (RM 41,100 per hectare) where optimality condition marginal stumpage ($P^{/}$(T) equal marginal cost of timber growth (r[P(T)+LEV]) holds good.

MATERIALS AND METHODS

In order to carry out an economic analysis for teak rotation in Bangladesh, the following information is needed. The current study attempted to estimate by both Fisher and Faustmeann models

i. Yield of different age group, average yield MAI ($m^3\, ha^{-1}\, year^{-1}$), marginal yield-CAI ($m^3\, ha^{-1}\, year^{-1}$), which is obtained running logistic growth model, where stock data is obtained from Forest Department.
ii. In order to calculate Fisher model the information needed are growth of discount rate [e^(-rT)] stumpage value that requires price, cost and profit margin where from net present worth (Tk /ha), r* P(T) and marginal stumpage are estimated. The price is obtained from Forest Statistics, volume data from Forest Department and interest rate is assumed to be 10% close to bank rate.
iii. To estimate Faustmann model, land expectation value, marginal cost of timber growth (r* [P(T)+ LEV] is calaculated.

Optimal Rotation Model for Bangladesh

The logistic growth model was used to derive the predicted volume of timber production for teak plantation in Bangladesh, which is given as:

$$V = \frac{a}{(1+ (e^{-bt}))}$$

The figure 4 reveals the yield pattern of teak stand over 40-year's period. The maximum physical yield is attained at the age of 21 years, where mean annual increment (MAI) and current annual increment (CAI) are equal (Figure 5). From economic point of view, this is the age giving the highest yield, which is considered to be the right time to harvest the trees.

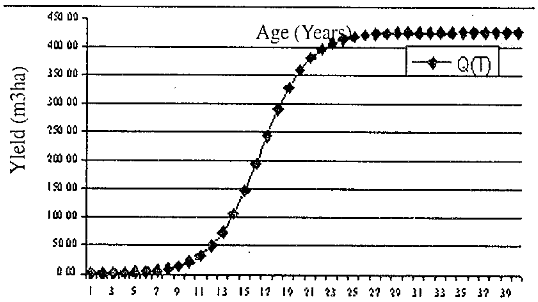

Figure 4. Estimated yield of teak stand

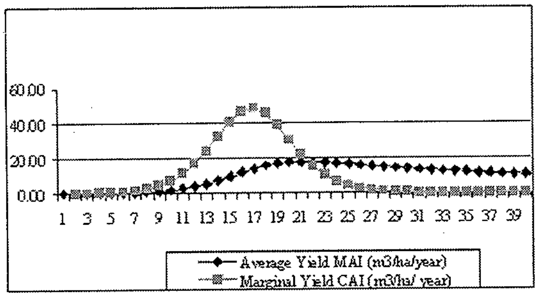

Figure 5. Mean annual increment (MAI) and Current annual increment (CAI) of teak stand

Fisher Model

Fisher and Faustmann models were applied to determine the optimal rotation of length. The interest used in the analysis is 10%. The price of teak is used from Forest Statistics of Bangladesh (2000) for the year 1997-98 (current price). The cost is assumed to be 35% of timber price, which is closer to price - cost proportion of Malaysian study. The calculation of present net worth (PNW) of teak stumpage are shown in the Figure 6, optimal rotation is achieved when $P^{/}(T) = r^{*} P(T)$, where PNW is the maximum as shown Figure 7.

Faustmann Model

The land expectation value (LEV) is estimated adopting Faustmann model. The optimal rotation is achieved at the age of 20 years. At this value the optimality condition is satisfied when marginal stumpage $[P^{/}(T)]$ equals marginal cost of their timber growth $(r^{*}[P(T) + LEV])$. The figure 8 revealed the land expectation value and figure 9 depicted the optimality condition of equality of marginal stumpage and marginal cost of timber growth.

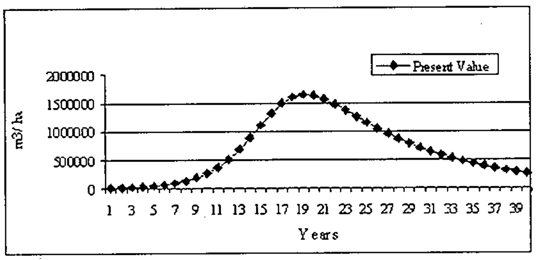

Figure 6. Present vet worth Vs age

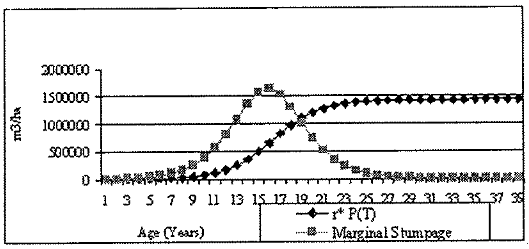

Figure 7. Marginal stumpage, tree rental value Vs age

From the above analysis, it appears that optimal rotation of the teak plantation should be between 20-21 years. Thus, question arises whether the rotation for 40 years or 60 years as practiced is optimal in economic sense. The above economic analysis clearly indicates that rotation of teak plantation can be reduced substantially that would encourage investors to have quick yield. However, decision to change the current optimal rotation length needs other considerations like uncertainty, interest rates and management practices.

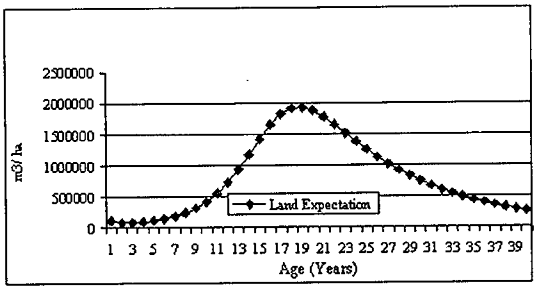

Figure 8. Land expectation value

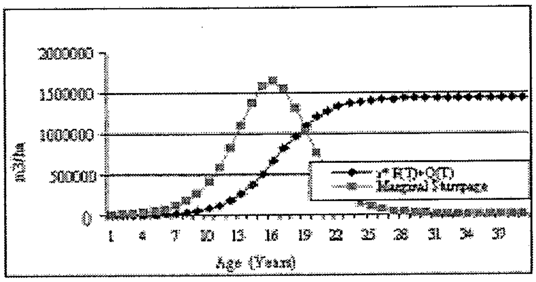

Figure 9. Marginal stumpage, tree rental value Vs age

The other important factors that need to be taken into consideration are the value of non-timber forest products, carbon sequestration, biodiversity and environmental regulations. These values must be included in the calculation of resource valuations..

RECOMMENDATIONS

There should be economic analysis before undertaking any investment in the forestry sector including teak plantation, in order to justify the economic viability of the project. There is an urgent need for generation of data for plantations, including management costs. There should be comparative study on competitiveness of species of both short rotation and long rotation timbers. By reviewing the comparative analysis, decision can be made to reduce the opportunity cost of holding land for timber production. "Time is money" should be borne in mind before undertaking any long investment programme of teak plantation.

There are many limitations like reliability of data and assumptions made for interest rate, management cost and use of current prices need to adjusted in the future studies in order to get better estimate for more realistic decision making process.

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Should Forest Encroachers be Evicted - A New Way of Looking at Sustainable Production of Teak Timber in Kerala State, India

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ABSTRACT

For any forest administrator, environmentalist or policy maker, the biggest threat to the forests of Kerala is encroachment. Since 1947, Kerala might have lost about 2000 km2 of forests by way of encroachment. Some of these encroachments have already been regularized and some are yet to be regularized. Some (about 73 km2 -mostly encroached after 1977) are earmarked for eviction. Whatever be the status of forest encroachments as far as regularization is concerned, freedom on tree growing in these lands is highly restricted. Whether forest encroachment is a problem or solution to a problem. The Government believes that the former is correct. On the other hand, this paper argues that the later is more correct. Similarly, whether eviction of encroachment is more sensible or management of encroached area is more sensible. Here also this paper argues that the latter is more correct. This paper looks at the ideological problems of the Forest Department in understanding this issue and solving it. Most of forest encroachment problems could be contained not by the present practices of restricting tree cultivation in the encroached forestland but by stipulating land-use patterns. Instead of discouraging tree farming on encroached land, tree farming alone need be permitted on such land. Such a measure will be a boon to the encroachers and it will ensure sustainable supply hardwood timber in the market. Among hardwoods, Kerala farmers are keen in growing teak in their homesteads. Given freedom to grow teak, farmers will grow it. This will relieve natural forests from the burden of growing timber for the market. To all concerned with forest protection and conservation, eviction of encroachments is the monolithic solution for forest encroachments. This paper suggests a new model to contain the forest encroachment problem, to increase production and productivity of teak in the State.

Keywords: Teak, forest encroachment, forest management, homesteads, productivity

INTRODUCTION

The fallacies of the existing policy on the so-called forestry, forest management and sustainable forest management are argued in this conceptual paper. The need for a new perspective on the age-old problem of forest encroachments in Kerala was underlined. Growing teak in forests alone will not be sufficient to meet the growing demands of the State of Kerala. Exactly 13 years back the Kerala Forest Research Institute came out with some startling revelations on the contribution of different sectors to the supply market of wood in Kerala. That study shattered the myth that Kerala Forest Department is the major contributor to the wood market in the State. The finding of the study was that the recorded production of wood from forests of Kerala is only 1.9% of the total wood supplies of the State (Krishnankutty, 1990). The same study also claimed that the homesteads of Kerala contribute 74.4 to 83.6% of the total wood supply. The study was an attempt to estimate the demand for wood by various sectors and supplies from different sources in Kerala during the year 1987-88. Much water has flown under the bridge after that. If that was the position 15 years back, now it is only reasonable to assume that the share of homestead in the supply side of the wood market of the state has increased especially after the strict enactments in Forest (conservation) Act 1980, National Forest Policy 1988 and various court judgments against commercial forestry. Finding of another study suggests that at least 50% of the timber requirements in the construction industry in Kerala is met through import from countries Southeast Asia, Africa and Latin America (Ouseph, 2002). The picture regarding contribution of forest and homesteads towards the wood market will be more clear when the results of a current study titled "Wood balance study in Kerala and training in market survey" will be published. This being the situation, what worries a researcher is the utter negligence of administrators and policy makers towards the above facts. Certainly, at the moment, there is a tilt favoring the Public Enterprise (Forest Department) against the private initiatives as far as forestry in the state is concerned. This is more so in the case of teak cultivation and harvesting. There are many lands outside forests where teak can be grown more efficiently than in the Public Enterprise, of course, with a little more support at the policy level. Non-Revertible Forest (NRF) Land is one such area. Major chunk of NRF land is either encroached forestland or forest assigned under various schemes to the public for the cultivation of agricultural crops but yet to be unreserved. As on today there are umpteen restrictions strictly prohibiting teak farming in these lands. The best option to ensure sustainable supply of good quality teak timber could be by encouraging teak farming in all such "restricted sites" and this could be used as a tool to combat the perpetual problem of forest encroachments in the State. If the real intend of the Forest Department is forest conservation, what is required is not restrictions on tree farming but incentives for growing trees outside forests. The objective of this paper thus is to highlight the possibility of increasing supply of good quality, teak timber through new policy options, which will also ensure a solution for the problem of eviction of forest encroachments wherever it is impossible.

Profile of Kerala

Kerala State is situated on the southwest tip of India. Its geographical area is 38855 km^2 of which about 57% is used for agricultural purposes and 28.8% is forest by legal status. The effective forest area in the state is about 24%, rest being used for various projects. Total extent of teak plantations (including teak mixed plantations) in the state is about 1071 km^2. As per conventional norms too many people and very little land is the root cause of all forestry problems of the State. The population of Kerala in 1951 was 13.55 million and this increased to 31.838 million in 2001(Government of India census 2001). During the same period the area under forest has been reduced from 35%-40% to 24% of the total geographical area. Naturally the heavy pressure of population had its negative impacts on forests too. The biggest onslaught on forests by population pressure was manifested through large-scale alienation of forestland for cultivation of food crop and through forest encroachments. Although, alienation of forest land by Government for cultivation purposes cannot be ruled out completely even now, (e.g.: recent Government decision to give land for landless tribals), the area of the land thus alienated has come down drastically. On the other hand the forest encroachment is a never-ending process going on unabatedly, even today, in many parts of the State especially Idukki District.

Forest under Encroachment

Forest encroachment in Kerala has a history of at least 60 years. During the 2nd World War when the food shortage was acute in the State, Government decided to assign temporarily, swamps inside forest for cultivation of food crops (GO No:11774/42, Devt. Dtd.24-11-42). This scheme is popularly known as Grow More Food Campaign and the area thus alienated is now known as Food Production Areas. These temporary assignments have become permanent, as Government never cared to resume it back. To aggravate the situation, farmers have encroached much more forest areas than actually assigned. Apart from this, "Government sponsored" encroachments, by individual farmers have resulted in forest encroachments all over the State. As per the latest statistics of the Department, the total forestland under encroachment in the State is about 43877 ha of which 36588 ha are of pre- 01-01-1977 encroachments and 7289 ha are of post – 01-01-1977 encroachments. Government has tentatively decided to regularize all pre-01-01-1977 encroachments and to summarily evict all post 01-01-1977 encroachments. It is assumed that the encroachments from 1940 onwards are to the tune of over than 2000 km^2.

Pattayam and its condition

Once the land is assigned to the cultivator, he will get a *Pattayam* (a sort of ownership certificate) from the Revenue Department. This *Pattayam* invariably will have some conditions attached to it. Most common conditions which are detrimental to tree cultivation in the assigned land are the following:

1.The full right over the forest trees stipulated to be accountable within the grant and specified in the schedule vests with the forest Department of the Government and the assignee is bound to take care of all such trees standing on the land at the time of assignment or that may come in to existence subsequent to it.

Schedule	Name of Trees
1.	Teak
2.	Black wood
3.	Ebony
4.	Sandalwood
5.	Other reserved trees if any (to be specified)

So long as the above condition is in vogue, no assignee will have liberty to cultivate teak or other trees in the assigned land. Constant threat of eviction from the forest department is another constraint for tree cultivation. Until and unless farmers are assured of return from his investment he will not grow trees. On the other hand there is no ban on using the land for growing agricultural crop. It is a fact that annual agricultural crop such as tapioca, ginger, pineapple and plantain are more damaging than tree crops from soil and water conservation point of you.

Don't Evict them if it is impossible but restrict the land-use pattern

Government as well as Forest Department has only one remedy for the encroachment problem and that is summery eviction. Eviction means destroying the crops and other improvements made by the farmer and forcefully send him out of the encroached forestland. The reclaimed land often is then rehabilitated by appropriate reforestation techniques by the Forest Department. If the intend of the Department is conservation of forest and grow more trees, why not they permit farmers to grow trees in the encroached land and in case the department evicts the farmer, why can't it give compensation for the trees the farmer raised. So, instead of assigning the land for agricultural crop the assignment should be for tree cultivation. Instead of restricting the pattern of land-use favoring cultivation of agricultural crops it should insist on a land-use, mimicking forestry, i.e. tree cultivation. Similarly the appropriate method of protecting the mountain environment of the State is by growing trees whether it is done by forest department or by private farmer. Tree farmers' cooperatives through Participatory Forest Management style can be thought of. Let there be trees on hills irrespective of the ownership of land.

Critical outlook

There is no doubt that above proposition will raise many eyebrows. The chief complaint could be that this sort of active sympathy towards the encroachers alone is the reason for further encroachments. Regularization of encroachment from 1950 onwards caused biggest damage to the forest wealth of Kerala. After all, encroachers are lawbreakers and they need to be dealt with stringent punishment. Destroying crop and evicting them is only a mild punishment, thus goes the arguments against the present proposal. Is farmer alone responsible for forest encroachment?

To answer this question one has to look at the *modus operandi* of forest encroachments. There are two types of encroachments. They include marginal encroachments and organised massive encroachments. In marginal encroachment the farmer who lives on the fringe of the forest, clears undergrowth from a small portion of forest land, a few cents every month, and cultivate seasonal annual crops. It may take a few months for the local forest staff to locate this nefarious activity and by the time he noticed the cultivation, the crop (tapioca, ginger, turmeric etc.) might have reached the harvesting stage. The encroachers would plead the local forest staff for granting a few weeks' time to harvest the crop before vacating the forest area (of course, they may have to bribe the forest staff for this concession). By the time the annual crop is harvested, the encroacher might have planted a few seedlings (or even mature trees) of coconut, areca nut etc in the encroached land (may be, again by bribing the local staff). In some cases the local staff may get a transfer to another Forest Range or Section on administrative grounds. The newcomer will not take any action to evict the encroachment, as he will have an alibi to escape from the charges that the encroachments took place not in his period but during his predecessors' period. The encroacher repeats the exercise during next month/ season also. By the time the above process comes to the notice of some officers (if at all somebody is concerned) at least five years might have been passed and a few hundred hectares might have been under the illegal possession of the encroachers. This is mostly at this juncture, the forest authority decides to evict the encroachment. It is quite natural that politician will interfere against any such eviction. Encroacher may get favorable court judgments (mostly by showing improper Survey Nos, etc.) also to maintain status quo. It is not rare that the encroacher lodges private complaints against the forest staff who evicts him which has to be fought by the forest staff alone (reference OR nos 26/03, 25/03, 23/03, 44/02, 36/02, 35/02 etc. of Walara forest station of Neriyamangalam forest range).

The second type of forest encroachment is a more organised and massive encroachment. In this type, a group of landless people generally under the leadership of some political parties encroached the forestland, put up sheds and start cultivation. Political leadership will take care of the future legal battle with Forest Department and law and order issues with the Forest and Police staff.

While forest staff express cold shoulder to encroachment, they are very active in arresting criminals involved in timber smuggling. Normally timber smuggling is done by habitual offenders. They fell trees in the night and transport to a nearby sawmill or furniture shop in the same night. There are many market intermediaries playing in between. As soon as theft of tree has been detected by the staff, and if that is a genuine theft (wherein no bribe money had been paid to the staff!) they will search for the smuggled timber in the sawmills/furniture making units, confiscate theft material, seize vehicle used for transportation of smuggled timber, and arrest culprits most possibly within a fortnight.

Now, the most dismaying question is this. If the forest staff can nab criminals who steal trees from forests immediately, what prevents them from evicting encroachers as soon as it happens? That too when the culprit involved in encroachment is living right amidst them. Only on this account one has to doubt that forest encroachment is happening due to some inherent institutional problem of the Department and not due to any external factor. What could be that inherent institutional problem?

Firstly, politicians and policy makers do have a soft corner towards the encroacher because 'he is a poor landless urchin'. Secondly, Forest Department in India has a colonial legacy. This legacy has made us to believe that the sole objective of this Department is to produce timber and to trade in timber depot. Any other forest produce other than timber is "minor" for the Department. Substituting "Non-Wood" or "Non-Timber" for "Minor" in Minor Forest Products (MFP) will not bring the required change in mindset. The above elucidation of encroachment vs. timber smuggling is a typical case in this line.

In colonial forestry (even current forestry as explained above), natural forest is meant for clear felling and conversion. Timbers of 5 or 6 species alone are useful and all others are fit for "minor forest produce". Land is a precious resource which has to be used in a most profitable/"economic" way for the cultivation of timber species. Forest other than plantations shall work as handmaid to agriculture. If forests cannot serve the purpose of timber production (of course of 'Royal' species like teak or rose wood) the area has to be better utilized for agriculture. In other words, in colonial forestry, encroachment and growing agriculture crop was a better land-use option than keeping it as natural forest. It is the right time for a change in our mind-set for looking at the encroachment problem and conservation strategy of the Department from a different angle.

Foresters further believe that trees ought to be grown only by the Forest Department and none else shall encroach into their self assumed monopoly of timber production. This attitude is further exemplified in all regularities on timber harvesting and transportation by the Forest Department.

CONCLUSION

Sustainable Forest Management will be meaningful only when it takes care of growing needs (not greed) of the society. Sustainability is an achievable goal only when it takes care of the teeming millions of poor living on the fringes and inside of forests.

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Teak Wood Farming: A Success Story from Karnataka State, India

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ABSTRACT

Teak is recently accepted by the farmer as a tree crop not only for its high quality of the timber but also for relatively quick returns on the investment. A success story from Karanatka state, India is presented based on a *3-month to 30-year plan* of teak farming with interim dividends. Based on the experience gained, a viable cultivation scheme is proposed for planting with the most suitable provenances or seed sources to match with the plaanting sites. For an acre (0.4 ha) of land, about 80 trees are to be planted along the boundary. Of the 80 planted trees, it is certain that after 30 years there is a return of Indian Rupees of 1.5 millions (15 lakhs) which is equivalent to US $ 34,000 with a permissible mortality rate of 30%. This handsome return is from almost nil investment without incurring any extra costs. A case example was presented based on a farmer who earned Rs 30 lakhs (US $ 67,000) from 89 trees with an average diameter of 120 cm in the age group 30-35 years in the year 1996.

