Processing and Marketing of

TEAK WOOD PRODUCTS

of Planted Forests

Proceedings of the Regional Workshop held during
25-28 September 2007, Kerala Forest Research Institute,
Peechi, India

Editors

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International Tropical Timber Organization, Japan

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 7 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 rattan 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. The Secretariat of TEAKNET has been relocated in KFRI to start functioning from 2008 with the support of FAO Regional Office for Asia-Pacific, Bangkok.

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 percent of world trade in tropical timber and 75 percent 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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Processing, Marketing and Price trends

PREFACE

Timber trade and sustainable forest management are the two key components of an overall trend towards globalization in the forestry sector. The area of teak plantations in South and Southeast Asian Region is reported to exceed 5.63 million ha by 2005. Teak is now being grown in plantations in as many as 36 tropical countries across the three tropical regions. About 92% of the global teak plantation estate is in tropical Asia, including about 43% in India and 31% in Indonesia, while 4.5% is in tropical Africa (mostly Côte d'Ivoire and Nigeria) and about 3% is in Central and South America, especially Costa Rica, Trinidad and Tobago, and Brazil. The production of high-quality wood in relatively long rotations of 50–70 years has been the usual practice ever since the first world's teak plantation was established at Nilambur, Kerala State of India in 1842. However, shorter rotations of 20–30 years for both veneer and sawlog production for relatively quick returns are now being employed in many countries.

It is strongly felt that regional and national studies need to be undertaken to assess the long-term demand, supply and price trends for teak. Realizing this need of hour, under the auspices of esteemed organizations, viz., International Tropical Timber Organization (ITTO), Ministry of Environment and Forests (Government of India) and IUFRO Teak Wood Working Party 5.06.02, the Kerala Forest Research Institute has organized a Regional Workshop on Processing and Marketing of Teak Wood Products of Planted Forests at Peechi, India during 25-28 September 2007.

I gratefully acknowledge the untiring efforts of Drs. K. M. Bhat, M . Balasundaran, K. V. Bhat, E. M. Muralidharan and Mr. P.K. Thulasidas in timely bringing out the edited proceedings. I hope, this document will serve as an invaluable reference source for all international stakeholders especially growers, processors, traders, policy makers and researchers. I also express my sincere appreciation to all contributors, participants and organizers of the Regional Teak Workshop 2007.

19 June 2008

Dr. K. V. Sankaran
Director, KFRI

Report on Regional Teak Workshop

Report on Regional Teak Workshop

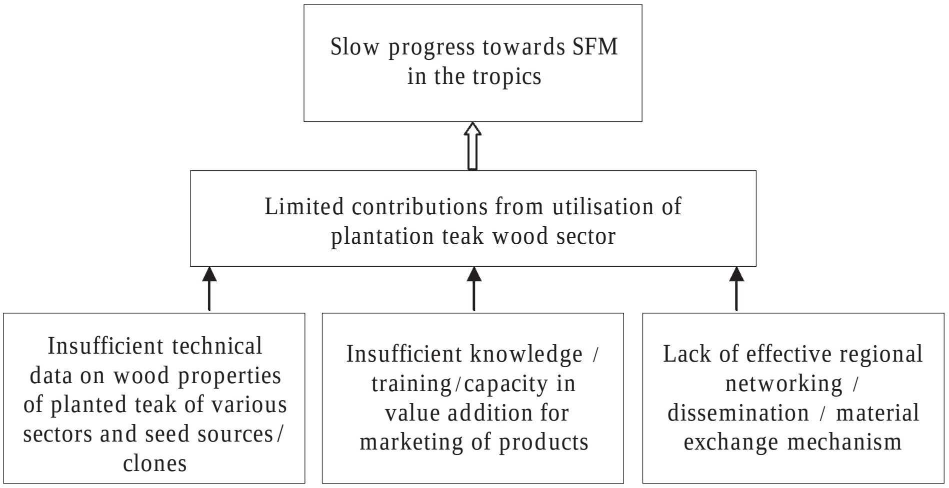
Regional Workshop on Processing and Marketing of Teak Wood Products of Planted Forests