Keywords: Teak, agroforestry, economic returns.

INTRODUCTION

Conventionally in Dakshina Kannada District of Karnataka, agriculture means nothing but growing annual crops like rice, vegetables and often commercial crops of areca nut, coconut, etc. However, we strongly feel that tree growing out side the forest in agricultural lands and homesteads is also a kind of farm practice to be adopted by the farmers not only for the cash income but also to meet the increasing rural timber demands. Teak is the most accepted tree crop for farming not only for its high quality timber but also for relatively quick returns to the farmer although there is an initial period of gestation.

When we started agriculture in 1973, we had a small land of 8 ha, As small land holder, it was not possible to make huge investments on agriculture. However, we were keen to develop the land by farming and the following scheme was developed as a model for small holders:

3-month to 30-year Plan of Tree Framing with Interim Dividends

The model provided:

- Returns in 3 months from vegetable cultivation
- Annual returns from banana cultivation
- 3-yearly return from areca nut, pepper, cardamom (spices)
- 5-yearly returns from Coconut, cashew cultivation
- 10-yearly returns from mango, sapota, jack and fruit trees
- 30-yearly returns from teak (green gold)

In 1973, there was no department which engaged in supplying teak seedlings/stumps. Yet, to develop and implement our 30-year-plan, we made frantic efforts to collect the teak seedlings from various places to grow in the marginal farm land. Those 30-year-old trees have now attained the diameter 105-120 cm.

Our teak cultivation scheme

It is imperative to fence our arecanut or coconut gardens either mechanically or with boundary plants. In doing so, teak can be planted at the intervals of 3m and during the initial period of 3 year-estabslihment, little irrigation with fertilizer treatment can boost the growth and in subsequent years, farmers will have no worry about their growth; for an acre (0.4 ha) of land, about 80 trees can be planted along the boundary. Of the 80 planted trees, it is certain that after 30 years there is a return of Indian Rupees of 1.5 millions (15 lakhs) equivalent of US $ 34,000 with a permissible mortality rate of 30%. This handsome return is from almost nil investment without incurring any additional costs. For instance, one of my farmer friends earned Rs 30 lakhs (3 millions) from 89 trees having a diameter range of 120 in the age group 30-35-years in the year 1996.

Choice of planting material

As we see, there are five distinct varieties of teak which are available for planting. The differences may be due to their seed origins/ provenances:

I. Local provenance (indigenous) : Seems to be a good variety which grows fast and straight

II. Another provenance being supplied by the Karnataka Forest Department: Tender leaves are reddish; leaves relatively small in size, Relatively slow growth of the trees

III. Another variety where ventral surface of the leaf is grayish, Growth is average; tender leaves are reddish yellow.

IV. Large –leaved tree. Leaves are relatively smooth. Average growth rate is recorded

V. Nilambur provenance (Malabar teak): This seems to be the superior variety. Leaves are large and rough with greenish colour. Faster growth rate. This seems to be an allied variety of local provenance established in the region. Trees grow straight with rounded stem.

Our *Bharathiya Kisan Sangh* encourages to grow Nilambur provenance for high quality timber and we do appreciate the efforts of the Kerala Forest Research Institute in supplying the quality stumps in large scale to the farmers of Dakshina Kannada District of Karnataka.

Our farm practices

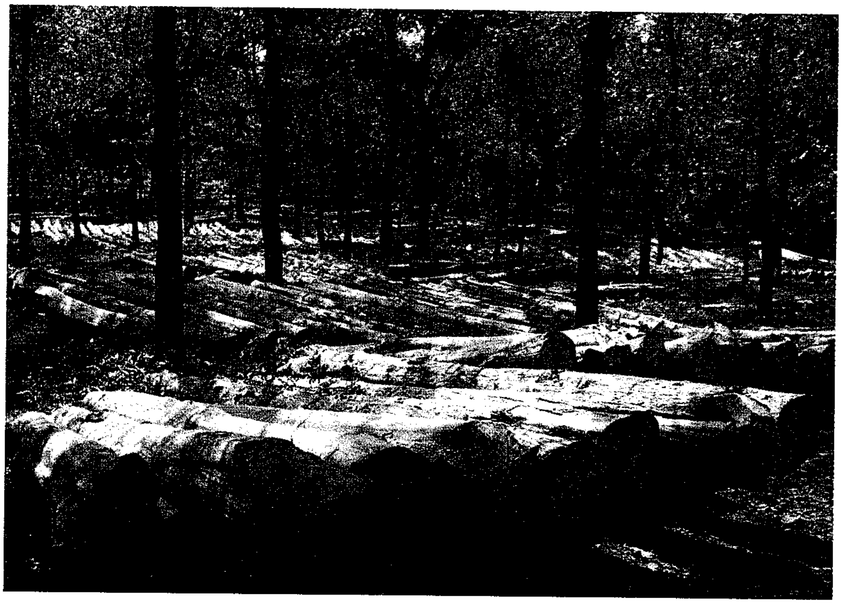
Our farm-*Mangala Farm* has now two 8-year-old plantations with 2000 and 4000 trees in two locations. Average height of the trees is about 30 ft (10 m) with a diameter of 45 cm; spacement is 2.5 m x 2 m . In each plantation, organic manuring is practiced by composting in 2 x 2 ft trenches. The trees grow well only if there is open canopy to receive good sun light and wind.

Land with sandy red or black soil seems to be desirable edaphic condition although fast growth is recorded in river beds. Lateritic or fine textured soil is not so favorable for teak growth.

When pure plantation is established, it needs adequate manuring like any other agricultural crop such as areca nut, coconut, etc. In the first year after planting, Treatment with cow dung mixture with leaf litter or with NPK of about 100 gm per plant favours establishment and the quantity needs to be increased year afer year for adequate nutrient management. In case, teak is planted in hilly slopes, water trenches may be necessary to retain desired moisture for growth. About 1 ft length trench for each plant in the slopes helps to retain moisture of from about 120 litres of rain water.

Secondary crops like pepper can also be grown in teak plantations for additional income as we succeeded.

Teak Timber Trade and Wood Industry



Quality Timber Products of Teak from Sustainable Forest Management pp 603-606

Teak Trade in India

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Abstract

Since 1982, when cutting of teak from native forests was restricted, Indian processing enterprises and traders have been depending on imported teak logs. Teak of natural forest origin is being imported from Myanmar, even though imports from this source have been dwindling. Currently, West African and Central American countries have been the major suppliers of plantation teak. Although the wood is not of superior quality, Indian markets are resilient to accept what is available. However, there has also been a shift from teak to other durable hardwoods. If quality of teak timber from sustainable sources does not improve, the market will shrink further to the detriment of teak trade in India as well as overseas. Plantation technology needs to be reviewed to get better quality of wood from teak plantations. Timber coming from thinning operations has flooded Indian markets and has adversely affected the prices.Despite various factors as above, India is still the biggest market for teak wood.

Keywords: Teak wood trade, wood quality, imported teak, India

BACKGROUND

India is one of the major natural teak (*Tectona grandis*) growing countries in the world. The other natural teak growing areas are restricted to Indo-Malayan Peninsula which includes Myanmar (Burma), Thailand and Laos. The adjoining countries like Cambodia and Vietnam had introduced teak in monoculture plantations where the quality seems to be different from what is obtained in India and naturally occurring areas of Indo-Malayan Peninsula. Commercial importance of teak had been recognized by the colonial powers over the last 2-3 centuries. who also introduced teak in areas of their possessions; Dutch introduced it in Indonesia long before while some believe it to have been introduced along with *Dalbergia latifolia* (Sonokling) by Hindus when colonised Indonesia. much earlier than Dutch. The quantities obtained in Indonesia were quite large but have no comparison with the quality of teak from original areas of India and neighbouring countries. French introduced teak in their colonies in West Africa i.e. Togo, Cameroon, Ivory Coast, Equatorial Africa while British introduced in Nigeria and Ghana in West Africa and Tanzania in East Africa. Large scale plantations were established in Central and South America particularly Trinidad and Tobago, as also in Honduras by the British, in Venezuela, Ecuador, Columbia, Panama, Mexico, Costa Rica and El Salvador by other European powers. All these plantations are now productive and India is the major buyer of teak harvested from plantations of those countries. List of countries supplying teak to India is exhaustive and I will refer to them in this paper at appropriate places as subject matter of my paper is teak trade in India. Thanks to the demand for teak in India that those countries are able to sell their products. Otherwise there is no commercially viable market for the first and second thinning harvests from those countries.

Trade trends in the past

The fossils of Kanhargaon Fossil Park in Chandrapur District of Maharashtra State revealed that teak existed in India in huge sizes even a million years ago. It has all along been a very popular timber for house building, boat building and other marine uses. Production of teak was estimated at over one million m^3 in 1982, since then, with a view to conserve our own forest reserves, which had dwindled to 9.2% from 23% at the time when we gained independence in1947. The conservation policy introduced by the then Prime Minister Smt. Indira Gandhi has yielded fruits and the latest estimated forest cover is above 20 per cent. With a view to meet the shortfall, our government put wood and wood products under "Open General License" and since then most of our requirements of teak were met from the imports. Felling ban imposed in our forests was originally planned for 10 years; extended to 21 years, but production from our forests has still not been resumed at earlier levels. Our government is thinking in those lines that so long as other countries are having surplus resources and are able to export, we should continue to buy from them allowing our forests to improve. Our environment is thus improving at a comparatively small cost.

With a hope that some day we will resume harvesting our own forest reserves, I would like younger generation to know the system followed earlier for the teak to come into the market for trading. The State Forest Departments had prepared working plans prescribing the minimum girth qualification for cutting tree and there used to be selective felling. Coupes were marked with trees to be felled and either they were auctioned for operation by private parties – forest contractors – who would fell, trim and dress the logs and bring them to the market for trading in the public. Some states had their own working operations and felling in the marked coupes was done departmentally and the teak logs were brought to forest depots where they would sell by auction to the public. In India majority of teak was coming from the states of Kerala, Karnataka, Maharashtra and Gujarat. Having been associated with teak trading in our family business from 1948 and having been an importer of teak from 1982, I can say that some of the finest teak wood for decorative and fancy plywood productions came from the forests of Chandrapur district of Maharashtra and Mandla division of Madhya Pradesh – from the forests located in the central part of India. For boat building the best teak was coming from Kerala and for thousand years teak for boat building was exported from the west coast of our country to Middle-East and European shipyards. For silvicultural reasons we will have to start harvesting our forests also. Sooner or later Indian market will start getting teak from our own forests also. At this moment supplies from those sources is only a trickle resulting from dead, dying, storm-fallen and from submersible areas around new dams coming up in our country. So let us take a look at the timber being imported for teak trading in India.

Import of teak started in 1982. The dollar-rupee ratio was around Rs.10 = 1 US $. and the landed cost of teak from Myanmar for 4' and above girth logs was around Rs.100 per cft landed at Indian Ports. Logs were coming from natural forests. During my 55 years of trading teak logs, I have noticed that teak coming from natural forests is superior in quality especially color, grain, texture as well as oil content. Teak from monoculture plantation is fast grown and the grain pattern and its texture are not so good. Teak from Myanmar used to come to the Indian market through European companies operating in Myanmar like Steel Brothers, Bombay-Burma Trading Company Ltd etc. Though the old generations were familiar with it, since 1953 import of timber was banned in India because of low *forex* reserves, therefore, those who came in the trade between 1953and1982 were not familiar with Burma teak. We started importing teak from Sawing Grade I to Sawing Grade IV logs from Burma and from those logs alone plywood companies were sorting out material suitable for fancy veneer production. These imports from Myanmar were therefore satisfying requirement of plywood industry as also for boat building industry, joinery, housing and furniture industry's requirements. As the rupee went on depreciating against dollar, the landed cost of imported timber kept on rising, moffusil areas were feeling the pinch of higher cost and the search started for cheaper alternates. It was at this stage that importers went to Indonesia, Vietnam, Cambodia and Thailand. Since Thailand had its own strict conservation policy it could not remain a supplier of teak to India for a long time. Indonesia did supply good quantities but because of dark color and some of them with reddish / violet colors lost favour with furniture and plywood manufacturers. Enterprising Indians continued to search other sources and in a span of 2 to 3 years West African sources of Nigeria, Ghana and Ivory Coast took over. There has been heavy exploitation of teak plantations in Nigeria and Ghana and their governments have now restricted export of teak logs. However, Sawn timber is permitted and Indian traders are importing rough sawn squares of teak from Nigeria and un-edged boles of teak from Ghana. The advantage in getting teak in this form is lower incidence of import duty. Logs and rough sawn squares attract import duty at 9.2% whereas square edged regular sawn timber would attract import duty @ 30%.

Ivory Coast, Benin and Togo still continue to export teak logs to India. However, since they come from poorly managed plantations, the quality is nowhere comparable neither to Indian origin nor to Myanmar teak. Teak growing along with its natural associates like *Dalbergia latifolia, Adina cordifolia, Terminalia tomentosa, Gmelina arboria*, Bamboo etc. has definitely much better quality of wood. It is compact, oily with waxy feeling to touch and closer grain with thin sapwood as well as thin bark. Because of the century-old use of teak in India in mofussil areas this lower quality is also accepted because of the price difference – almost 50% cheaper than Myanmar teak. Cities and provincial towns which are most quality-conscious as also who want to use mostly heartwood of teak and dislike the presence of sapwood, they have to use Myanmar teak but then price is a deterrent. If clear quality teak costs Rs.1600 for 1 cft, then sawn hardwood timbers like Merbau (*Intsia* spp.), Yellow Balau and Red Balau (*Shorea* spp.) from Malaysia and Indonesia cost one-third or even less. In certain areas hardwoods from West Africa i.e. Padauk (*Pteroocarpus* spp.), Bubinga (*Guiburtia* spp.), Kusia (*Nauclea* spp.) and such other durable hardwoods are taking over teak market.

PRESENT SCENARIO

Looking to the present situation I would like to draw the attention of teak experts in this seminar to seriously consider for introducing a couple of more friendly species. With teak giving it as close an environment as existing in the original natural forests to study whether such a change would improve quality of teak from plantations. I have also noticed during my visits to teak plantations around the world that flora and fauna existing in natural forests is very much missing in the plantations. Where are those birds, animals and insects? The whole bio-diversity is affected by going for pure teak plantations, hence my appeal to this august body to find a consensus about making some alteration in monoculture practices so that better quality of teak would be available to the traders and consumers from outside natural forests as well.

Teak is one of the most valuable timber tree species of the world, due to its flexibility of use on land as also in water; Its resistance to termites, fungi and other wood destroying agents is remarkable. This has made it very popular. Because of this popularity of teak and regular demand by the traders and consumers in India, there was a move to have lots of private plantations of teak. Unfortunately that did not prove a success . The yield and income projections given by the plantation companies were no where the realities. This has been observed in Indonesia, Malaysia, Philippines and some of smaller countries in the Pacific Region and many are now converting their teak plantations into oil palm plantations due to non-economical returns from teak plantations. In some of the countries I have seen teak plants being poisoned so that they die and do not deplete the soil of its nutrients. Then they offered such poisoned teak logs to me for marketing in India. This is indeed not a favourable development for teak production and trade.

Poles and Logs obtained by first and second thinning operations from Venezuela, Costa Rica, El Salvador, Panama, etc have flooded Indian markets. There were no buyers for these logs as they had hardly 10% heartwood with high proportion of sapwood and the plantation owners disposed them off at low prices. These logs are bought by saw mills from the importers. After conversion – including all the sap, they go for low cost housing doors, windows and internal joinery. They are happy that we are buyers and we are happy that there is a ready market for such material also in our vast country. Arrival of increased quantity of such material has kept the price curve for teak logs going downwards for last 5 years and this has further dampened the sprit of teak planters in India and possibly abroad.

List of countries supplying teak to India is quite exhaustive. Countries like Brazil going in for ever-increasing plantations and the countries which have already supplied first and second thinning material are now ready to give bigger sizes and better quality. For last 3 years from Myanmar, a lot of small girth material i.e. from 2′ to 2′ 11″ and 3′ to 3′ 11″ have been coming and finding ready market. Of course large size logs also continue to come from Myanmar but the volume is slowly decreasing. The expensive quality is being replaced in many parts of India by durable hardwoods from South East Asia as also West Africa and now some quantities of tropical hardwoods from Europe and USA as well. In a way it is better that part of teak market is being replaced by non-teak durable timbers as otherwise it will be difficult to meet the demand of Indian consumers for teak only. India is still the biggest market for teakwood. I see no problem for coming years to get the supplies. Let us help to keep them up.

Future Trends in the Availability of Teak Wood from Forest Plantations in Kerala State, India

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ABSTRACT

The history of forest plantations in Kerala dates back to 1842. Plantation forestry has been the prime sector in the forest economy of Kerala. The area under forest plantations in Kerala is 16 per cent of the total forest area of 11,124 km^2. Most of the long-term investments in timber production have concentrated on teak plantations, which form the major source of teakwood supply in Kerala. At present, the area under teak plantations is 75,883 ha, which constitutes about 42 per cent of the total area under forest plantations. Forecasts on future supply and demand for teakwood are essentially required for proper planning and decision making in the forestry sector of Kerala. In this paper, trends in area under teak plantation, age-class structure and production have been analysed and the results are presented. Future availability of teakwood from plantations up to the year 2050 have been projected under different scenarios, taking into account the factors such as species-mix, age structure, rotation age, productivity and planting rates. Based on the forecasted production, the potential role of teak plantations in meeting the future demand for teakwood and policy implications are also discussed.

Keywords: Teakwood availability, teak plantations, price projections, future wood production.

INTRODUCTION

Teak (*Tectona grandis*) is indigenous to India. The important teak bearing forests in Kerala occur in an appreciable proportion, as a natural component of the moist and dry deciduous forests of the Western Ghats. Kerala is the first state, which raised teak plantations in India. The long-term revenue and expenditure in plantation sectors of the forest department have been centered on teak plantations, which form the major source of teak wood supply in Kerala. The major objectives of this study are i) to analyze the trends in the extent of teak plantations and age structure of teak plantations and ii) to project the future trends in the availability of teak wood from forest plantations in Kerala up to the year 2050, based on the present age-structure of the teak plantations under different scenarios. Such efforts will help to plan the required activities ahead for addressing the future demand-surplus situation.

Database and methodology

The data for the study was taken from the database software developed by the first author (Sivaram, 2004). The database was developed referring a number of secondary sources such as Forest Administrative Reports and Forest Statistics Reports published by the Kerala Forest Department and Research Reports published by the Kerala Forest Research Institute and others. Some of the data were also collected through personal communications with the Divisional Forest Officers and other Officers of the Forest Department.

The future availability of teak wood from forest plantations in Kerala were determined under different scenario taking into account the age structure and variations in planting rate, rotation age and mean annual increment (MAI). The specific details of the projection and assumptions made are presented under the section specific to projection.

History of teak plantations

The history of teak plantations in Kerala has been discussed by Chundamannil (1993). The beginning for the establishment of teak plantations was first made at Nilambur, which dates back to 1842. It later grew to become the genesis of network of teak plantations in India. The great majority of teak plantations in Kerala have been established under the government plantation programmes. With the introduction of working plans from 1895 to 1905 and 1906 to 1915, teak plantations were brought under systematic management for the scientific working. The period after the Second World War was marked by a sincere effort in afforestation in areas ravaged by excessive felling during the war period. Teak was the most preferred species for raising plantations during this period. During the early 1960's liberal approach was considered advisable in selecting areas for raising teak plantations due to preference over even poor quality teak. Consequent to this teak plantations were raised extensively. Further, the initiation of planned development under Five Year Plans accelerated the plantation activity in Kerala. Plan funds were provided for the establishment of plantations. Even special teak plantation divisions were formed for intensive expansion and management of teak plantations. In the year 1922, 'taungya' system of raising teak plantation was introduced. However, it was discontinued in the early 1980's in view of its adverse effects on the soil and plant growth (Rao *et al.*, 1997). Mixed planting of teak with softwood species from 1970 onwards and bamboo as under planting in 1980's were other important management strategies adopted.

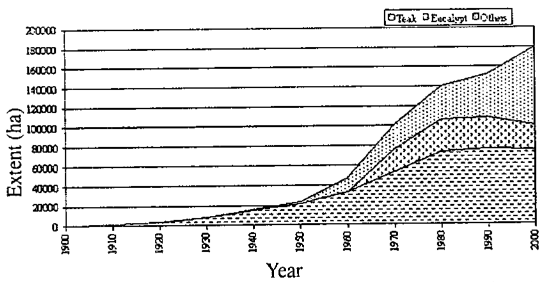

Figure 1. Decadal trend in extent of teak plantations (1900 to 2000)

Table 1. Extent of teak plantations in different forest divisions (1999-2000)

Forest Division	Extent of teak plantations (ha)	Total extent ofall the species (ha)
Territorial Divisions		
Thiruvananthapuram	585 (9.0)	6483
Thenmala	1544 (34.8)	4431
Punalur	1339 (22.0)	6096
Achenkovil	2203 (24.8)	8892
Ranni	3285 (49.8)	6598
Konni	7940 (82.2)	9660
Kottayam	2954 (43.0)	6864
Munnar	726 (6.4)	11297
Kothamangalam	4811 (78.6)	6120
Mankulam	-	442
Malayattoor	5590 (59.8)	9349
Vazhachal	3932 (53.9)	7292
Challakkudy	4578 (76.5)	5981
Thrissur	2119 (25.7)	8261
Perumbavoor	36 (58.1)	62
Nenmara	1140 (37.9)	3005
Palakkad	928 (33.1)	2803
Mannarkkad	1985 (38.1)	5213
Nilambur (South)	4788 (86.2)	5557
Nilambur (North)	4047 (44.5)	9087
Kozhikode	308 (13.9)	2213
Wayanad (South)	2476 (37.8)	6553
Wayanad (North)	518 (15.1)	3436
Kannur	1035 (10.1)	10273
Wildlife Divisions		
Agasthyavanam	42 (4.4)	950
Thiruvananthapuram	10 (1.0)	984
Shenthuruni	-	324
Idukki	293 (17.4)	1688
Eravikulam	-	35
Peerumedu	-	6847
Thekkady	-	248
Peechi	385 (23.7)	1625
Parambikulam	8569 (96.6)	8872
Wayanad	7427 (66.9)	11097
Aralam	292 (57.4)	509

Figures in parentheses indicate the percentage of area under teak plantations to the total area under plantations.

Trends in the area under teak plantations

The total area under forest plantations in Kerala was 16 per cent of the total forest area of 11,124 km^2.

Teak and eucalyptus have been the principal forest plantation species. Figure 1 presents the decadal changes in the area under plantations. It reveals that the total area under plantations of all the species was exponentially increasing. However, the area under teak plantations was exponentially increasing till 1980 and thereafter remained constant indicating no expansion. The annual trend in the area under plantations for the past 20 years (1980-2000) shows that the total area under plantations increased from 1,43,221 ha during 1980-81 to 1,79,169 ha during 1999-2000 by 25 per cent with an annual increase of 1.25 per cent. However, the area under teak remained more or less same.

During the year 1999-2000, teak being the major hard wood species, contributed as much as 42 per cent and eucalyptus, a major softwood species, contributed 14 per cent. The forest division-wise area under teak plantations is presented in Table 1. The total area under teak plantations under territorial divisions was 78 per cent. The remaining 22 per cent of the teak plantations was under the purview of the protected area management.

Age structure of teak plantations

The age structure of presently available plantations determines the future outturn of timber. The list of plantations as on year 2000 from all the forest divisions was classified according to age groups and presented in Figures 2 and 3 for territorial and wildlife divisions respectively. The teak plantations that come under the territorial divisions covered all the age groups ranging from 0-4 years to 59 years and above and nearly 60 per cent of them were found in the age group of 20-40 years. As far as teak plantations in the wildlife divisions were concerned, they were mostly found in the age group of above 15 years.

Productivity and volume estimates of teak

Stocking and site quality

The productivity of teak depends on the stocking and site quality of the plantations apart from the quality of planting materials, the extent of pest and disease problems. An assessment made by Jayaraman and

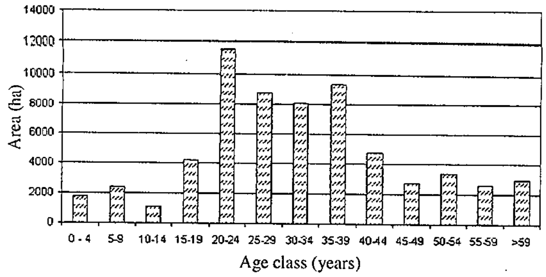

Figure 2. Age structure of teak plantations under territorial divisions, 2000

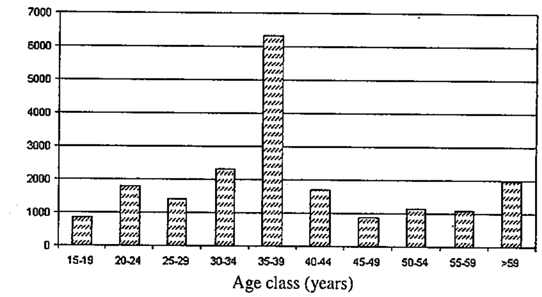

Figure 3. Age structure of teak plantations under wildlife divisions, 2000

Chacko (1997) showed that only 5 per cent of the area under teak belonged to site quality class I. 86 per cent of the area belonged to moderate site quality classes either II or III. In terms of stocking, the under stocked and overstocked plantations were 74 per cent based on basal area per ha and 81 per cent based on number of trees per ha.

Thinning and rotation age

Thinning is an important operation to reduce competition between trees for producing commercially sizeable timber. The prescribed thinning years are 4, 8, 12, 18, 28 and 40 years. However, in practice, there is a variation in thinning years followed. The average thinning years worked out by Jayaraman and Chacko (1997) based on the data obtained from the records of the forest department are 7, 10, 16, 24, 31 and 35 years.

Rotation age is the time between establishment of plantations and clear felling of the final crop. It is mostly determined by the maximum volume production and economic return. In the field, it varies across geographic boundaries due to factors such as latitude, altitude, climatic conditions, site-specific factors etc. The rotation age of plantation teak in its natural range has varied between 50 and 90 years, while outside the natural range the rotation age is between 40 and 60 years (Pandey and Brown, 2000). In general, teak plantations in Kerala are managed on a rotation age of 50 to 60 years.

Volume estimates

There is a paucity of data on actual yield at harvest of teak from different site quality classes. The general conclusion arrived from the available data is that the actual productivity has often been much lower than indicated in the yield table. Expected yield in India is 4 to 6 m^3 ha^{-1} yr^{-1} over the likely rotation length (Leech, 1998). MAIs obtained from government owned plantations ranged from 2 to 5 m^3 and are often below the potential yield of the site (Enters, 2000). The actual yield obtained from thinnings and final fellings in Konni forest was reported to be 2.5 at 70 years (Pandey and Brown, 2000). Estimates of MAI of teak at 60 years including yield from thinning for different forest divisions were worked out by Jayaraman and Chacko (1997) based on the data collected from standing crop. The MAI varied from 4.0 m^3 ha^{-1} in Kozhikode division to 2.2 m^3 ha^{-1} in Kothamangalam at 60 years. The State level MAI was 3.1 m^3 ha^{-1}. Chundamannil (1998) reported actual yield realized from teak plantations in Nilambur Division during the period 1967 to 1994 based on the data available in the files of the forest department. The MAI ranged from 0.97 to 5.64 m^3 ha^{-1} with the overall mean of 2.85 m^3 ha^{-1} at 53 years.

Projection of availability of teak wood

The future projection of supply and demand of forest products is essential for the planning and sustainable forest management. The future availability of timber depends on the age structure of the existing plantations, future planting and harvesting policies. Nonetheless, it is possible to project the availability of timber under certain assumptions. In this study, within the scope of the available data, an attempt has been made to project the availability of teak wood up to the year 2000 under different scenarios based on the age structure of the teak plantations.

Options and assumptions

In Kerala, the rotation age for teak generally ranges from 50 to 60 years due to varying growth attainment. Therefore, it was decided to make different projections according to three rotation periods 50, 55 and 60 years. With regard to yield figures used for projection, two options were available. The first option was utilizing the potential yield as per the All India Yield Table (FRI, 1970) and the other was the average yield as estimated by Jayaraman and Chacko (1997) based on the field measurements made on the standing trees in number of representative plots belonging to different age and site quality classes covering all the territorial divisions. The projection was attempted based on both the options. The potential yield in Kerala was considered to be the yield referred against site quality III (the lowest potential yield that may be assumed to Kerala conditions). This is because majority of the teak plantations in Kerala were of site quality II or site quality III (Jayaraman and Chacko, 1997). The

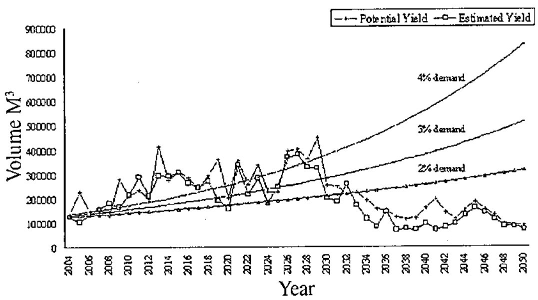

Figure 4. Future trends in the gap between demand and availability of teak wood from forest plantations (rotation: 50 years)

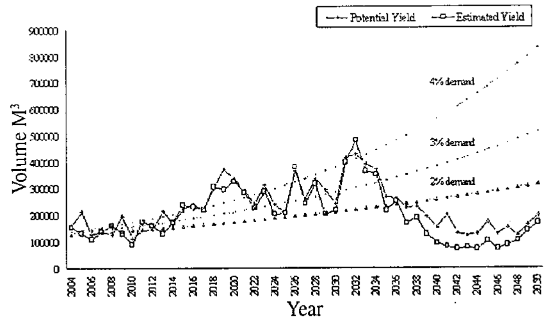

Figure 5. Future trends in the gap between demand and availability of teak wood from forest plantations (rotation: 55years)

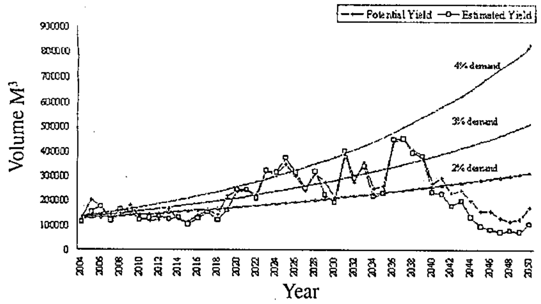

Figure 6. Future trends in the gap between demand and availability of teak wood from forest plantations (rotation: 60years)

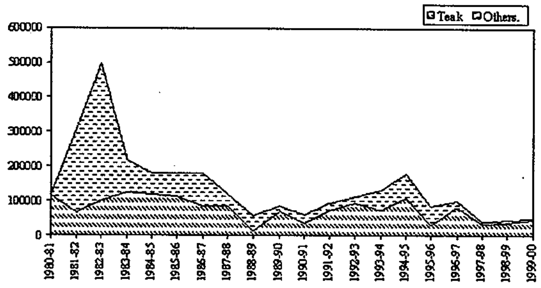

Figure 7. Trends in the production of teak wood (round wood equivalent*) and other species from the forests of Kerala. (1980 -2000)

thinning years considered for the projection of potential yield were 4, 8, 12, 18, 28 and 40 years. In the case of projection of estimated yield, the thinning years of 7, 10, 16, 24, 31 and 35 years were considered according to average thinning years worked out by Jayaraman and Chacko (1997) based on the records of the Kerala Forest Department.

One of the important assumptions made in the projection is that plantations that are felled will be replanted in the subsequent year. It was also assumed that the addition of new teak plantations during the projection period would be negligible. This assumption seemed plausible because there was no land available for extending teak plantations as indicated earlier.

Projection and related discussions

For the projection purpose, only teak plantations that come under the territorial divisions were considered. The teak plantations belonging to wildlife divisions were not considered for projection because there were no routine managements practices such as thinning, felling adopted in those plantations. A general trend found in all the possible projections shown in Figures 4 to 6 reveal that the period around 2020 to 2040 will have higher availability of teak wood.

The total demand for teak wood in Kerala during 1987-88 and 2001-2002 was estimated by Krishnankutty (1997 and 2004) through statewide survey. The total teak wood demand was 64,000 m^3 in 1987-88 and 1,18,000 m^3 in 2001-2002 showing the annual compound growth rate of nearly 4.5 per cent over the period. The future trends in the demand for teak wood was projected by considering differential annual growth rate with the demand estimated in 2002 as base (Fig. 4 to 6). The different annual growth rates considered were 2 per cent, 3 per cent and 4 per cent respectively.

When the projected demand are compared with the projected figures of availability of teak wood it appears that the extent of teak plantations in Kerala at the existing level are potential enough to meet the future demand at least up to the year 2030 even at the maximum assumed annual growth rate of 4 per cent demand. However, the past trends in the annual production of teak wood from forest plantations have been small (Fig. 7) and far less when compared to the projected demand scenario. For example, the production of teak wood from forests during the last few years was only about one fourth of the demand. Therefore, activities in promoting teak outside the forests such as home gardens, farmlands should be continued. This would fill-up the gap between future demand and supply from forest plantations.

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*The conversion factors adopted for obtaining round wood equivalent are i) 0.85 m^3 sawn wood = 1 m^3 round wood (for teak); 0.75 m^3 sawn wood = 1 m^3 round wood (for species other than teak), ii) 14.1 Nos. of medium sized poles = 1 m^3 round wood (for all species).

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Processing Technology for Value-Added Products of Teak from Small and Medium Sized Entrepreneurs (SMEs) of Developing Countries

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ABSTRACT

One of the major problems faced by wood sector entrepreneurs is drying the timber prior to the manufacture of various items. Among the small and medium entrepreneurs, a majority lack the capital for establishing drying facilities. Therefore, whether developed or developing countries, there is real problem in getting properly dried material. For large wood industries, by stocking raw material as logs, which they can afford, air-dried material is available for working. In the case of small and medium woodworkers this is not possible and also the establishment of a heat - and - vent drying kiln is only a pipedream and the traditional self-made kilns are not fuel-efficient. Air-drying the raw material, practiced by some of the medium-sized units is also not very effective due to the way in which they design air-drying stacks. Educating them is also not always practical. In order to get quality products from teak or any other timber, the workforce should understand the different aspects of drying and methods to measure moisture content of wood, temperature, humidity, etc. for which, either providing 'simple to read' printed materials or organizing small workshops may be proper. In 1996, the Timber and Forestry Department of Enterprises, Ireland made such an initiative, which is successful. The European Commission also conducted 8 similar concerns in different countries. Establishment of co-operative kilns is also another possibility. Forced air dryer, solar kiln or even heat and vent kilns can be made, whereas the dehumidifier kilns are too expensive and uncompetitive. However, it is important that the woodworkers need to be educated on the importance of timber drying for the manufacture of wood products of superior quality.

Keywords: Timber drying, drying kilns, air drying, woodworking

INTRODUCTION

Probably the most problematical and least understood aspect that almost every Wood Sector Entrepreneur (be they small, medium or large) faces seemingly almost on an on going basis is that of being able to adequately dry his raw material prior to manufacture. It would therefore, in my opinion, be reasonable to assume that about 95% of timber problems are moisture content related. For many, be they workers in teak, or any other species of wood for that matter, the drying of wood has for years been surrounded with a considerable degree of "muck and magic". Indeed some exponents of the art have attempted to project themselves as philosophers that have an "understanding", that is way in advance of normal folk. Others have attempted to demonstrate that they have mystical powers and that those skills verge on "wizardry".

So as not to become entrapped within this perception of sorcery, others have paid a heavy price and escaped having to learn anything about the subject and now rely on a highly sophisticated computerised box of tricks to do the work for them. *WHAT A LOAD OF NONSENSE THAT IS.* Timber Drying is nothing more than 1st Form physics and a little bit of common sense. For our small to medium sized entrepreneurs it is a very real problem because generally the majority do not have the necessary capital at their disposal to invest in even the smallest of forced dryers and if they do, they are more often than not, totally at the mercy of a Salesman to guide them as to the equipment they should or should not buy. The Salesman has probably never dried a stick of wood in his life before, and in my experience, often compounds the problem by adding his own half-baked theories as to how wood should be dried and as so often I find, we then have a total disaster on our hands.

As I travel around the world visiting woodworking establishments, I cannot help but to be amazed at the pathetic lack of knowledge that there is within the industry generally about drying. I am not just restricting that criticism towards "wood users in developing countries", or even to the wood users in "recently developed countries", but the "world over". Obtaining stocks of properly dried material is for many, a real problem. Moreover under standing and being able to specify a suitable moisture content, for a particular application, is another very real problem for a huge number of people in the wood industry and until that situation changes little headway will be made.

The industry's solution to the problem

The larger operators can generally afford to lay down significant stocks of raw material, which with advantage, can be air-dried prior to drying in a more traditional type of timber drying kiln, but even the larger operators get it seriously wrong from time to time. For the small and medium sized enterprises, a traditional "heat-and-vent drying kiln" is probably nothing more than a pipedream, albeit that for perhaps a few of the largest of the medium sized operators, a 20 m^3 self-build traditional heat and vent kiln running on waste fuel has at last become a reality through some of the European Aid Agencies.

For the small and medium sized enterprises therefore the prospects are fairly bleak. A number have invested in either small dehumidifier units or solar dryers, which they have then attempted to install either within an existing building, or within a purpose home made structure, without really understanding the way in which they should be going about it. The exact configuration of the chamber was probably based upon either a simple sketch or drawing, left with the entrepreneur by the Salesman who sold them the dehumidifier unit, or a few circulation fans.

At the point of sale, the entrepreneur probably thought that he would only ever want a kiln of a certain capacity, or for a given length or width. From this information the Salesman probably then calculated the size of the dehumidifier unit and / or, the number of fans required. The Salesman, who will, more often than not, leave with the order, and then prices the project.

The first set of problems then start to rear their ugly heads, because between "the point of sale" and "the point of the delivery" of the equipment, the goal posts will have almost certainly shifted. In my experience the kiln will have miraculously grown in size. Initially our entrepreneur may have ordered a dehumidifier or circulation fans sized for example, a 3 m^3 capacity chamber, but without realising the significance, the entrepreneur then re-designs his chamber with a capacity of 5 m^3; and that's leaving aside all the other pitfalls that he can fall into when building a timber drying kiln. When the time comes to actually running the kiln, the goal posts will probably have shifted yet again, and instead of filling his kiln with 5 m^3 of wood, he now only has 2½, or, if he is lucky, 3 m^3 of wood to dry, such that he now has massive voids in the kiln. The result is that the wood within the kiln never dries properly and the electrical cost of running the kiln has nearly broken the bank, especially if it happens to be a dehumidifier type chamber. If it's a solar dryer the degradation caused to the more exposed boards, especially the ends will be massive.

The number of small and medium sized operators that I have met over the past 30 years that can relate to this scenario is more than significant.

For the remainder who have relied simply on air-drying their raw material the principles of air-drying seem to have long been forgotten. Seldom can there be found (and I hasten to add not even in some of the Wood Use Training Centres I have visited around the world,) where air-drying stacks have been correctly configured, such as elevating them above ground level and a suitable roof covering to protect the upper layers from the rigours of the sun, the wind and the rain.

In my opinion the cause of the problem is education or rather a lack of it. I accept that many entrepreneurs, especially the small and medium sized ones do not have the time or the inclination to attend workshops or seminars on drying, because they are often fighting to survive. The financial cost of a workshop or seminar is a further burden and more often than not the stock excuse is that "Training and Education is too expensive". In my opinion if you think that "education is expensive then please try ignorance".

We cannot hope to even begin thinking about "Quality Products" from Teak or for that matter any other species of wood, unless our entrepreneurs and their respective workforce start beginning to understand at least some of the basics. For example:

1. What happens to a piece of wood when it dries. In other words tangential and radial shrinkage.
2. That wood is a hygroscopic material that can both absorb and lose moisture and thereby shrink or swell according to the atmospheric conditions in which it is placed.
3. How to measure both temperature and humidity and then to relate that to wood.
4. How to measure the moisture content of wood.
5. To have an appreciation of casehardening – how to test for it and if necessary how to correct for it.

In my opinion we need to start with a series of "simple to read" and suitably illustrated, effective technology guides. For those who would be willing to attend a workshop or short course, this should be provided, but it is vital that the workshop is tailored to suit the academic ability of those attending the workshop. Organisers and Facilitators of this type of workshop must not be guilty of spreading even more "muck and magic".

Practical solutions

In 1996, the Timber and Forestry Department of Enterprise Ireland took such an initiative, having identified a huge need within the Republic of Ireland and developed a one-week training course for those involved in the day-to-day operation of a timber-drying kiln. I was invited to join a four-man team whose brief it was to put such a Course together. The first course was held in Dublin in January 1997 and it was heralded as a major break-through for the Industry.