25-28 September 2007
KFRI, Peechi, India: A Report

K. M. Bhat and R. Gnanaharan
Kerala Forest Research Institute, Peechi, India

INTRODUCTION

Teak (*Tectona grandis* L.f.) is being grown in plantations in more than 36 tropical countries across the globe although its natural occurrence is limited to India, Laos, Myanmar and Thailand. Of the estimated 187.1 million hectares of global forest plantations in 2000, about 5.7 million hectares (3%) were teak, representing about 75% of the world's high-quality tropical hardwood plantations, the major producers being India, Indonesia, Myanmar and Thailand. It is little wonder that teak excites more interest among the general public than any other tropical hardwood for its versatile wood with sterling properties. The rapid expansion of teak plantations, however, poses a risk of undermining its reputation in global market place because of wide variations in wood quality with the net effect of reducing the prices and therefore the financial viability of teak planting programmes. To avoid this, teak growers at the community and industrial levels, must ensure that the wood they produce is of the highest possible quality, which will mean choosing the right sites



carefully, using good genetic stock, employing optimal rotation cycles and appropriate silvicultural techniques.

Over the past decade, at least four international seminars/workshops were held in the Asia-Pacific Region to address the issues relating to teak resource management and utilisation. However, knowledge of performance and behaviour of teak wood products of planted forests/clonal trees of shorter rotation including agroforestry/community and home garden forestry sectors is still inadequate in the context of sustainable tropical forest management (SFM). Timber trade and SFM are the two key components of globalization and sustainable development of teak wood sector. The Workshop addressed the major challenges of 'new age eco-products' of teak that use innovative technologies for quicker production of quality timber and value addition to the products together with reducing wood waste for overcoming the limitations of small dimensional new resources as summarized below:

CORE ISSUES ADDRESSED IN THE REGIONAL TEAK WORKSHOP 2007

OBJECTIVES

In pursuance of sustainable development of teak wood sector in the Asia Pacific Region, the Workshop provided an international forum for developing a regional project on processing and marketing of quality products of planted teak from sustainable tropical forest management. It was envisaged that participation of major Asian teak producer countries, viz., India, Indonesia, Malaysia, Myanmar and Thailand together with the importing countries would accomplish the task as project partners.

The major objectives of the Regional Workshop were:

1. Clear understanding of national policies and programmes of the producer countries as project partners particularly in promoting the trade from further processing and marketing of teak products
2. Identification of the lead countries in relevant areas of research and training as well as networking to cater to the needs of the international stakeholders
3. Establishment of working relationships with necessary commitments from among the project partners for developing a regional project on teak.

Organizers and sponsors

The Workshop 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

Participants and target beneficiaries

A total of 90 delegates representing 14 countries of Asia, Australia, Europe, Central and South America participated in the 4-day Workshop including one day field excursion. In addition to the scientists/researchers from various organizations/universities, the target beneficiaries of the Workshop were small timber holders/farmers, processing enterprises, traders, State Forest Departments, Forest Development

Corporations and Policy Makers representing the following Governmental NGOs:

Farmers / Associations

Bharathiya Kisan Sangha, Karnataka
Mangala Farms, Karnataka
Varanashi Research Foundation, Karnataka

Industrialists and Traders

OLAM International Ltd., Singapore
Timber Importers Association of India,
Regency Wood Products, Mumbai
The Western India Plywood Industries Pvt. Ltd., Kerala

Policy Makers and State Forest Departments/ Corporations

Ministry of Environment and Forests, Govt. of India
FAO, Regional Office for Asia and the Pacific (RAP), Bangkok, Thailand
ITTO, Japan
Kerala Forest Department, India
Kerala Forest Development Corporation, India