And having sat through the Course and without wishing to sound like Martin Luther-King - "I had a dream", because this course (and not just because I was one of the team that had put the Course together) was in my opinion, far too good for Ireland to keep to itself. With the agreement of my three colleagues and Enterprise Ireland, I took the course by the scruff of the neck and re-wrote it, such that it could be run in any region of the world, on the basis that it is cheaper to transport two lecturers and all the course material to a region than to transport up to 15 people to Ireland. Furthermore it was pointless talking to a group of people from, shall we say, West Africa about the drying characteristics of European Beech or Ash, because they would not have a clue what these species even looked like, let alone have an appreciation as to how they might dry in a kiln. Fortunately in the case of teak that problem does not exist because in my experience it is a species that is thankfully almost universally known.

At the conclusion of each course each attendee is required to sit for an examination with a Certificate of Competency awarded to each successful candidate. The Certificate of Competency is issued by The National Standards Authority of Ireland and is therefore internationally recognised and to date the Register of Certified Kiln Operators numbers around one hundred.

The European Commission (through their ACP-EU Agency, C.D.E. working within the framework of the Cotanou Agreement) immediately spotted the advantages of such a course and to date a total of 8 courses have been arranged. Courses have been held both in the West Indies and Central America, West Africa and in two of the Pacific Rim countries. To the best of my knowledge and belief it is the only Timber Drying Training Course of its kind in the world, utilising the very latest teaching aids. Each attendee receives a 120 page comprehensive Course Manual.

Having acted as the Course Facilitator on each of the 8 Courses that have been arranged to date under the sponsorship of the E.U. I am pleased to report that the impact that these Courses have had, has been incredible. Moreover the same ACP-EU Agency published a simple but nevertheless straightforward guide to wood drying.

The objective of the guide was to provide a simple and straightforward introduction to wood drying and hopefully to contribute to demystifying the process. The book illustrates how to accurately determine the moisture content of wood as well as how to specify the moisture content corresponding to particular climatic conditions, enabling producers to prepare their products for markets where the climatic conditions may be significantly different. The publication (just 40 pages) is not intended to be a comprehensive guide to wood drying, but an introduction and overview of the subject; it can nevertheless be used as a practical tool by anyone involved in the wood industry.

In my opinion we need to begin by teaching our entrepreneurs how to air-dry effectively and I am sure many of you will know air-drying, if conducted correctly can achieve some pretty remarkable results especially with such species as teak. Stacks must be elevated at least 500 mm above ground level. Stacks should also be placed on well-drained land, which of course should be kept clear of weeds and other insect harbouring vegetation. The stacks themselves should also be constructed correctly using stickers of exactly the same thickness. It is pointless in my opinion trying to produce a quality product if stickers or separators are being used that have been sawn from any old off-cut, or worm infested material. Stickers or bearers must also be positioned in such a way that the weight is transmitted to the ground without causing any form of distortion to the stacked lumber. Finally the stack must be covered, not with scrap cover boards, or leaves cut from palm oil trees or any other form of foliage, but using either corrugated metal or some such similar roofing material.

Some years ago I became involved with a couple of very good friends of mine in conducting a useful little piece of research into the effects of fitting a clip-on roof to an air-drying stack and comparing them with an identical stack without a roof. We were not trying to protect the lumber being air-dried from the rigours of the sun, but the rain. The trial was conducted in probably the wettest part of the British Isles you could find, because we wanted to empirically prove to the industry that it was perfectly possible to air-dry down to quite low levels of moisture content in areas of quite heavy rainfall provided the stack was suitably covered.

The trial demonstrated that having laid down two identical stacks for air-drying on the same day, at the same location and at the wettest time of the year, which in this particular case was the month of January. One stack had a roof and the other did not. The stack with a roof started to dry immediately and reached 15% moisture content within 150 days. The stack without a roof, never really achieved a moisture content of 15% even after some 280 days. The stack did however manage 18% on a couple of occasions but then only after 5 days of persistent sunshine. I have subsequently proved exactly the same thing in tropical countries. Indeed only last year I carried out some trials with a client in Guyana, South America drying Greenheart and for those who are familiar with this species it can be best described as "naturally manufactured concrete". On a light well drained sandy soil, we were air-drying 25 mm thick sawn Greenheart from "fresh off saw" to 16% moisture content in between 3 and 4 weeks. 16% moisture content was the equilibrium moisture content for the region and is based upon an average over a 24-hour period. In this particular case the material was going to be used for external decking within the Caribbean and therefore further kiln drying was deemed unnecessary.

Considerable success has also been achieved with *Forced Air-Dryers*. These units are not quite as sophisticated as perhaps even a simple solar dryer. They are very simple to construct and well within the ability of most small to medium sized enterprises, but to enable them to do so they need some very simple construction drawings and instructions that they can follow. The results of this *Forced Air Dryer* were quite remarkable. As with the air drying trial, with and without a roof, they were conducted in a region of the British Isles where the annual rainfall was higher than anywhere, so that we then had the worst case scenario in terms of the level of humidity and in consequence the rate of drying.

For convenience and to keep the cost of these trials to a minimum 50 mm thick native grown Sitka spruce was used. Both the air-drying and the forced air-dryer were commenced at the same time. Without going into the fine details of the trial, especially as they are available to be read, the basic results were as follows:

- The average starting moisture content was 93.7% with a maximum of 196%.
- After 35 days, the forced air-dryer had reached an average moisture content of 15.8% with a maximum moisture content of the highest sample being 16.9%.
- On the same day the maximum moisture content of the air-drying stack, which incidentally did have a roof over had reached an average moisture content of 22.0% with a maximum moisture content of the highest sample being 25.8%.

It was therefore concluded that a simple forced air-dryer can and does have a role to play especially for the very small entrepreneurs, because it would be perfectly possible to scale down a unit holding less than 0.5 m^3. Quite frankly to consider very much smaller than 0.5 m^3 would, I suggest, be almost impractical.

CONCLUSIONS

I sincerely hope that from the foregoing it will be seen that the prospects for the small to medium entrepreneurs are perhaps not quite as bleak as they at first appeared. I accept that the high capital cost of perhaps a full scale waste heat "heat and vent" type dryer may well be beyond all but the larger of the medium sized operations except where the dryer has been run as a co-operative.

However, before I leave the subject of "a cooperative kiln", I would like to leave you with just one thought. The majority of those attending this Conference would appear to be from Forestry Research Institutes around the world With ever increasing demands being made upon Research Institute's budgets, here might be the perfect opportunity for you to perhaps create some income generation and at the same time provide assistance to the small to medium sized enterprises and at the same time be totally transparent.

I have seen it work twice and extremely successfully. Locally to one Wood Industry Training College, were approximately six or eight small furniture and manufacturers of craft. Not one of these small entrepreneurs could financially justify the capital cost of installing a timber-drying kiln powered by waste fuel. The Wood Industry Training College needed a kiln to continue its programme of providing dry wood to its furniture and joinery school, but it could not maintain on a continuous basis even the smallest of the commercially available chambers. The Principal of the College took the imitative and invited the six or eight local entrepreneurs to send him their wood and he would dry it for a commercial rate. The result was the local entrepreneurs had correctly dried wood at a reasonable cost. The College maintained their kiln in full production and at the same time were able to dispose of the waste (sawdust and chips) produced by their own school workshops and finally the income generated from drying for the local entrepreneurs made a very significant contribution towards the costs of providing dry wood to their school.

However, there is quite a lot that can be done to enable the small to medium sized enterprises to produce a quality product, but if long before that goal is achieved there has to be an understanding of the consequences of not drying correctly that will in turn ultimately lead to a willingness to do something about it and to invest in some form of drying equipment, albeit a Forced Air Dryer, a Solar Kiln or even a co-operative traditional Heat and Vent Kiln.

Some may question why have I left out Dehumidifier Kilns. I have left them out quite deliberately because their power usage (in the form of a compressor) is too expensive in terms of energy and I believe that if we encourage their use we will be putting our entrepreneurs at risk of being uncompetitive.

Moreover, more and more countries are introducing Plant Health Regulations whereby unless a shipper can satisfy an importer that his timber products have been "heat treated" or "pasteurised" those timber products will simply not be allowed into that country. I fully appreciate that air-dried wood, or wood that has been placed in a Forced Air-Dryer is probably in the same situation as a dehumidifier in that it may not necessarily be able to reach the required level of "pasteurisation". A Solar Kiln may also fall into the same category such that the only alternative left will be to use a traditional Heat and Vent type dryer. I have heard a number of countries insisting on 55° C for a period of 30 minutes whereas others require a temperature of 60° C instantaneously. But initially the most important aspect I believe to start with is education and as I said earlier if you think that's too expensive, just try ignorance.

Quality Timber Products of Teak from Sustainable Forest Management pp 619-621

Development of Teak Plantation Industry in North Queensland, Australia

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ABSTRACT

The establishment of commercial scale teak plantations in North Queensland, Australia, signifies the commencement of a new plantation industry in the country. Excellent establishment success and fast early growth provide the indication that plantations teak has strong potential for commercial success in Australia. Government silvicultural research on teak has occurred irregularly over several decades.

Keywords: Teak, plantation development, North Queensland, Australia

INTRODUCTION

Commercial scale teak plantation development commenced in Australia only recently in 2000 although teak silvicultural research has been conducted irregularly for at least 40 years (Cameron, 1985).Young teak plantations in north Queensland seems to have high productivity. This is based on the principles of high input plantation forestry. This includes the use of high quality, well drained agricultural soils, tissue culture production with high quality germplasm sourced from South East Asia breeding programs, intensive site preparation, weed control and plantation nutrition. This paper provides a brief overview of teak plantation development as a new and exciting industry in north Queensland, Australia.

Impetus for teak plantation development

Teak plantation development makes both commercial and environmental sense. However, it is surprising that teak plantations have not been established in Australia in the past. There are a number of reasons for lack of interest in past development.

Historically, there has been a relatively plentiful supply of high value hardwood timber available from native rainforests of north Queensland when logging in these rainforests was permitted. As a result, there was little impetus in growing hardwood rainforest species in plantations. In northern Australia, government plantation programme has primarily focused on exotic and native softwood species, such as Hoop pine (*Araucaria cunninghamii*), Kauri pine (*Agathis robusta*) and Slash pine (*Pinus* spp.). However, the increasing prices of tropical hardwoods have now lead to a renewed approach to establishing hardwood plantations.

Secondly, the past few years have witnessed a dramatic increase in the level of private forestry investment and plantation development in Australia. This has generated considerable awareness of the benefits of sound and well managed plantation development.

Thirdly, over the last decade a greater emphasis has been placed on teak research and research into establishing plantations on cleared agricultural land in northern Australia. This research has assisted in refining the silvicultural requirements for teak. In particular, research conducted by the Federal government funded the Community Rainforest Reforestation Programme, the Queensland

Department of Primary Industries, the Queensland Department of Natural Resources and the Western Australian Department of Conservation and Land Management.

Past research on teak in Australia

Research on teak plantation development in Australia was mainly due to the work of Kennan et al (1997) and Brennan and Radomiljac (1998). Two local seed sources of teak of unknown original provenance were tested in an exotic and native species performance experiment situated about 50 km north of Tully, north Queensland. Despite hot dry conditions, following establishment survival rates of teak at 2.3 years of age ranged from 94.1 and 100%. At 9.5 years of age, average tree height was 17 m with DBH of 20.3 cm. Kennan et al. (1997) state that the superior overall performance of teak suggests its good potential for timber production in the region.

The wood properties of a single irrigated plantation of 22-year-old teak trees were assessed by Brennan and Radomiljac (1998). A teak tree was harvested from a plantation located near Kununurra, north west Australia to study basic wood properties as well as recoveries. Green sawn recoveries (using a thin kerf 'Wood-mizer' bandsaw, and the boards dried to 7% moisture content in solar kilns) were 56.5%. Mean density was 610 kg m^{-3} and a mean air-density was 700 kg^{-1} m^{-3} . Teak colour was golden brown with dark markings. The wood exhibited good gluing, working and staining properties, indicating its potential for value adding.

Teak plantation development programme

Location

Rewards Management's teak plantation programme is centered around the Tully agricultural region, which is located on the central coastal lowlands of north Queensland (longitude: 145° and latitude: 18°S). The coastal lowlands of the wet tropics in north eastern Australia comprises a relatively narrow strip of land (latitude between 16°S and 19°S). Altitude ranges from sea level to about 80 m. m. s. l. The region has a tropical maritime climate. The region has good access to both road and rail infrastructure, which run north and south. Major port facilities are located 197 km south at Townsville (Figure 1).

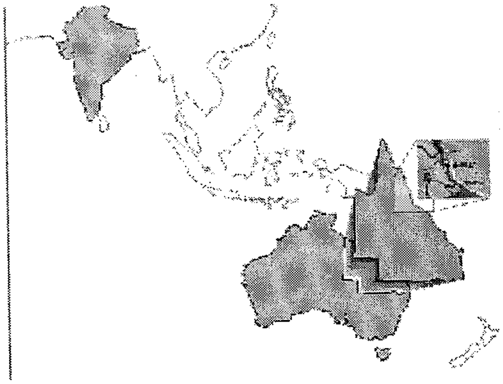

Figure 1. Map of North Queensland

Land use history

Australian teak plantations are established on cleared freehold agricultural properties. Land use history of agricultural farms in this region has been cattle grazing, sugar cane and banana production. Properties have been cleared for at least 50 years. In most cases farms have been extensively cleared and developed for these farming purposes. Prior to land clearing the original vegetation was a complex mesophyll vine forest, dominate commercial genera consisting of *Cardwellia, Castanospermun* and *Flindersia.*

Soil types

Well drained soils form on alluvium are extensively found through out the Tully region. The plantation's soils are classified as Coom Tully Type. These soils consist of dark greyish brown silty clay loam to light clay surface soil overlying light brownish grey medium to medium heavy clay sub-soil. The soil generally has yellow or brown mottles at depth. Soil pH is mildly acidic and ranges between 5.2 and 6.2 (Cannon *et al.*, 1992).

Climatic data

Climatic records exist from the town site of Cardwell (119 years), which is about 20 kilometers south of

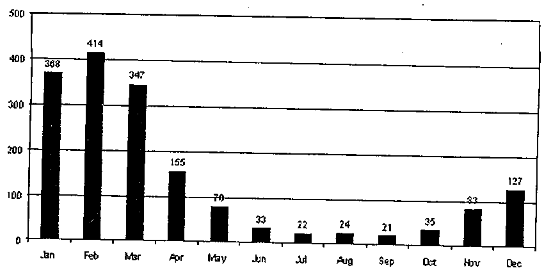

Figure 2. Cardwell median monthly rainfall

the plantation. The median annual rainfall for Cardwell is 2,040 mm. Figure 2 shows the monthly median rainfall for Cardwell. The area generally receives greater than 100 mm of rainfall per month over the period from December to April. After which there is a dramatic reduction in rainfall, with one in every two years receiving less than 25 mm rainfall per month for the period from June to October.

Genetics and nursery production

Genetic material for Rewards Management's teak plantation program was sourced from breeding programs in Thailand. The teak germplasm consisted of over 120 clones. Tissue culture teak plantlets were produced using standard techniques. Teak plantlets were de-flasked and grown on in 100 mm pots for a further period of 6 months under sophisticated nursery conditions.

PLANTATION ESTABLISHMENT

Plantations were established during the wet season months of January and February. The plantation is prepared by removing pasture and weeds by herbicide spraying, then this followed by cultivating the entire site to achieve a 100% soil tilth. Planting lines were ripped 4 m apart to a depth of at least 50 cm and trees mounds were formed over the rip lines to a height of 40 to 50 cm using a grizzley mounder. Pre-emergent herbicide was broad sprayed over the site about two weeks prior to planting. Teak plantlets were planted once tree mounds were saturated. Plantation density was 1250 stems per hectare, with a spacing of 4 m between rows and 2 m along the row.

The initial fertiliser application was 125 kg/ha of Diammonium Phosphate (DAP) as individual tree application (100 grams per tree @ 1,250 stems/ hectare). This is applied within the first twelve months following plantation establishment. This gives an elemental fertiliser component of 60 kg P / ha, 54 kg N / ha and 6 kg S / ha, which is sufficient to meet the requirements of the early tree growth in the first year.

At 18 months teak achieved heights between 6 to 8 m and DBH between 3 to 5 cm.

CONCLUSION

The development of teak plantations in north Queensland is a new plantation forest industry in Australia. Growing global demand and declining supply suggests sound commercial potential for the continued and aggressive expansion of teak plantation estate using high input forestry techniques in north eastern Australia. Australia offers the opportunity for a secure commercial plantation industry with an attractive investment environment that will result in the sustainable development of a new plantation industry.

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Institutions, Investment and Networking

The Importance of Quality in Teak Plantations

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ABSTRACT

Tropical countries need to protect their forests and also satisfy their wood requirements. One option is to increase substantially, the area of managed natural forests. However, sustainable management of natural ecosystems and at the same time satisfying the demands are not always realistic. Supplementary plantations are urgently required to produce renewable hardwoods for economic development, poverty alleviation and to decrease pressure on natural forests. Plantations that use best management practices can be 20 times more efficient, in terms of production, as compared to the natural forests. Teak is the most widely cultivated quality hardwood and has many advantages as a plantation species. However, critical problems are encountered in conventional plantations. New quality approaches are required to overcome such problems. The approaches must be open-ended and innovative. A range of possibilities is examined, including the innovative Consortium Support System of TEAK 21. The impacts of plantation production beyond the growing site, like the natural forests, environment, downstream industries and the consequences of using timber instead of other industrial commodities must all be taken into account while identifying new approaches of plantation management. Ultimately, the whole process must have positive impacts on the human efforts to achieve sustainable development.

Keywords: Teak plantations, sustainable management, Consortium Support System, natural forests.

THE CRISIS

In the year 2001, the events surrounding September 11th brought home the real threat of international terrorism. However, a silent, unnoticed threat is endangering the life support mechanisms of our planet and must be taken seriously. This is the destruction of the planet's natural tropical forests. Annually, the tropics loose about 15 million hectares of tree cover, an area twice the size of the island of Ireland. Demand for high-grade hardwoods coming from tropical forests is 90 million m^3 per year – equivalent to 12 towers of the former World Trade Centre in New York. Yet demand is forecast to rise in line with population increase.

Tropical countries need to protect their forests and yet satisfy their wood requirements. One option is to increase substantially the area of managed natural forests. However, to satisfy present demand it would require 180 million hectares of managed forests, equivalent to three times the area of France. To access the timber would require laying down a road network of 60,000 km annually for next 30 years, equal to wrapping the equator 1.5 times per year. In addition, a large work force would have to be trained and deployed in some of the world's remotest areas. Clearly, management of natural forest on this scale is not realistic. Supplementary efforts are needed to solve the tropical hardwood crisis.

There is a case to make for more efficient use of hardwoods, and some substitution is possible but increasing domestic demand will hamper efforts to provide a lasting solution using these methods alone. Sustained tropical hardwood plantations, which provide positive economic, social and environmental benefits, are scarce. For these reasons new plantations are urgently required to produce renewable hardwoods for economic development, poverty alleviation and to decrease pressure on natural forests. Plantations that employ best management practices can be 20 times more efficient, in terms of production, compared to natural forests. The tropics now need to establish sustainable hardwood plantations of the right sort.

High-grade tropical hardwood plantations

Most high-grade tropical hardwood species have evolved in highly competitive environments of forests composed of many species and ages of trees. Many species are shade tolerant and will grow only in small gaps in mature forests. Such species are usually unsuited to growing in pure stands or in open environments when young. Attempts to grow them in such circumstances usually result in chlorosis and in fatal insect attacks. Pest and disease problems prevent some species, like mahogany, from growing consistently well, especially in humid areas. The notable exception is teak (*Tectona grandis* Linn f.).

Teak is the most widely cultivated quality hardwood species and a useful indicator of hardwood plantation trends. In 1980, teak constituted about 75% of the area under high-grade tropical hardwoods or 11% of the total area of tropical forest plantations. However, in 1990, it constituted only 5% of the reported total area under tropical plantations, of which more than 90% was located in Asia, mainly Indonesia, India, Thailand, Bangladesh, Myanmar and Sri Lanka. This apparent drop in teak's proportion reflects the relative lack of emphasis on high-grade hardwoods compared with species used for other purposes.

The advantages of teak are:

- Mature teak has a strong reputation for excellent wood quality;
- Teak is a highly marketable species (mature wood is well known and accepted by the market);
- Mature timber fetches relatively high prices on the international market;
- Teak can be grown in plantations and its conventional silviculture is well understood;
- It is economically viable under appropriate plantation conditions;
- The species has good carbon retaining properties (mature wood is used for long-term end uses);
- Demand for sustainable plantation based tropical high-grade hardwoods, like teak, is likely to increase due to future restrictions on the unsustainable output from natural forests (which is the current supply source of most of these timbers);
- Demand for long-lasting, renewable and carbon-retaining raw materials, like tropical hardwoods, is set to increase.

Problems with teak

Although teak has many advantages as a plantation grown species, critical problems are encountered in conventional plantations. A stark warning is provided by Keth (1997) who says, in reference to Myanmar: "Past experiences and the results of modern teak research findings on teak plantation establishment are fraught with problems and conflicts pertaining to soil, nutrient loss, site deterioration, growth and yield decline, insects and disease attack ..." when it is established in unsuitable localities and unfriendly environments. But the problems with teak are wider than this and can be summarised as follows:

i. Improved seed or reproductive material is in short supply; plantations are often established with a poor genetic base;
ii. Site selection is often inappropriate;
iii. Poor silvicultural management is common, particularly in relation to thinning and pruning, which leads to crops of low value;
iv. Soil erosion problems are frequent where thinning is lacking, is too light or where soils are inappropriate;
v. Investors must wait long periods before obtaining a return on investment;
vi. Young teak plantations produce a high proportion of waste when converted (only a small percentage of the plantation is in the high value mature category);
vii. Marketing of young teak is difficult (price information is poor; sellers have little bargaining power; proper timber grading is lacking; there is no future market for young timber);
viii. High impact logging is a problem associated with mature conventional plantations;

ix. Clear-felling is the norm in conventional silviculture.

New approaches are required for teak to overcome these problems. New approaches must be open ended and innovative. Some ideas are explored next.

Our Thinking - Unlimited

Obtaining Sufficient Finance - Problems and Solutions

To provide a sustainable supply of high-grade hardwoods at the levels required, a substantial investment is imperative. An increasing number of landowners are interested in quality hardwoods like teak. Many more would be prepared to plant if provided with incentives such as appropriate financial packages, including annuities, grants, special interest rates on loans, tax incentives, a means to cash the value of the investment during the rotation through forest bonds or equivalent financial instruments, sales of growing plantations, stock market transfers, etc. to overcome the problems of locking-up large quantities of capital over long periods.

Financial resources are key ingredients to developing quality hardwood plantations. However, many private forestry initiatives, for one reason or another, have encountered major difficulties in obtaining the necessary investment capital. This is due to several factors related to the *modus operandi* of the financial sector. There is the often-cited lack of understanding of the forestry business amongst the money lending fraternity.

There is also the general non-competitiveness of forestry investments. In the case of teak, expected Internal Rates of Return (IRR) may be 10% or higher, sometimes exceeding 20 %, if the plantations are cultivated and managed properly in appropriate sites. Nonetheless, these rates are not attractive to many commercial banks and lending institutions, even though they are extremely good in terms of forestry investments.

Another difficulty is a lack of confidence in investments in developing countries. From the point of view of sustainable forestry investments, commercial capital in OECD mostly flows, as it were, within a semi-permeable membrane. Whereas inward flows from the developing countries are welcome through the membrane, outward flows to sustainable forestry, are difficult if not impossible unless sucked out against natural osmosis by promises of rich (unrealistic) returns.

Hardwood plantations attract marketing campaigns that over enhance their advantages. Some private companies see that, with the demise of the natural forest, which provides most of the tropical quality hardwoods in developing countries, this material is likely to be in short supply in the future. The argument is made that future shortages should guarantee an increase in real prices for quality hardwoods coming from plantations. If returns come quickly (short rotations) and growth is good (high productivity), plantation investments are more attractive.

This has resulted in some private companies making the case that their plantations can produce higher than average (over-optimistic) growth rates accompanied by promises of very high (unattainable) financial returns. The attempt to attract funding into forestry, albeit by questionable means, is a manifestation of the relative attractiveness of the hardwood plantation concept on one hand but the neglect, on the part of what may be termed the 'international forestry regime', of the high-grade tropical hardwood issue in general, based – at least in part - on a reluctance, or lack of confidence in its abilities, to become involved with the private sector. An array of literature has appeared in recent years, which deals with the problems associated with financing teak plantations (Centeno, 1996; Chaturvedi, 1995; Romeijn, 1999; Scholtens, 1998; Balooni, 2000).

The developing country like Costa Rica has been providing fiscal and financial incentives to growers and this has enabled the expansion of plantations (Watson *et al.*, 1998). But, in the absence of sufficient government funding, the private sector in the developing countries themselves is sometimes attracted to make capital investments in plantations. Indeed, the private sector in India has become interested in commercial tree investment programmes (Balooni, 2000).

However, because of relatively high in-country interest rates, forestry enterprises must provide equal or greater returns to investors than alternative commercial activities in order to compete. Investment capital in the developing world is scarce and therefore it is difficult to envisage sufficiently large sums finding their way into projects that require the relatively long periods demanded by hardwoods. Domestic investors, like their overseas counterparts, understandably, have a preference for short term and high return ventures.

Aid funding is limited and decreasing. Besides, such funding is often not the best means of solving forestry problems. Aid agencies are heavily influenced by external politics and mandate limitations, and do not provide the long-term backing and continuity that is necessary in forestry undertakings. Of greater concern - aid money has been associated with many project failures in the past (Byron, 1997). This is mainly because it has been channelled through government systems which, in many cases, are hampered by bureaucracy and corruption and do not have the capacity to carry out practical and sustained forestry.

Bass and Hearne (1997) explain: "In the 1980s and 1990s, after long experience of inefficient government management, poor delivery of services, increasing public sector debt, corruption and rent seeking, and the dominance of central government which were not accountable to the citizenry, the prevailing politics made an about-turn in favour of privatisation and deregulation." The authors further suggest that there is almost no nationalisation going on and indicate that state funding to forestry is in decline. For these reasons, government is unlikely to provide, directly, the necessary resources to solve the problem.

In recent years the hope for a new departure, on the part of many aid agencies, is shifting to the private sector – at least verbally. Donors are being encouraged to incorporate the private sector into development but many agencies tend to feel out of their depth when dealing with commercial entities and often fail to make use of available opportunities.

Funding in the developing countries from the private sector has increased in the recent past but such flows tend to gravitate towards non-sustainable components of the forestry sector (Crossley *et al.*, 1996; 1997). In addition, this funding is poorly distributed and volatile (FAO, 1997). There are few clear-cut ways of mobilising private funding into sustainable forestry development on the scale of finance required. If the situation is to change – it will need substantial investment. Assuming, for the sake of argument, that 20% of the present demand for high-grade hardwoods is to be satisfied from new plantations producing 10 m^3 $ha^{-1}year^{-1}$. In this case, more than 2 million ha of quality hardwoods would need to be planted over a period of 20 or 30 years (equivalent to planting 80,000 to 100,000 ha $year^{-1}$). The scale of investments to cater for the establishment and running costs until the plantations become self-sufficient are high. Assuming establishment costs of US $ 1,000 or 2,000/ha, the required investments could amount to between US $ 80 and 200 million per year for establishment costs alone. Is it realistic to expect that funding of this sort is available?

If capital investments from OECD commercial sources, from developing governments and from the private sector in the industrialised and developing world, and aid funding, all appear to be available only in very limited or declining amounts, then the calls to mobilise sufficient capital to correct the forestry and associated environmental problems in the developing world look decidedly empty. There is the added danger that the international community will rest its hopes on the private sector but that the funding will fail to materialise. If so, the time taken before this becomes apparent will exacerbate the forestry and environmental crisis in the developing world and new ways will have to be found to solve an even greater problem.

There is no time to wait. Alternative and realistic ways forward must be sought urgently. It makes sense, in light of all of these developments, to explore in depth, the optimal use of scarce financial resources that are available. Although aid money is relatively small in relation to requirements to solve the overall forestry problem, it could be significant as a catalyst creating enabling conditions for capital investments rather than as a direct outlay into projects. This could be much more effective than the present scenario if it resulted in the mobilisation of many times the scale of current investments.

For example, certain inducements to the private sector may be necessary to initiate the required flows of finance into the sustainable high-grade hardwood sector. Creating enabling conditions for capital investments could be realised in the following ways:

- Support or develop a financial entity to identify, attract, handle and distribute capital to growers (all costs of establishing and running the entity covered by aid money, at least in the short run or until a return is realised from forestry activities);
- Provide resources to supporting facilities that are designed to help and encourage growers and other entities to undertake appropriate developments and ensure that all activities reach set technical, environmental, social and financial standards;
- Provide guarantee mechanisms for investors (risk insurance, currency hedging etc.,);
- Develop a sufficient scale of activity to enable the financial entity to become listed on the stock exchange.

Purchase of carbon credits under the Kyoto Protocol is an important potential source of capital. The annual payments for carbon may be insignificant in terms of establishment and management costs on a per hectare basis. However, if annual payments were capitalised in return for dedicating land to timber plantations, they could be significant in terms of covering a percentage of the costs of establishment (Hardcastle, 1999).

These measures, and others, some of which amount to indirect subsidies to growers, would boost investor confidence and eliminate the handling costs of capital in the period in which new plantations were developing. The result would make sustainable forestry more attractive and competitive.

The donor community should have no problem justifying its involvement in the scheme. In view of the hardwood crisis (the non-sustainability of the resource, the urgent need for new sources of funding, and the poor use of existing funds) a radical re-appraisal is imperative. Re-examining uses of aid deserves serious consideration. At least a partial use of funds to entice even greater flows of finance to forestry may be doubly effective by withdrawing money from the type of project that has provided few benefits in the past, into projects that have a high probability of success. Aid support to sustainable forestry undertakings may provide the one missing ingredient to encourage investors to make deposits, namely: confidence. Investor confidence is likely to be increased in undertakings that are backed by the international community.

Guaranteeing superior management

The application of superior forms of management embraces such things as management planning, the establishment of proper quality controls and monitoring and auditing systems, capacity building and the timely execution of all silvicultural operations. These guidelines are well known to conventional teak growers who aspire to excellence. However, as we have seen, conventional plantations have their limitations and opposition to pure plantations is increasing. It is of interest to growers to explore how the species might be grown in alternative arrangements, where conventional planting is inadvisable, in order to allow the species expand across a range of sites that are currently off-limits, including high potential agricultural land and sloping ground where erosion is currently a potential problem.

Alternative management techniques, beyond the limits of conventional silviculture, may be found by looking to the natural forest. In natural ecosystems teak is encountered individually, in dense thickets, in groups, in patches or pure, depending on a range of site factors and stand history (Troup, 1921). It is found in mixed deciduous forests and sometimes in dense evergreen types and often grows on undulating terrain.

Growth with a suitable understory species is nature's way of overcoming the erosion problem on sloping ground. Accompanying species must be able to grow under the teak canopy, yet have a rooting system that does not interfere with the potential of the teak roots. A low-growing and non-climbing understory is preferable. As the introduction of an artificial underlayer of vegetation may be expensive, it is advisable to encourage any existing natural undergrowth or introduce a crop that can provide some economic return. A woody fire-retardant layer, that maintains its cover throughout the dry season, is ideal.

Bamboo forms one of the most common associations with teak in the crop composition of natural deciduous forests in many undulating hilly areas within its natural range (FAO, 1958; Troup, 1921). These are precisely the sites that require the soil holding capabilities of bamboo. Bamboo is less frequent or absent in teak bearing deciduous forests on lower ground which is flat and alluvial (Troup, 1921). This may be due to the teak being more competitive than bamboo on these sites.

Bamboo often appears as the understory of teak. Troup (1921), referring to the Tharrawaddy division in Burma (Myanmar), states: "A considerable area of flowered bamboo sowings has proved to be highly successful culturally, resembling a well-stocked plantation with a dense underwood of bamboo, which gives the teak a healthy and natural appearance."

An array of artificial patterns of establishment of bamboo with teak can be conceived, from intimate mixtures to rows, lines, clumps, contour planting etc. The overall production of teak within such arrangements will be less than conventional plantations. However, if teak-bamboo combinations are feasible on a commercial scale, it may be possible to produce output to satisfy the quality hardwood market and pulp and fibre demand from the same plantations. An early return on the fibre crop could make hardwood growing more attractive. White (1991) notes that inter-cropping allows the transfer of costs of tending (weeding) etc., to the cash economy of agricultural sector enabling a cash flow during the early years of the rotation. Also, costs may be offset by benefits in terms of an ability to meet social, environmental and landscape objectives from species combinations.

Bamboo species provide many environmental benefits including erosion control and can help to maintain the continuity of the nutrient cycle for sustained fertility. Besides, their leaf fall builds humus (Farrelly, 1984). In addition, teak-bamboo combinations can increase substantially the biological diversity of plantations. The ranges of uses to which bamboo can be put are enormous and include craft development, paper making and house building. Therefore, teak-bamboo combinations can provide flexible local benefits. Why then are teak-bamboo combinations not practised more often?

Outside Asia, bamboo is not used to the same extent in economic and cultural activities and populations need to be educated about their potential uses. Besides, there is a lack of knowledge amongst teak growers and, indeed researchers, about:

- What commercial teak-bamboo mixtures are possible;
- Where to obtain appropriate bamboo plant material;
- How to manage and harvest teak-bamboo combinations.

It is more difficult to manage combined crops than monocultures. In teak growing areas, natural reproduction of teak can usually be obtained by felling bamboo and clearing all teak-impeding vegetation. However, bamboo has to be cut back periodically until the young teak plants are free from danger of suppression and this can be an extremely costly operation (FAO, 1958). In first rotation plantations, on the other hand, the grower is in control of when bamboo plants are introduced. This, of course, will depend on the bamboo species, the site and the relative speed of growth of the teak plants.

Also, non-compatibility of teak and bamboo has been suggested. For example, Kadambi (1972), after Coster (1933), reports that shallow rooted understory species like bamboo, are more harmful to teak than deep rooted ones like *Leucaena*. However, it is stated, "The notion that shallow rooted and self thinned bamboos can mar the regeneration of timber species is not backed by the concept of origin and succession of vegetation" (Singh, 1969; Farrelly, 1984).

Another potential problem is that some bamboo species are spiny (e.g. *Bambusa arundinacea*) and impede access (Mascarenhas and Muralidharan, 1993). Thus pruning, thinning, harvesting and other silvicultural operations with teak are difficult. Considering the enormous range of possible permutations and combinations with teak and various species of bamboo, there is need for further research.

Chandrashekara (1996) assesses the contribution of bamboo to the vegetation structure, biomass productivity and nutrient cycling pattern in 15- and 20-year-old teak plantations in Kerala, India. Given the particular circumstances of the areas examined, he suggests that patch planting, rather than inter-planting appears to be more appropriate. Inter-planting with *Leucaena* has been advocated because it is a green-manure crop that can enrich soil humus, supply nitrogen, keep out weed growth and prevent soil erosion. However, it should not be allowed to overtop and suppress the teak. *Leucaena* has also been claimed to provide a balanced phosphate nutrition (Kadambi, 1972).

Excellent teak sites are frequently found on prime agricultural land. To plant such areas is often equated with endangering food supply in developing countries. However, much of the rich productive land in the tropics, for which teak has to compete, is given over to monocultures for the production of cash crops like palm oil, sugar cane, cotton, tobacco or cattle ranching etc. Therefore, competition from teak may have little direct influence on local food production. Besides, some cash crops have negative or questionable environmental and health effects and, in many cases, teak provides a positive alternative.

Foresters have been trained to view prime agricultural land as 'out of bounds' for tree planting either because of the felt association with food production or on the basis of an intuition that trees can not compete with cash crops.

New thinking on sustainable development is not confined to the forestry sector. It must involve a holistic exploration of every aspect of human development, including agriculture. Combinations of teak and other quality hardwoods with agricultural cash crops are legitimate and require further exploration.

With emphasis on China, Kunnan (1999) discusses combinations of teak with pineapple and other tropical fruits. Moore (1966) and Keogh (1987) outline the alignment of plants in the Group Planting System in which crops like banana can be planted. In this way teak may even assist in providing alternative food crops and help decrease the very large areas of agricultural monocultures. Dr. Harris Salleh, former Chief Minister of Sabah, has developed innovative methods of combining teak with agricultural cash crops like palm oil and cocoa, as illustrated by Tee *et al.* (1995). The term *industrial agroforestry* is appropriate for these schemes.

Other species that can be planted with teak include a wide variety of crops planted under the *Taungya* system. Taungya in Burma, signifies the raising a forest crop in conjunction with agricultural crops. Crops may include: rice, cotton, maize, sesame, pigeon pea, various vegetables, chillies, ginger, etc. (Kadambi, 1972). For teak to become cultivated effectively in agricultural settings, the traditional mind-set boundaries between disciplines like agriculture and forestry must be dissolved. Such a change in the paradigm would have significant consequences for the supply of high-grade tropical hardwoods and the release in pressure on natural forests as suppliers of quality timber.

Where teak is planted at relatively wide spacing, in small blocks, rows, lines or single trees, the importance of side branches becomes critical. In these cases, genetic improvement programmes are required to provide varieties with light branch architecture. Rather than advocating particular arrangements, an exploration of as wide a range of patterns of cultivation as possible should be undertaken by researchers with the aim of providing growers a menu of options to suit local sites and conditions.

Flexibility would allow for the development of core commercial plantations together with complementary out-grower plots on commercial agricultural farms in combination with cash crops and on community lands. The private and community sectors, working in unison, are the most appropriate entities to develop new plantations. Unconventional schemes that incorporate rich and poor are more likely to succeed if arrangements can be made for mutual gain (e.g. out-grower schemes). Synergy between large-, medium- and small-scale cultivators can provide greater benefits to society and the environment as a whole than segregated development and may include mass certification for small growers and the tackling of common pest problems, like the teak defoliator, etc.

Fears, on the part of aid agencies and NGOs, of supporting multi-nationals that wield massive power must be replaced with a reliance on the counter balancing forces of certification programmes that contain strong social dimensions. A key ingredient is that all participants must gain to the ultimate benefit of the environment. By making available the right catalytic forces and organisational frameworks, it is possible to mobilise the collective latent power of all potential stakeholders and make a major impact in favour of tropical hardwoods.

Mayers (2000) acknowledges the growing trend in the range of company-community relationships in out-grower schemes, joint ventures, other contractual and informal arrangements. All these have application in the growing of quality hardwoods.

In this way, the private and community sectors can participate in common plantation programmes. A wide choice of planting and silvicultural arrangements is essential to achieve workable options. Under these circumstances, the orchestrating of common planting programmes is a critical undertaking and requires a new order of co-operation between all interested parties.

TOWARDS A HOLISTIC VIEW OF TEAK PLANTATION IMPACT

Industry and the market

To confine the exploration of teak cultivation to the planting sites alone is to render its invisible holistic impact. The combined site and subsequent *ex situ* economic, environmental and social impacts of the raw material as it moves from plantations, through the processing industry and into the market or markets it supplies is the true measure of the overall value of teak and other quality hardwood plantations. Such an approach focuses the analysis on the entire forestry-wood-chain with a view to enhancing the overall impact of the commodity and with the aim of optimising its contribution to the development of a sustainable society. Where teak is combined with other species like bamboo, the analysis must be further broadened.

Life Cycle Analysis (LCA) is a technique for examining industrial raw materials that involves a cradle-to-grave environmental and social assessment of a material. All processes of a product, including its extraction from rock strata or production through photosynthesis, its further conversion, the transportation of the material at all stages, its further forming, its ability to conserve heat in buildings, the energy requirements of recycling, its value as a safe and non-toxic commodity from the human health point-of-view and its environmental impact as a waste product must all be considered. In this respect, wood, but especially teak, has many benefits compared to its main competitors.

Carbon and energy

From the wider environmental point of view, preference is likely to be given in future to materials which, like wood, require low energy inputs in their creation, are renewable, biodegradable and aesthetically pleasing. Where energy for the timber industry arises from wood waste, further environmental improvements are possible. It is acknowledged that a feasible global forestry programme (all species included) could remove the equivalent of 12 to 15 per cent of the total fossil fuel-generated carbon dioxide emissions between now and 2050. This increases to 25 percent if widespread use of wood is made as a substitute for products manufactured using large amounts of energy (Brown *et al.*, 1995; Rotter and Danish, 2000). Teak heartwood tends to be employed for long-term end uses that support the retention of carbon over extended periods. If mature timber is processed and used in an appropriate manner, it requires little or no maintenance and no chemical preservatives, even in contact with water and under outdoor conditions. This makes the wood highly environmentally friendly.

Toxic chemicals

Treated timber is clearly not as environmentally friendly as non-treated timber. The dangers of chemical leaching and toxicity during treatment processes need to be considered as well as the disposal of the chemicals themselves. In addition, treated timber which is to be disposed may be considered a hazardous waste. Another consideration is the necessary maintenance associated with wood. Also, chemicals, like glues, used in the manufacture of laminates and veneer are coming under closer scrutiny by specifiers, especially with regard to emissions from formaldehydes and isocyanates, which are contained in the glues used to manufacture boards (Botting 1994). In this respect, teak is a clear winner amongst the timber species as an eco-friendly material. The species tends to be used in the solid state, which is generally more environmentally friendly than reconstituted wood. When eventually it comes to be replaced, teak can be reused, recycled or burnt without causing environmental problems.