Financial and Networking Institutions

Floresteca Agroflorestal LTDA, Netherlands
IUFRO, Austria
TEAK 21, Ireland

INAUGURAL SESSION

The Workshop was inaugurated by Mr. S. Regupathy, the Hon'ble Minister of State for Environment and Forests, Govt. of India and presided over by Mr. Rajaji Mathew Thomas, Member of Legislative Assembly, Govt. of Kerala. The welcome address was given by Dr. E. P. Yesodharan, Executive Vice President, Kerala State Council for Science, Technology and Environment. Dr. R. Gnanaharan, Director, KFRI welcomed all delegates to the host organisation. Mrs. Lilly Francis, President of local Grama Panchayat and Mr. S. C. Joshi, IFS, Chief Conservator of Forests, Kerala State gave felicitations. Dr. S. Appannah, National Forest Programme Advisor, FAO, Bangkok gave the keynote address. Dr. K. M. Bhat, Workshop Convener proposed vote of thanks.

TECHNICAL SESSIONS

A total of 20 oral papers and 18 posters were presented in nine different sessions including panel discussions. The technical sessions of oral presentation included: Plenary, Country reports, Status papers and other themes as stated in this report elsewhere.

Country Reports from Asia and Plenary Papers

The session was chaired by Mr. Masakazu Kashio, Forest Resources Officer, FAO, Regional Office, Bangkok. Mr. R.T. Somaiya, President, Indian Timber Importers' Association, India was the co-chair. Dr. K.C. Chacko and Dr. V. Anitha were the rapporteurs.

The country reports were presented from four Asian countries: India, Indonesia, Malaysia and Thailand. While addressing the policy issues for India in Dr. Bipin Behari's paper, Dr. Mammen Chundamannil presented a paper on investments and economic returns from teak plantations. He examined the economics of teak plantations in relation to some alternative species. After tracing the history of teak plantations in Kerala, Dr. Mammen stressed on the environmental benefits from planted teak and proposed teak as an economically viable plantation species.

Mr. Sadhardjo Siswamartana presented a report on Indonesian teak wood marketing and industries. His report brought out the following points:

- Teak is a highly preferred timber species in Indonesia and unauthorised logging is common. The productivity has increased by 75 percent by way of tree improvement programmes.
- The plantation activity should take into account the environmental and community based conservations.
- About 50% of annual teak wood production is exported from Indonesia.

The report on policy and status of teakwood production, processing and marketing from planted forests in Thailand was presented by Mrs. Chumnun Pianhanuruk. Thailand had extensive teak forests, which were later brought under the management of the Royal Forest Department. Logging ban introduced in 1989 has adversely affected the plantation activity after which Thailand became a teak importing country. Wood processing still uses low technology and immature wood and the products fall short of international standards. She recommended for training programmes to improve wood processing skills and productivity.

Dr. Lim Hin Fui, Malaysia, presented the report on Policy and status of planted teak wood, its properties and processing in Malaysia. The country has around 6000 ha of teak plantations. The technology for processing and marketing is yet to be developed. Indications are that teak products have a market potential which have initiated much planting activity while some growers pose the question - where they can sell off the wood from their young teak plantations. He suggested that more information on potential markets and end-uses of teakwood need to be disseminated to the planters and wood-based industries.

Mr. Jukka Tissari, Finland, presented the plenary paper on processing of planted teak in producer countries; problems and prospects. They stressed the point that plantation teakwood is generally inferior to the reputed wood of naturally grown teak and therefore processing costs would be higher to make the product suitable for refined applications. The papper recommended for the producer countries to carry out domestic processing of teak as a policy objective. Greater stress may be given to provenance selection and silvicultural management for improvement of wood quality for intended end-use and to adopt innovative processing methods such as heat-treatment system and camera vision and CAD (computer-aided design) technologies.