Health

There are other social and environmental benefits to consider. In the mid 1990s, hardwood flooring had captured less than 3 per cent of the floor covering market in UK, compared to almost 90 per cent for carpets (TTJ, 1996). However, with growing worries in UK about the health risks of carpets, particularly for asthma and allergy sufferers, the Healthy Flooring Network (HFN) has launched a campaign to reject the use of fitted carpet, PVC and vinyl in favour of wood, linoleum and laminated floors (TTJ, 2000). This offers a potential market for teak growers. On the downside, sawdust from teak machining operations can cause skin irritation and adequate protective measure is required.

Teak and bamboo in industry

Combinations of teak and bamboo can provide many downstream benefits. As an example, houses constructed of bamboo and teak can be designed to resist earthquakes in prone areas and can be safer than units constructed of many competing materials. An outer natural protective shell of teak with an inner bamboo structure is an ideal combination. In such cases, teak and bamboo can be grown for the same target market.

Vision to reality

Many suggestions have been made. How can they be put into practice? How can recommendations be translated into action? How can the development of teak and other quality hardwood plantations be raised to a new plane of activity in future and overcome the problems exhibited in plantations of the past? Thinking alone is not enough; more papers are not enough. How many conferences end up with a set of documents, resolutions and nothing more? Within a short time there is another conference and the first is forgotten. This is wasteful. There is now an opportunity to ***act*** on the ideas generated. What form of action that might be contemplated is open for discussion.

Unfortunately, there are many missing links between several of the components required to change the way quality tropical hardwood forestry is organised, funded and undertaken in practice. These gaps include the wide gulf between investors and growers, the lack of appropriate transfer of technology, the loss or 'bleeding' of relevant information over time, the inability of growers to put into practice many research findings (particularly those relating to genetics), the inability of the donor community to relate adequately to the private sector. There are many other drawbacks. To bridge important missing links between components, TEAK 21 was developed. Details of the concept are provided elsewhere (Keogh, 1996, 2002). In brief, TEAK 21 was launched as TEAK 2000 in October 1996, in the Royal Tropical Institute, Amsterdam. The basic design feature is the Consortium Support System (CSS). As the name suggests, it is a system under which support (financial and technical) is given, directly or indirectly, to groups (consortia) of growers to enable them to produce more and better quality tropical hardwood timber in an economically beneficial, socially acceptable and environmentally friendly manner. Target growers are the private and community sectors rather than government services.

The components of the system include:

- The growers, processors and the market;
- Supporting services (financial, technology transfer and quality control);
- Genetic improvement;
- Supporting entities - governments and international agencies including donors.

TEAK 21 is, essentially, a support mechanism for growers and processors who are being organised within local, national and regional associations. The first association (ANARAP-TEAK 21) has been set up in Panama, Central America. Associations are accountable to an international federation of associations based in Ireland.

TEAK 21 is a flexible go-between facility, to enable growers, obtains all facilities required to carry through their plantation programmes. It is also designed to assist processors. Its work includes:

- Assessment of consortia groups' needs
- Drawing up project proposals to satisfy the identified needs
- Seeking finance from donors (in the widest sense of the word) to implement projects geared to satisfying identified needs
- Linking research entities and growers to identify gaps in knowledge
- Compiling information data bases on behalf of growers and processors
- Developing best short-term solutions for growers through intermediate research
- Developing best practice guidelines
- Training a cadre of foresters to undertake the CSS work
- Compiling a roster of expertise in quality tropical hardwoods
- Creating links between associations
- Orchestrating common planting programmes amongst growers
- Approaching donors, investors, governments and other entities on behalf of associations
- Encouraging and arranging for the leasing (or other agreements) of government plantations by private and community sectors
- Encouraging and assisting the development of financial mechanisms on behalf of growers and processors
- Ensuring technical and financial quality control on behalf of investors
- Assisting in the development of quality processing industries
- Educating the market place about quality tropical hardwoods
- Promoting the marketing of grower and processor produce
- Ensuring plantation developments are achieved in harmony with undertakings in natural tropical forests
- Executing any other activities required to assist in the development of high grade tropical hardwood plantations

TEAK 21 is not a certifier but will prepare growers for certification. Its aim is to ensure quality control in technical, financial, social and environmental aspects. Essentially, it is designed to facilitate growers and processors in areas where other entities cannot work due to mandate or other limitations. It works on the premise that it will avoid duplication of effort and focus attention on areas that are not being dealt with, or not being dealt with properly, rather than competing with work that is ongoing successfully. It aims to complement achievements and ensure they are carried successfully to the next level of development.

Its activities - while project based - are accumulative and congruent (i.e. project developments are intimately related; for example, project 1 output is project 2 input, and so on). In this way, an organisational memory is developed and used as an incremental learning and development tool. Also, developing and industrialised country co-operation in the system is on an equal and shared footing that maximises the contribution of each to problem solving. In addition, a south-south network of information exchange is developed.

The organisational structure of TEAK 21 is simple. It consists of an overall coordinating unit – the International Federation of Tropical Hardwood Associations and linked national associations. TEAK 21 and the CSS represent a novel approach for supporting the growing of quality hardwoods in tropical countries. Teak is the species that will be used as the 'flagship' for high-grade hardwoods. The initiative serves as an example of 'new forestry' and should be of interest to a wider audience than that specifically involved in the growing of tropical hardwoods. The CSS encompasses all the elements needed in a large-scale sustained forestry programme. As the method focuses on a particular sub-sector it enables the introduction of new and innovative methods within a limited arena of forestry activities. The concept may be applicable across a broader development sphere than the hardwood sub-sector and may have applications beyond the forestry sector itself.

TEAK 21 is designed to make a significant contribution to sustainable forest management. The initiative must be seen as the beginning of a process, which will eventually make a substantial contribution to providing alternative sources of supply of quality tropical hardwoods for the market and alleviating pressure on natural forests as suppliers of timber. Lessons learnt from TEAK 21 should make an important contribution to sustainable development as expressed at the Earth Summit in Rio in 1992 and articulated through Agenda 21. If the development of TEAK 21 – or a similar approach - is not successful, then the advancement of appropriate (best practice) plantations, on the scale required, will be delayed. Pressure will continue to mount on natural forests to provide increasing volumes of tropical hardwoods.

A Bright Future

Clearly, management of natural ecosystems alone - to satisfy current and future demand of tropical hardwoods on a sustainable basis - is not realistic. In a recent ITTO editorial (Sarre 2003) it is admitted that sustainable forest management of natural forests remains elusive. Therefore, the development of supplementary hardwood plantations is more urgent.

However, improvements must be made to ensure better returns on investment and to attract the quality and quantity of investors that will secure the sustainable supply of tropical hardwoods into the future and release pressure on natural forests. This is the objective of TEAK 21. The impact of plantation production on natural forests, the environmental friendliness of downstream industries, the consequences of using timber instead of – or to supplement - other industrial commodities must all be taken into account. Ultimately, the whole process must impact positively on the creation of environmentally benign, safe, long lasting and aesthetically pleasing human physical surrounds.

The good news is that the niche market for high-grade teak remains strong. This is the conclusion from a recent survey of high-grade tropical hardwoods (Varmola and Carle, 2002) and points to a bright future for investors and growers alike.

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Quality Timber Products of Teak from Sustainable Forest Management pp 635-639

Transformation of Tropical Forestry Starts with Teak

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ABSTRACT

This paper argues that transformation of tropical forestry starts only with teak . Also it discusses new dimensions of the giant leap towards global thinking, new limitations of the human behaviour, new issues of growing population and increasing role of tropical forestry. New perspectives of tropical forestry are further elaborated considering teak as the flagship of tropical hardwoods for throwing light on the potential of sustainable investments, today's practices and benefits from such investments

Keywords: Tropical hardwood, plantation, investment, economic return, sustainable forest management, environmental regulations.

The giant leap towards global thinking

"A small step for men, a giant leap for mankind" Neil Armstrong said when he landed as the first man in the Moon in 1969. This refers mainly to the technological achievements. The photographs, the astronauts took home, gave us the first view of the Earth from outside. The picture of this small sphere hanging in space created a wave of consciousness around the world. This small familiar picture showed clearly and bluntly that the world is one and that we all have to deal with this globe alone. Global thinking started here, as is illustrated in the emergence of new organisations like the Club of Rome and Green Peace.

New limitations for the human behaviour

Since then, many global issues have been raised and man was posed with a new term: Sustainability. In history man was not really bound by limitations of space in using natural resources, because there were always new horizons and continents to be discovered and explored. After the Second World War, especially after many of the former colonies became independent, there were no more new frontiers. The view on the Earth from the Moon has finally settled this understanding. Sustainability implies that in our actions and decisions we not only have to consider the boundaries of the source itself, but also the dimension of the planet as a whole ánd the dimension of time. From a single limitation of the source itself we took a giant leap to three limitations of the source, the planet and future generations.

The growing population creates new issues

When we refer to natural resources we immediately think of raw materials like metals, crude oil, natural gas and wood. Due to the ever-increasing world populationclean air, clean water, biodiversity, natural habitats and stable climates have become scarce posing new challenges to man kind.

The role of tropical forestry

When we take a closer look at the definition of new natural resources, it is compelling how many sources are fundamentally attached to tropical forestry. Forests in the tropics:

- produce wood, one of the major global raw materials
- provide medicines to both known and unknown diseases
- stabilise local and global climatic systems[1]

- act as carbon sinks
- provide clean air and water
- conserver the biodiversity
- provide the natural habitat for indigenous people

Did these put tropical forestry first?

All these vital functions dominate the international debates on the global environmental issues. Did these put tropical forestry on top of the list in international collaboration and politics? Did the international society take immediate measures to halt tropical deforestation? Do we pay the forests for the "new" natural resources? The only result so far is a long-stretched, heavily debated and compromised process for the valuation of carbon sinks, which we know as the Kyoto Protocol. We are losing the forests anyway, as we speak.

Who represents tropical forestry?

Most economic sectors are well represented. Agricultural industries like palm oil, soja, cotton, tobacco, and mining industries like oil, gas, gold, copper or aluminium are well organised, heavily funded and strongly represented. They have intensive political lobbies and defend their cases at many costs. Who is taking care of forestry? Tropical forestry has to compete for land with the agricultural and mining industries and does not stand a chance amidst this powerful competition. This has led to the phenomena that everybody is representing tropical forestry except the real stakeholders themselves. Consultants, policy makers, wood traders, politicians, researchers and NGOs are all claiming to care for the forests. But none of them has the real responsibility to the foresters. Either local communities who have managed their sources since their ancestors, or public forestry departments or private forestry enterprises. The real stakeholders see their sources diminishing year by year but stand powerless to act against it. In the light of the global importance of tropical forests this is an alarming conclusion.

[1] Not just by the absorption of CO_2, but even more by the absorption of direct sunlight; tropical forests represnt as stabilising factor in the complex system of the world climatic system. E.g. the reflection factor (Albedo) of a dense natural tropical forest is lower thanany alternative cover.

Wood is the key

Foresters have a strong card to play as wood has many virtues:

- as renewable source of energy and raw material
- as strategic raw material which can be measured, forecasted and planned
- it fixes green house gasses in the most efficient way
- it is a natural product, that will always be preferred by consumers
- it needs a low energy input for its production
- it has a long product-life cycle

These benefits mostly come from hardwoods. The large scale sustainable production of tropical hard woods is one of the corner stones of a global sustainable society. The slogan should be: "save the world, use wood!". If produced on sustainable terms, hardwood carries the benefits that makes it a key strategic commodity.

Teak is the flagship of tropical hardwoods

The favourable qualities of teak are numerous, both as a plantation species and as a wood species with outstanding characteristics. It needs no explanation why it is the most commonly planted hardwood species in the world. This puts teak in a crucial position within the family of tropical hardwoods. The species is so widely known and represents such a big economic value in terms of trade, that it is the ideal starting point to focus on.

Transition from developmental aid to sustainable investment

Since the Second World War, billions of dollars have been spent to the enhancement of the forestry sector in the tropics. This has been done and still is practiced today by donor agencies, multi-lateral development banks and NGOs. In general, developmental aid is more and more under dispute, both in the donor and beneficiary countries. Unfavourable results from studies in the effectiveness of developmental budgets have put this form of aid under a lot of pressure. The relationship of dependency is increasingly rejected by tropical nations. The insight is breaking through that real investments and transfer of technology is what the tropical nations need and not post-colonial gifts.

At the same time we notice the tendency that normal business develops into sustainable business. Experts are clear that this is not a temporary fashion, but a long term trend, most likely evolving in a permanent reshape of the businesses world-wide. Here we come back to the pictures of the Earth from the Moon that initiated global awareness and the growing limitations of the "new natural sources", with the climatic disturbances on the heels of northern (and southern) societies. The new way of doing business is often communicated as the "triple P" principle: People, Planet and Profit. These three objectives should be balanced, with people first. In the United States nowadays already 10 per cent of all the money invested goes into sustainable business. The trend of sustainable business and the eventual bankruptcy of post-colonial developmental strategies unavoidably leads to interest in tropical forestry. The earlier stipulated advantages of tropical forests and wood itself puts tropical forestry on top of the list for sustainable investments.

How can tropical forestry benefit from sustainable investments?

The demand for reliable, professional and profitable tropical forestry projects among investors is evident and will only increase. Private investors in Western Europe, the USA and Japan deal with superfluous capital. Large groups of consumers within these regions have arranged their pensions, are save with their housing properties and own a basket of shares or other regular investments. Still there is money to spend and then the new sustainable investments are wanted for.

When the focus is on tropical forestry, the investment community meets however a non-structured, poorly represented and near chaotic sector of tropical forestry. It is unclear who is an expert and who not. Who is representing forestry and who isn't? Now the large number of so-called "stakeholders" turns out to be a hindrance and the lack of co-operation and a structured lobby even so. This is the opportunity that tropical foresters have to seize. With the principles of People, Planet and Profit in the back, tropical hard wood has an outstanding position. Long production ánd product cycles, labour intensivity, high growth and yields and a high potential in carbon uptake are without doubt features to the advantage of tropical hard woods. No surprise that the gate is wide open for teak as the true flagship of tropical hard woods.

What does sustainable business need from tropical forestry?

First of all the investment societies need proof and reliable sources for the potential of long term profits. The sector needs to provide an instrument that generates figures and track-records of yields, prices and returns that is undisputed and can be verified and certified by accountancy firms and the like.

Secondly, but possibly even more important, investors need security. Reliable insurances and in some cases guarantees, will remove the barriers for large numbers of investors. Such insurances and guarantees can not be financed by the sector alone. Here we see the potential new role for donor agencies and multilateral development banks. Instead of giving away money for developmental aid, these funds should be addressed to create the required conditions for third party investors. In the third place the forestry investment projects will have to meet strict international standards, both for the quality of the management and for the aspects of sustainability. Nowadays there are plenty of systems in place and developments are at high speed. In the cases where projects fail to finance this by themselves, the traditional donors and development banks should assist. This will create a true development of the sector.

How will investments affect tropical forestry?

As a whole, these changes and facilities will turn tropical forestry into a more entrepreneurial sector. The stakes in tropical forestry on a global level are however so high, that it will always have to keep a strong public involvement. It also means no money or bread for the poor but a steady job and income. No dependency on gifts but self-esteem and a meaning of life. No schools built by foreign experts, but local teachers trained as part of the company's strategy.

No fence around the natural reserve, that will be lost anyway, but integrated management of natural habitats amidst commercial logging or planting activities. This is the only sustainability that will last. And wasn't that the meaning of the word itself?

When a part of the tropical forestry sector has become more like a business, it can realistically compete with other land-use sectors. Then it has the competitive advantage of being the care-taker of the new natural resources, whereas the competition is mainly adding to causes of the global environmental problems. Sooner or later, this will be translated into an economic benefit for tropical forestry.

Who will organise the match between tropical forestry and investments?

If nothing happens: nobody. This is the challenge for tropical foresters. It would be wise to focus on one specific species and take that species as a starting point: *Tectona grandis*. This is thé opportunity for the teak sector to organise themselves and be represented at high level on international forums and negotiations. No doubt that it should be the foresters and not the wood traders, NGO's, consultants and politicians to take part in such a structure. The foresters know ánd bear the daily responsibility of dealing with the forests and their employees. They chose the long term vision and have the understanding and experience in making slow cash under the tightest budgets. Other interested parties can be of help as much as they want.

What are the potential benefits?

First of all a joint effort will require the mandate and power to negotiate the needs for third party investments. If these needs are met, it will free the way for large sums of investments into the forestry sector. Secondly, basic investments in the development of the sector can be centralised and coordinated. Investments in Research and Development that could not be born by one party alone, now can come within reach for the society of teak growers.

A third direct benefit would be re-claiming the ground that has been lost to the other so-called stakeholders. As a result from that the public now can be informed properly about the truth of tropical forestry. E.g. that not every tropical forest is a rain forest. That rain forests are not the lungs of the Earth and that the losses of tropical forests does not mainly come from forestry or wood trade, but from the agricultural and mining business. And last but not least, that it is wise to use tropical hard woods where you can. Wood is a blessing to our planet!

A fourth benefit to mention is the potential to finance the certification of local forestry initiatives. It is not something to be proud of that the vast majority of certified forests today are not within the tropics. But thát's where the problem is! So far, certification has mainly strengthened the market position of non-tropical wood producers. This is a dangerous development that needs to be adverted soon. Again here is a useful goal for the funds of donors that have to step down from their ancient strategies. If the vision and collaboration within the teak sector is strong enough, barriers like the rules of the WTO can be overcome as well.

Today's example in practice

Back in 1993 a group of entrepreneurs from Brazil and the Netherlands recognized both the problems and the opportunities in the sector of tropical forestry. They decided not to wait until somebody started to move but began themselves. On a small scale the teak producing company of Floresteca Agroflorestal proofs what investments can mean for the production of tropical hard wood. The benefits in terms of quality, returns, advancements, preservation of nature and motivation of labour are huge.

On the other hand, to attract finance, in the Netherlands a commercial entity was created under the name of the Amazon Teak Foundation later as GoodWood Investments. Ten years of experience with investors from several European countries have learned what investors need and when they consider forestry as a wise investment. GoodWood and Floresteca have created themselves guarantees and insurances and have taken up a piece of Research and Development that has been unattended for in the sector more then a century.

The principles of People, Planet and Profit are fundamentally practised in the field and have led to an unprecedented motivation of the 800 employees, a high level professional management system and true nature conservation. It will unavoidably lead to a great output for the investors.

Floresteca and GoodWood are not driven by commercial objectives alone. The seriousness of global environmental problems is too big and the availability of high quality hard woods so low, that they recognise that their example should be applied more widely. But this can not be done alone, not even by successful companies like Floresteca.

Co-operation is required, which has to materialise in a centralised body and a membership of the real stakeholders, the producers of teak. Most importantly, a well developed and wisely communicated vision is needed. For the benefit of the tropical forests, for the benefit of all the people that depend on them and for the benefit of all global citizens that need the tropical forests more than anybody has ever realized.

Report on the Conference

International Conference on Quality Timber Products of Teak from Sustainable Forest Management, 2-5 December 2003, KFRI, Kerala, India : A Report

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INTRODUCTION

Teak (*Tectona grandis* L. f.), is an undisputed global leader of high quality tropical timbers. It is referred to as standard timber for comparative evaluation of the qualities of other tropical hardwoods in assessing their utilization potential. Lately, teak has attracted the investor's attention on production of high quality timber from both public and private sectors through plantation programmes. While the global teak plantations are estimated to exceed 5.2 million ha, 94% is located in tropical Asia with a major share in India (44%) and Indonesia (31%). Involvement of farmers and small land holders in the model of industrial wood supply from shorter rotations of 20-30 years of teak is increasingly becoming common in many countries. Many farmers prefer teak to fruit trees and other crops because of better market potential, cash income and wood for construction. With an annual national target of 50,000 ha of forest plantations, teak is planted extensively in India and about half of the forest plantation area in Kerala state is under teak. Generally, the productivity of teak plantations in India is low compared to the world standards and raises the question on the investments to be made in establishing extensive teak plantations.

Theme of the Conference

The international conference on - *Quality Timber Products of Teak from Sustainable Forest Management (SFM)* - was held at Kerala forest Research Institute, Peechi, Kerala, India, during 2-5 December, 2003 to address the following crucial issues:

- Does teak maintain superiority in timber quality when grown in high input short rotation plantations with silviculturally and genetically modified trees?
- What is the potential of teak for sustainable forest management (SFM) to meet the environmental and economic criteria in the tropics?
- What is the role of teak plantations in the livelihood of rural communities and poverty alleviation in promoting the tropical timber trade with value-added products?
- Is teak amenable, under socially acceptable conditions, to advanced technology of production and further processing for better marketability with certification and "green" labelling?

Objectives of the Conference

The specific objectives were:

- To provide an international forum for critical appraisal of the role of teak plantations in tropical timber development programmes and market situation, including the recent research findings, in environmentally acceptable and socially desirable conditions.
- To identify the constraints and strategic solutions for sustainable utilization of plantation grown teak

Organizers and sponsors

The Conference was hosted by the Kerala Forest Research Institute (KFRI) under the auspices of the following sponsors :

- International Tropical Timber Organization (ITTO), Japan
- International Union of Forest Research Organisations - Teak Wood Working Party (IUFRO 5.06.02)
- Ministry of Environment and Forests, Government of India
- Indian Council of Forestry Research and Education (ICFRE), Dehra Dun
- Floresteca Agroflorestal LTDA, The Netherlands
- Council of Scientific and Industrial Research (CSIR), New Delhi
- National Bank for Agriculture and Rural Development (NABARD), Mumbai

Participants and target beneficiaries

A total of 175 delegates representing 26 from Asia, Australia, Africa, Europe and North, Central and South America participated in the 4-day Conference including one day in-conference field excursion. In addition to the scientists from various research organizations/universities, the target beneficiaries of the Conference were small timber holders/ farmers, processing enterprises, traders, State Forest Departments, Forest Development Corporations, Policy Makers and scientists as highlighted below:

Farmers/Associations

Bharathiya Kisan Sangha, Karnataka
Mangala Farms, Karnataka

Industrialists and Traders

Export Dept., Myanmar Timber Enterprises, Ministry of Forestry
Forest Industries Travancore (FIT) Ltd. Kerala
Ginnacle Import-Export Pte. Ltd, Singapore
Goodwood Investments, Netherlands
Manuelson wood Industries, Kerala
Royal Global Exports Pte. Ltd, Singapore
Timber Importers Association & Regency Wood Products, Mumbai
United Timber industries, Mumbai

Policy Makers and State Forest Departments/ Corporations

Planning Commission, Govt. of India
Ministry of Environment and Forests, Govt. of India
FAO, Regional Office, for Asia and the Pacific (RAP), Thailand, ITTO, Japan, Andhra Pradesh Forest Department, Indira Gandhi Forest Academy, Dehra Dun, Karnataka Forest Department, Kerala Forest Department, Kerala Forest Development Corporation, Madhya Pradesh Forest Department, Maharashtra Forest Department, Punjab Forest Department, Tamil Nadu Forest Department, Uttar Pradesh Forest Department

Fianancial and Networking Institutions

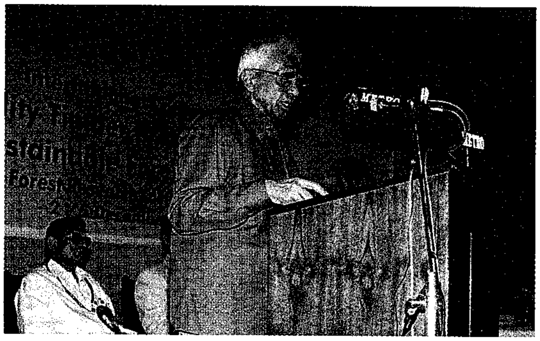
Floresteca Agroflorestal LTDA, Netherlands; Goodwood Investments, Netherlands; IUFRO, Austria; Kerala State Industrial Development Corporation; National Bank for Agriculture & Rural Development (NABARD); Teak 21, Ireland

INAUGURAL SESSION

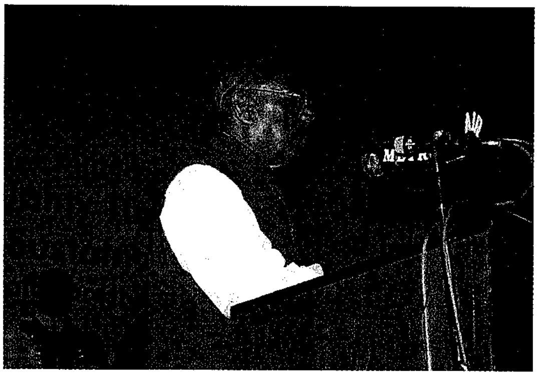
The Conference was inaugurated by His Excellency Sri Sikander Bakht, Governor of Kerala State, and inaugural session was presided over by Mr. K. Sudhakaran, Hon'ble Minister for Forests and Sports, Govt. of Kerala. The keynote address was delivered by Dr. D. N. Tiwari, Member, Planning Commission, Govt. of India. Mr. R.P.S. Katwal, IFS, Director General, Indian Council of Forestry Research & Education and Chairperson of the National Organizing Committee briefed the rationale of the Conference. Dr. J. K. Sharma, Director, Kerala Forest Research Institute, welcomed the dignitaries and the Conference delegates.

The special addresses were delivered by Mr. Bivash Ranjan, Assistant Director General of Forests on behalf of Mr. N.K. Joshi, IFS, Director General, Minsitry of Enviornment and Forrests and Special Secretary to Government of India. Mr. P. K. Surendranathan Asari, IFS, Principal Chief Conservator of Forests, Kerala, Dr. Ma Hwan Ok, Projects Manager, Forest Industries, ITTO, Japan and Prof. Takashi Okuyama, Coordinator of IUFRO Teak Wood Working Party, Japan. Dr. K. M. Bhat, the Conference Convener proposed vote of thanks.

Welcome address by Dr. J. K. Sharma
Director, KFRI

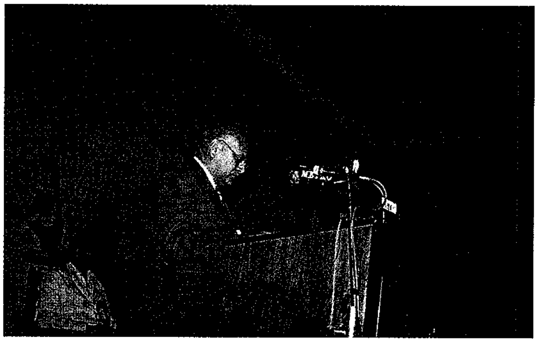


His Excellency Sri Sikander Bakht Governor
Kerala State delivering inaugural address



Keynote address by D.N. Tewari, Member,
Planning Commission, Govt. of India

Presidential address by Mr. K. Sudhakaran
Hon'ble Minister for Forests & Sports, Kerala



Mr. R.P.S. Katwal, Director General, ICFRE
delivering speech on the rationale of the
Conference

Vote of thanks by Dr. K. M. Bhat, Conference
Convener

Glipmses of the Conference

Lighting of lamp

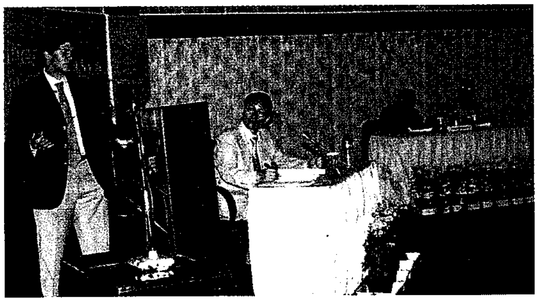
Dr. Hwan Ok Ma, Japan and Dr. Daniel B. Krishnapillay, Malaysia

Dr. S. Sankar , India

A view of audience

Dr. A.A. Oteng-Amoaka, Ghana

Dr. K .S. S. Nair, India



Mr. Silvio de Andrade Coutinho, Brazil

Prof. T. Okuyama, Japan and Dr. D.N. Tewari, India

TECHNICAL SESSIONS

A total of 69 oral papers and 26 posters were presented in sixteen different sessions. The technical sessions of oral presentation included : Country reports, Status reports, three sub-plenary sessions and ten wide ranging themes as stated in this report elsewhere. in the themes.

Technical session I: Country reports

The session was chaired by Mr. P. K. Surendranathan Asari, IFS, Principal Chief Conservator of Forests, Kerala and co-chaired by Dr. Hwan Ok Ma, Proejcts Manager (Forest industry), ITTO, Japan. Dr. Jamaluddin, TFRI and Dr. R. V. Varma, KFRI were the rapporteurs.

While acknowledging the significant developments in stadardisation of plantation techniques, harvesting and post-harvest utilisation methods, in his presentation of the Country report for India, Mr. R. P. S. Katwal emphasized the need to consider the ecological and economic aspects of teak plantations especially in monoculture for developing long-term management strategies and the potential of biotechnology for rapid tree improvement. Mr. Sadharjo Siswamartana reviewed the situation in Indonesia and the policies adopted on teak plantations especially after the political crisis in 1998. Mr. Somyos Kijker reviewed the status of natural and plantation teak forests, teak wood marketing and research and development in Thailand and raised the issue of defining the criteria for classifying quality timbers. Dr. Krishnapillay expressed the concern of the availability of sufficient quantity of good quality planting material for supporting the genuine interest of investors in plantation programmes in Malaysia. In addition the situations have been reviewed for other main teak producing countries, viz. Brazil, Costa Rica, Ghana, Myanmar, Nepal, Trinidad and Tobago, and Sri Lanka.

Session II: Status reports

Dr. S. Chand Basha, Principal Chief Conservator of Forests (Rtd) and Ex-Director, KFRI, India and Dr. Markku Kanninen, Director, Environmental Services and Sustainable Use of Forests Progarmme, CIFOR, Indonesia were Chair and Co-chairs respectively. Dr. K.K.N. Nair, KFRI and Dr. N. C. Induchoodan, KFD, India were the rapporteurs.

Status reports were presented for six different states of India, viz. Kerala, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka and Tamil Nadu. The main topics covered are:

History of teak plantations, growing stock, decline in productivity, tree improvement, demand, supply market and price trends, and sustainable management, agroforestry, JFM, Sustainable harvests from natural strands and plantations.

Sub-Plenary Session I: Sustainable Forest Management (SFM) with reference to teak

The session was chaired by Mr. R. P. S Katwal, IFS, Director General, ICFRE India and co-chaired by Mr. Raymond Keogh, TEAK 21, Ireland. Dr. K. Jayaraman, KFRI and Mr. K. C. Chacko, KFRI were the rapporteurs.

Three plenary papers were presented. Dr. Sankar described the efforts made to develop criteria and indicators (C&I) for sustainable management of teak plantations and presented several indicators derived for the purpose. Two other presentations were on Malaysian experiences in timber certification by Mr. Chew Lye Teng and on certification and labelling of teak wood products : opportunities and challenges in India by Dr. K. Satyanarayana Rao.

The points of interest that emerged in this session are the following:

- Plantations will play a major role in meeting the demand for wood. Development of a framework of criteria and indicators for sustainable management of plantations has caught a lot of attention in the recent times.
- There is need to make more efforts in this direction.
- Timber certification would have an important role to play in forest management in the future as there is a tendency to prefer certified timber globally.

Sub-plenary Session II: Quality timber products of teak from SFM

Mr. Raghavan Nair IFS, PCCF Kerala Forest Department (Rtd) and Dr. P.J. Dilip Kumar IFS, Addl. PCCF, Karnataka Forest Department were the Chairperson and Co-chairperson respetively and Dr. R.V. Rao, IWST, India and Dr. C. Renuka, KFRI were the rapporteurs.

Five plenary papers were presented in this session. In his presentation on the policy issues relating to the development of teak as a quality timber, Dr. C. Chandrasekharan mentioned that teak as a business enterprise raises several policy issues relating to land tenures, land uses, land allocation, land laws, planting technology and system (monoculture vs polyculture), genetic improvement, market based approaches to teak development etc. Dr. K.M. Bhat highlighted the promises from teak wood farming and home garden forestry as sustainable options in the light of recent research findings. He pointed out that although generally teak attains mechanical maturity of timber around 20 years, the increased proportion of juvenile wood in the timber from short rotation plantations, with relatively low heartwood and extractive contents, has certain limitations for use in very durable products for which teak has world wide reputation. Mr. Luis Diego Perez Cordero and Dr. Markku Kanninen presented the experimental results on timber quality of high input plantations of Costa Rica and stressed the fundamental need for linking forest management practices to timber industry's requirements. Prof. T. Okuyama endorsed that many properties of teak are not adversely affected by faster growth rate and growth stresses are not major problems in teak. Mr. Myint Kyu Pe stated that Myanmar has four quality classes of teak for export and a timber Certification committee has been established to facilitate sustainable forest management and better marketing of teak.

Major points of interest that developed include:

- Policy needs to be translated into strategies after policy research, which is essential to address the problems and to avoid fads becoming policy is a neglected field of forestry.
- Growth acceleration by silvicultural treatments does not always adversely affect the wood qualities in teak. Opportunities seem to exist for timber production of acceptable quality from relatively short rotation plantations of farm forestry and home garden forestry by applying tree improvement / genetic modification technologies.
- Technological interventions in various stages of the wood chain from the multidisciplinary efforts of wood technology, biotechnology and silviculture are needed for sustainable production of environmentally acceptable wood products.
- While long rotation plantation management is to be maintained with long-term sustainable principles for traditional qualities, short rotations may offer dividends and quick returns on plantation investment.

Sub-Plenary Session III: Institutions, Investments and Networking

Mr. Raymond Keogh, International Coordinator Teak 21, Ireland and Mr. Masakazu Kashio were Chair and Co-chairs of the session, who were supported by Mr. Anthony Sturre, Rewards Group Ltd. Australia and Mr. Raul Polato, Italy as rapporteurs.

The representatives of different teak institutions, viz. Floresteca Agroflorestal LTDA, The Netherlands, Forest Research Support Programme of FAO for Asia Pacific (FORSPA), Bangkok, Goodwood Investments, Netherlands, IUFRO (5.06.02) Teakwood Working Party and TEAKNET, Myanmar presented perceptions of their respective institutions for effective networking of teak development programme including the investments.

The general consensus arrived at the session includes the following:

- To develop awareness/training programmes for marketing the tropical timbers from sustainable management with the involvement of stakeholders.

- There is a bigger role for financial institutions in future like banks to develop feasible programmes/projects for supporting the rural communities to participate in production, processing and marketing the quality timber/ products.
- Projects need to be developed and submitted in consultation with Asia Pacific Association of Forest Research Institutions (APAFRI) for support as Forest Research Support Programme of FAO for Asia and the Pacific (FORSPA) cannot directly support individual institutions of country directly.
- Effective regional/international networking programmes needs to be developed by reactivating the programmes of IUFRO Working party and other international teak institutions.

Session III: Genetic aspects of teak wood production

The session was chaired by Dr. K. Gurumurthi. Dr. A.K. Mandal was the Co-chairman, and Dr. M. Balasundaran and E.J. Maria Florence, the Rapporteurs.

Five papers were presented. In his plenary paper, Prof. Erik D. Kjaer from Denmark critically reviewed the options available for genetic improvement of teak through conventional methods such as provenance trial, plus tree selection, progeny trial and different selection methods. Dr. Nicodemus, India estimated the genetic variation in teak populations of Central India and the Western Ghats through Randomly Amplified Polymorphic DNA marker technology. He concluded that as genetic variation was more within population, selection within population may capture major portion of genetic diversity existing in the species. Hence, a seedling seed orchard-based approach was suggested to obtain broad genetic base for raising plantations. The problems related to flowering, fertility variation and fruiting in clonal seed orchards were presented by Dr. Mohan Varghese, India. Since imbalance in relative flower and fruit production were observed among the clones in the clonal seed orchards, selection of suitable clones and manipulation of their relative position in the orchard for maximizing quality seed production was suggested by him. Dr. E.P. Indira from KFRI presented the probable reasons for poor productivity of clonal seed orchards in Kerala. Mr. Rajesh Gunaga from Karnataka State proposed a few management options for seed orchards. Main points emerged from the deliberations are the following:

- Although the modern biotechnological options such as marker-assisted selection will enhance the speed and accuracy of genetic improvement of teak, such techniques may not be able to substitute the conventional methods such as provenance trial, plus tree selection, progeny trial and different selection methods.
- RAPD marker study of teak populations of Central India and the Western Ghats suggest that selection within population may capture major portion of genetic diversity existing in the species. A seedling seed orchard-based approach is suggested to obtain broad genetic base for plantation raising.
- Since there is imbalance in relative flower and fruit production among the clones in the clonal seed orchards, selection of suitable clones and manipulation of their relative position in the orchard for maximizing quality seed production pays significant role.
- Various management options were identified to improve productivity of seed orchards.
- There is a need to study the genes controlling heartwood formation, water use efficiency, wood quality, and exploitation of male and female sterility.

Session IV: Sustainability of teak plantations

Five papers were presented with a plenary paper on "Are intensive teak plantations in agroforestry practices environmentally and ethically sound?". The deliberations centred around the following crucial issues to develop further strategies.

- Implementation of tree improvement programmes be widely adopted in support of small holders and farmers wood lots which should be locally and community-based activities for sustainability.

- Soil management and coordinated long-term site and water resource management programmes are crucial to prevent the land degradation over successive rotations of teak plantations in view of sustainable forest management.

Session V: Clonal propagation and genetic improvement

Dr. Erik Kjaer (Chairman)
Dr. P.B.Gangopadhyay, IFS (Co-chairman)
Dr. Mohan Varghese (Rapporteur)
Dr. E.P. Indira (Rapporteur)

Six papers were presented in this session. Six Papers were presented in this session. In her plenary paper on tissue culture for improved productivity of teak, Dr. Kendurkar described the refined technology for micropropagation and scaling up of production of plants. She also mentioned about the progress made in the field of cryopreservation and wood quality of tissue cultured teak. Dr. D. K. S. Goh, Malysia, presented the results of the improvement programme launched in 1990 with the research support from CIRAD-Foret, France. Materials from selected sources were multiplied through tissue culture and field planted at different sites. Seed lots from natural forests, plantations and multiprovenence clonal seed orchards were also tested for superiority and CSO materials were found to be better in growth when analysed in fifth year.

The general recommendations are the following:

- There is a need to evaluate the both micro- and macro-propagated plants in comparison to seedlings in order to assess the genetic gain. It is also suggested to widen the genetic base and to use genetically improved material while cloning.
- The juvenility of the material used for clonal propagation should be tested and only juvenile material should be used for clonal propagation for raising plantations so as to increase the growth period and to avoid early flowering.
- When teak seed orchards are established the clonal variations should be taken into account so as to ensure panmixis and high productivity.

Session VI: Health of cultivated teak

This session was chaired by Shri. Trivedi Babu IFS, Chief Conservator of Forests (Planning), Government of Kerala and co-chaired by Dr. K.S.S.Nair, former Director of KFRI and Emeritus Scientist, Kerala University, Trivandrum. The rapporteurs were Dr. George Mathew and Dr. K.V. Sankaran of KFRI.

Five papers dealing with insect pest and disease problems were presented. In his plenary paper on " Pest factor in the intensification of teak cultivation: a global assessment," Dr. K.S.S.Nair gave an overview of pest problems of cultivated teak in various countries based on an assessment of factors controlling pest outbreaks in forest plantations. Dr. O.K. Remadevi, made an observation in Karnataka state that none of the clonal germplasm banks shows any significant variation with respect to defoliator incidence emphasising the need to look for other strategies of pest management. According to Dr. Jamaluddin, incidence of seed borne fungi, occurrence of various foliar diseases in nursery seedlings, bacterial collar rot, root rot and heart rot in coppice teak are some of the serious disease problems of teak plantations in central India. Besides, instances of teak die back due to non-pathological reasons were also presented which required detailed investigation. Dr. C. Mohanan noted that the root trainer nurseries are fairly free from major disease problems as compared to the conventional nurseries despite the new disease situations due to air borne pathogens. Based on the survey of soils under teak in Kerala state, he highlighted the potential of mycorrhizal manipulations for increasing the productivity of teak stands.

The session concluded with the following recommendations

- In all the major teak growing countries such as India, Myanmar, Thailand and Indonesia, the teak defoliator Hyblaea puera is the most serious pest. In Africa and Latin America, although teak plantations are more or less free from major pests, outbreaks of teak defoliator have been recently reported from some of the Latin American countries such as Brazil and Costa Rica, which suggests the possibility of this pest assuming major pest status over the years. Same will be the case with Australia considering the fact that this insect is already present in this country on other alternative host plants.

- Defoliation of teak by the defoliator is estimated to cause over 40% reduction in volume increment and considering the great economic potential of this pest in the global scenario, it is essential to include pest factor also in the management plan while considering the intensification of teak cultivation.
- Disease problems are on the increase in high input plantations. Incidence of seed borne fungi, occurrence of various foliar diseases in nursery seedlings, bacterial collar rot, root rot and heart rot in coppice teak are some of the serious disease problems to teak plantations in central India. Besides, instances of teak die back due to non-pathological merit further investigations.
- Enhancement of the productivity of teak stands through mycorrhizal manipulations needs to be addressed.

Session VII: Economics of teak plantations

The session was chaired by Mr. A.S. Dogra, IFS, Principal Chief Conservator of Forests, Punjab State, India, and co-chaired by Dr. Daniel B. Krishnapillay, Director, Forest Plantation and Medicinal Plant Division, Forest Research Institute Malaysia. Dr. Mammen Chundamannil and Dr. C.N. Krishnankutty of KFRI were the rapporteurs

There were three oral presentations in this session. Dr. S. Saravanan, based on his studies in teak planted in farmlands, recommends for cultivation of teak with site-specific technologies for optimum growth and yield. Dr. R.S. Dhanda. highlighted the opportunities for teak cultivation in agricultural fields by the farmers as well as by the State Forest Departments in avenues along roads, railway tracks and canals. Dr. P. Indira Devi stressed the need for scientific management to ensure maximum yield as the productivity in many plantations is below the site potential.

Main points of interest that developed from the deliberations include:

- Cultivation of teak in farmlands and outside forests in roadside, railway tracks and canal sides should be encouraged to obtain optimum growth and yield by appropriate site-specific technologies. The appropriate technologies should be transferred to rural communities by field demonstration and training programmes.
- There is a need for scientific management to ensure maximum yield as the average yields in many plantations are the site potential. Proper management even for ensuring the potential production and maximum economic efficiency is recommended.

Session VIII: Management, economics and policy

Dr. C. Chnadrasekharan, the Chairperson and Dr. M. S. Haque, Co-chairperson were supported by Mr. Sylvio de Andrade Coutinho, Brazil and Dr. P. K. Muraleedharan KFRI, as rapporteurs. This session had three oral presentations.

In his plenary paper, based on the observation on increasing the area of global teak plantations, including as exotic in South America, and decreasing the productivity in the home countries of teak, Dr. Mammen Chundamannil argued that teak plantation activity needs to be minimised under forestry sector while it is to be promoted more outside the forests involving private sectors in order to reduce pressure on forests to meet timber demands. According to Mr. K.P. Ouseph, the forest encroachment problems could be contained not by the present practices of restricting tree cultivation in the encroached land, but by stipulating the land use patterns. Dr. M.S. Haque presented the activities of National Bank for Agriculture and Rural Development (NABARD) relating to forestry. He informed that the Bank has funded some viable teak projects submitted by both the public and private agencies. According to him, the major problems faced by teak farmers is lack of quality planting materials and the strict transit rules which need immediate attention of the planners, policy makers, forest departments.

Major points that emerged are:

- There is a vital question with regard to raising teak plantations in public sector and quality teak plantations outside forests in mixed home gardens. The tone was to reduce size of teak plantations in forestry sector and increase in other areas, which will reduce pressure on natural forests.
- The farmers are by and large willing to cultivate teak in their land with mixed crops for which they should be encouraged. This will naturally lead to increase the production of teak to meet increasing demands.
- Financial institutions like national banks for agricultural and rural development support many viable projects of teak cultivation by farmers. The major problems faced by teak farmers is lack of quality planting materials and the strict transit rules which need immediate attention of the planners, policy makers, forest departments.
- Policy and economic studies on teak are as important as biological studies for enrichment of knowledge on teak as well as enhancement of more plantation activities.

Session IX: Growth and wood formation

Chairperson : Prof. H. G. Richter, Institute of Wood Biology, Hamburg, Germany
Co- Chair: Dr. K. Sathyanarayana Rao, Director, Institute of Wood science and Technology, Bangalore, India
Rapporteurs: Drs. Nobuyuki Tanaka, Japan and. K. V. Bhat, KFRI

The following four papers were presented in the Session.
Four papers were presented including a plenary paper on some characteristics of wood formation in teak with special reference to water conditions by Dr. Tadashi Nobuchi. Dr. Margaret S. Devall presented the results of a dendrochronological study on teak grown in Puerto Rico island of West Indies. Dr. A. K. Mandal gave an overall picture of the teak genetic improvement programme in India and emphasized that growth (height, DBH and basal area) and wood characters (specific gravity and heartwood percentage) are strongly inherited and most traits are under the influence of additive genes. Dr. R. V. Rao presented the results of a study conducted on a clonal seed orchard of teak established by the Karnataka Forest Department, India.

Main conclusions drawn are:

- Soil water is an important factor which influences wood formation in teak.
- Climate has also a pronounced effect on wood formation.
- Growth rate and wood characters (specific gravity and heartwood percentage) are strongly inherited and most traits are under the influence of additive gene action indicating scope for improvement through selection and sexual reproduction.

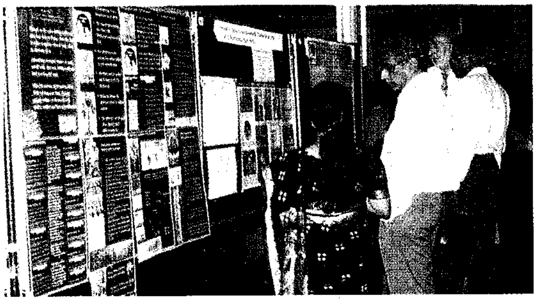
Session X: Growth and productivity

The Session was chaired by Mr. K. Subramaniam, Additional Principal Conservator of Forests, Maharashtra State Forest Department and Dr. B Mohankumar, Associate Professor, College of Forestry, Kerala Agricultural University, Mannuthy.
Mrs. P. Rugmini, KFRI and Dr. U.N. Nandakumar, KFRI were the rapporteurs.

Followed by a plenary paper on use of mathematical models, using stand density, age of economic rotation and effect of understorey vegetation, for optimising management of teak plantation by Dr. K. Jayaraman, two oral presentations were on growth convergence of teak by Dr. A. N Arun Kumar and effects of soil and leaf nutritional factors on productivity of teak by Dr. K. Sudhakara. The conclusions drawn from the deliberations are the following.

- Effective planning and implementation of density management practice with rotation age, as revealed from the mathematical models, returns from plantations can be doubled with no extra cost. To make the models effective, it is necessary to establish an international network of sample plots with facilities for data and information exchange and validation of models with field experiment are required.

Glipmses of the Conference

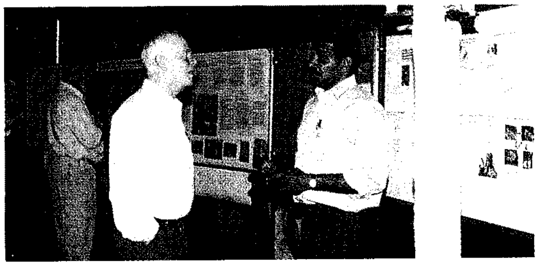


A view of the poster session

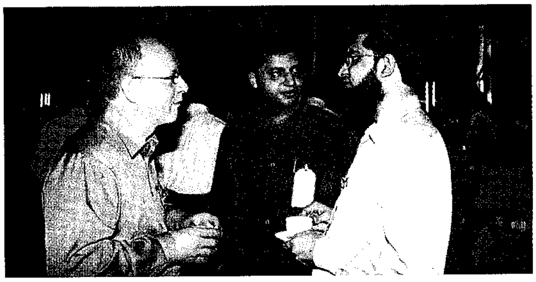
A view of the august audience

Mr. Sadhardjo Siswamartana, Indonesia

Dr. D.S. Sidhu, India



Dr. R. Keogh, Ireland and Dr. K. Surehkumar, India



Dr. Markku Kanninen, Indonesia leading discussion

Dr. C. Renuka, Dr.E.P. Indira and Ms. N. Saroja among guests.

Dr. Alexia Stokes and Dr. Adzo Dzifa Kokutse, France

- Irrespective of initial growth rate of the trees, there is a growth convergence in teak around 20 years as an age/time dependent phenomenon, which has wide ranging management implications
- Studies on effect of soil nutrients on growth of teak with larger data sets are required.

Session XI Wood quality of teak from short rotation plantation management

This session was chaired by Dr. Takashi Okuyaama, Professor, Biomaterial Physics, Graduate School of Bioagricultural sciences, Nagoya University, Japan and Co-chaired by Dr. Sunil Puri. They are supported by the rapporteurs: Dr. Margaret Devall, USA and Dr. R.C. Pandalai, KFRI.

Including the plenary paper on Assessment of some wood characteristics of teak of Brazilian origin by Polato, P.B. Laming and U Sonntag (Italy and Netherlands), two papers were presented. Mr. Polato argued with the preliminary scientific data on physical, chemical and mechanical properties that introduced teak in other countries like Brazil does not differ from the high quality Asiatic teak, and that it might be suitable for the same range of multiple end-uses. Dr. H.G. Richter, Germany concludes based on the study conducted in plantation grown teak from Ghana that the properties vary so much that it was difficult to define a juvenile-adult wood boundary as compared to Asian teak.

Major points of interests that developed include:

- Considering the fact that management techniques determine the plantation wood products, additional studies should be performed on trees growing in different site conditions/regions in order to confirm the expected natural durability and wood properties.
- As the juvenile wood volume does not increase further with age, the older the trees need to be allowed to grow for higher volume of the more profitable grade I timber with more uniform adult wood.

Session XII: Timber trade and price trends

Mr. Robert George Steber, Managing Director, Ginnacle Import- Export Pvt. Ltd, Singapore chaired the session who was assisted by Dr. V. Anitha, KFRI.

Altogether, including a plenary paper, there were four presentations dealing with teak trade, teak wood price projections, wood balance situation in Kerala and future trends in the availability of teak wood. The plenary paper by Mr. R.T. Somaiya dealt with historical overview of teak trade and pointed to the fact that since 1980s, when cutting teak was restricted, Indian processing enterprises and traders had to depend on imported teak logs. Dr. C.N. Krishnankutty, based on wood balance study in Kerala State, India draws attention to the fact that non-forest sectors are the major sources of teak timber supply while import is showing increasing trend. He also projected the teak wood prices for Kerala State, India up to 2020. Dr. M. Sivaram forecasted the future trends in the availability of teak wood from forest plantations in Kerala State, India

The major points of interest developed are:

- If quality teak timber from sustainable sources does not improve, the market will shrink further to the detriment of teak trade. Plantation technology needs to be reviewed to get better quality of wood from teak plantations.
- Home-garden forestry and trees outside forests will emerge as the major sources of teak wood supply implying that forests can be reserved to meet the objective of environmental conservation and sustainability.
- Real prices of teak wood showed an increasing trend though slightly declined up to 1968, Predicted future prices also show an increasing trend up to 2020 in India especially Kerala.
- Projections reveal that extent of teak plantations in Kerala at the existing level are potential enough to meet the future demand up to the year 2030.
- However, when compared with actual past trends in the production of teakwood from forest plantations it appears that activities in promoting teak outside forests such as home gardens, farm lands should be continued.

- This would fill-up the gap between future demand and supply from forest plantations.
- Teak growing stock in forest plantations can be conserved for future use by extending the rotation age.
- Domestic demand can be met from home garden forestry and trees outside forests.

Session XIII: Teak wood industry

The session was chaired by Mr. K. K. Nair, Ex-Chief Conservator of Forests, Kerala and Co-chaired by Dr. R. Gnanaharan, KFRI. Mr. Raul Polato and Dr. T.K. Dhamodaran, KFRI were the rapporteurs.

Two papers were presented with a plenary paper on processing technology for value-added products of teak from small and medium sized Entrepreneurs (SME's) of developing countries by Mr. Peter Ebdon. The major points emerged from this session are:

- Most of the problems in teak wood processing are related to moisture content.
- Lack of adequate knowledge of appropriate use of kiln for drying the timber.
- It is recommended to organize workshop/ seminar ands educational programmes for the benefit of SMEs as ignorance causes loss of precious materials and products.

CONCLUDING SESSION

The concluding session was chaired by Dr. C. Chandrasekharan, Senior Forest Economist, FAO (Retd.) and co-chaired by Mr. R.P.S Katwal, Director General, Indian Council of Forestry Research & Education, Dehra Dun, India. The panel, consisting of the following members, drafted the resolutions after a discussion and interactions with the august audience.

Dr. Ma Hwan Ok, Projects Manager, ITTO, Japan
Prof. Takashi Okuyama, IUFRO Teak Wood Working Party Coordinator, Japan
Mr. Raymond Keogh, Coordinator, TEAK 21, Ireland
Mr. Sylvio de Andrade Coutinho, Floresteca Holding N.V., Brazil
Dr. Andrew Akwasi Oteng-Amoaka, FORIG, Ghana
Dr. Luis Ugalde, CATIE, Costa Rica
Dr. Daniel Baskaran Krishnapillay, FRIM, Malaysia
Mr. Masakazu Kashio, FORSPA (RAP), Thailand
Mr. P. K. Surendranathan Asari, PCCF, Kerala, India
Mr. A.S. Dogra, PCCF, Punjab, India
Dr. P.J. Dilip Kumar, Addl. PCCF, Karnataka, India
Dr. P.B. Gangopadhyay, Addl. PCCF, Madhya Pradesh, India
Dr. J. K. Sharma, Director, KFRI, Peechi, India

POSTER SESSION

Presentation of 26 posters in a separate Poster session promoted the scientific interactions of the Conference.

RESOLUTIONS OF THE CONFERENCE

Preamble

The excellent properties and versatile nature of teak (Tectona grandis L. f.) timber and its eminent suitability for an array of uses are well documented. The potential for raising and managing teak in different agro-ecological zones and under natural forests, plantations, and agroforestry situations as well as trees outside forests under varying intensities and mixtures is being increasingly recognized. This has led to intensive domestication and cultivation of teak in countries/regions beyond its natural habitat in the tropics. Despite the value of teak timber and its increasing demand, its full potential for providing revenue, rural income, employment opportunities and development of value-added down stream processing, and contributing to national income is not fully utilized.

Although, considerable amount of research has gone into refining various aspects of teak silviculture, management and utilisation, knowledge on teak still suffers from serious gaps in certain vital aspects such as quality of planting stock, land categorization for site-species matching, short rotation intensive management, protection from pests and diseases, downstream processing with considerations respect to the environmental conservation measures, marketing and above all policy and institutional support including identification and action on research gaps as well as technology extension. Furthermore, the overall impact of range of benefits accrued from teak plantations to meet community requirements of wood products need to be better understood to ensure the long-term sustainability of teak wood resource.

Considerations

In line with the Conference theme - Quality Timber Products of Teak from Sustainable Forest Management (SFM) in meeting the growing teak wood demands of the modern society and taking cognizance of the dynamic nature of technology, socio-economics, market, institutions, governance, policy and policy instruments the following points need to be considered.

- To regain the pre-eminence of teak in view of its sterling properties,
- To reduce production cost and improve the quality of teak wood and to adjust to the changing market requirements and specifications,
- To meet the existing and emerging demand for teakwood at prices fair to the consumer and remunerative to the producer,
- To keep the forest land under appropriate use "where it will produce most and deteriorate least" by adopting species/ provenances/ varieties for their productivity, socio-economic benefits and utility,
- To install equity (social/gender) and sustainability as prime considerations without compromising on the imperative of efficiency (i.e., input-output relationship),
- To facilitate the involvement of different categories of investors (MNCs to local farmers), for mobilizing resources and to ensure adequate return on investment,
- To involve people, community, NGOs and other stakeholders in the process of planning and development of teak,
- To continuously enhance technology, management, value addition, marketing system and institutional support,
- To add incremental doses of competitive advantage (eg. reflected in efficiency of technology, human resource and governance) to the natural comparative advantage of teak, and to guide the dynamism of the situation in positive and appropriate direction,
- To benefit from the valuable experience of other countries and institutions with the aim of avoiding duplications and supporting sustainable forestry development.

KERALA CALL FOR ACTION

Sequel to the three Regional Seminars/Workshops held on teak in the Asia Pacific Region (Yangoon 1995, Chiangmai, 1999, Jakarta 2000) during the period 1995-2000, the International Conference on "Quality Timber Products of Teak from Sustainable Forest Management", hosted by Kerala Forest Research Institute at Peechi, Kerala, India under the auspices of ITTO, was attended by 175 participants representing 14 teak producer countries and 12 teak consumer countries. A total of 69 oral presentations and 26 poster presentations on various Conference themes were made.

As part of the resolutions/ recommendations, the International Conference hereby strongly urge and call upon the national governments, research institutions and agencies, international assistance and donor organizations, investors and funding agencies, to collectively and collaboratively strive for addressing the following 13 points which will promote the tropical timber development programme for meeting the societal needs of quality timber products.

Policy

1. Formulate and enforce appropriate (sub) policy on teak within the national forest, land-use and economic policies ensuring sustainability and long term security of investments.

Research and Technology

2. Evaluate and document the present condition of the teak crop/resource, and critically appraise the technology in use in the context of the new developments in research and linkages of research findings on teak with field practices.

3. Undertake appropriate steps to refine and package up-to-date technology for application in realistic field conditions involving, for example seed technology, plant genetics, silvicultural practices, agroforestry systems, protection, harvesting, product development, processing and value addition.

4. Research efforts should be directed to improving the productivity with fast grown and quality timber and designing new products for new markets and address technology transfer issues and commercialization of innovative and new products and services with a role of intellectual property, patents and licensing practices for better encouragement and support.

5. Recognizing the need for new teak producer countries to be aware of the danger posed by potential outbreaks of the teak defoliator, Hyblaea puera, teak growers need to implement appropriate pest monitoring systems, the international organizations to support basic research and work towards prevention of outbreaks and developing suitable non-chemical methods for control of the pest by taking advantage of research already carried out in Asia.

6. Conduct comprehensive studies on 'socio-economics' of teak, under different technological systems (monoculture, mixed planting, agroforestry, etc.), in comparison to other forest crops/products to demonstrate its economic viability/superiority and potential (in terms of competitive and comparative advantages) – as a means to attract investment flows.

Sustainable management of timber resource

7. Design and disseminate guidelines and codes of best practices relating to various steps and stages of teakwood production and utilization, through adequate extension mechanisms.

8. Develop integrated research and education, and the link between education and sustainable forest management (SFM) with multidisciplinary and multifaceted approaches that establish SFM and build partnerships for training and evaluation

9. Identify and analyse unsolved and emerging problems (both technical and non-technical) and initiate and implement measures to address them adequately in a coordinated and collaborative manner.

10. Collect, develop and disseminate trade/market information to promote and facilitate market access and success for teak products.

11. Establish and implement a comprehensive system of planning (involving long, medium and short term plans; and sites/locations, systems and market and so on) to avoid arbitrariness and ad-hocism in teak resource development.

12. Promote/facilitate establishment of targeted financing (in terms of adequacy and timeliness) to ensure that plans on teak development are financially supported.

Networking

13. Strengthen the system of regional and international collaboration, co-ordination and networking to promote exchange of research results and experience, trainings and human resource development between countries of tropical Asia, Africa, Latin America and the Caribbean, supported by private sector, including communities and relevant international agencies.

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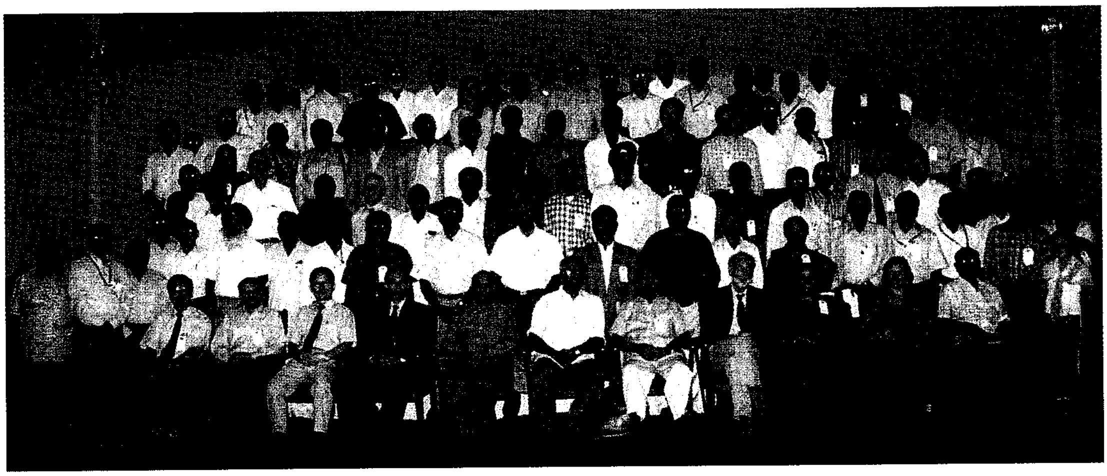

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