Mr. Raymond Keogh, Ireland presented the plenary paper on international pricing mechanism for the wood of planted teak. He pointed to the wide gap existing between demand and supply of hardwoods. There is a need to create more hardwood plantations and this calls for substantial increases in investments. He made it clear that due to lack of standards and appropriate information, there is wide spread uncertainty and confusion about teak investments, particularly in relation to prices. He further emphasised that establishment of an information system enabling investment decisions is a need of the hour.

Dr. John Joseph, India presented a paper on teak farming; its challenges and opportunities. Agroforestry is an important option to meet the demand of wood-based and other allied industries. Lack of quality planting stock and difficulties in following the existing timber trade rules are major constraints of teak wood farming. The following issues were emphasized:

- Strengthening of institutional arrangements to supply quality and source-identified planting stock.
- Review of policy, legal and procedural matters for entrepreneurial friendly teak wood farming.

A paper on genetic resources for higher productivity of planted teak forests was presented by John K. Hansen, Denmark. This paper brought out the following points:

- Genetic improvement of teak needs serious attention in improving productivity and timber qualities. International provenance trials are helpful in identifying source materials for propagation.
- Multi-locational international provenance trials for teak must be promoted to understand genotype-environment interaction thereby enabling selection of appropriate provenances for different sites around the world.
- Movement of teak seeds for propagation between countries should be made easier.
- Teak growing countries may be advised to make necessary modifications in their policy and procedures to enable easy movement of teak seeds across teak growing countries.

Session: Teak Wood of Planted Forests

The session was chaired by Dr. S. John Joseph, India and co-chaired by Dr. Ichiro Nagame, Japan. The rapporteurs were Dr. Jose Kallarakal and Dr. E.M. Muralidharan of KFRI, India. The first speaker was Mr. R.T. Somaiya, who spoke on the improvement of planted teakwood by Vrikshayurved methods. He described Vrikshayurved as the ancient science of (plant) life that in his experience could be revived to benefit teak cultivation. He spoke of teak being a 'social' species that grows with other tree species in the forests and therefore a mix of different species in the cultivation of teak would be beneficial. His presentation led to comments and questions on what is the right mixture of species would be and whether healing of diseases and pest was also part of the tradition. Others commented on the need for research on the subject and how economics and money govern the cultivation of species.

The next speaker was Dr. Gills Chaix, France who made a presentation on quality control and mass production of teak clones for tropical plantations and spoke about the performance of the trials conducted in Sabah ten years ago. Teak exhibited high variability in growth, morphological traits and wood properties. NIRS and molecular markers were used for assessment of the wood properties and for fingerprinting of the clones. Mass cloning of the teak through tissue culture was done.

The next presentation was by Mr. Peter Laming, The Netherlands on aspects of natural decay resistance and hysterisis of juvenile teak thinnings from Southern Mato Grosso, Brazil. He presented data on heartwood and sapwood of juvenile teak from thinnings. Fungal resistance, dimensional stability, gluing properties were studied vis-a-vis the suitability for utilization.

Mr. Sylvio de Andrado Coutinho, Brazil, described the activities of the largest teak plantation company in Brazil and spoke about the benefits and challenges of certification with regard to the sustainability of planted teak forests. He gave information about the different certification agencies.

Session: Processing, Marketing and Price Trends

The session was chaired by Mr. Jukka Tissari, Finalnd and co-chaired by Mr. Hiroshi Nakata, Japan. The rapporteurs were Dr. P. K. Muraleedharan and Dr. C. Surendran, KFRI, India. There were seven papers in the session of which one paper was on wood quality of planted teak, two on processing, three on marketing and pricing and one on forest certification of planted forests.

The first paper on wood quality of planted teak outside forests by Mr. P.K.Thulasidas, India attempted to assess the teak timber quality and value of home garden teak. The study evaluated timber quality of 35-year-old teak grown in homesteads representing wet and dry localities of Kerala in comparison with that grown in forest plantation of Nilambur. The general assumption is that teak grown in forest plantations is much superior to that grown in home gardens and based on which the price received by the latter is less. One noted conclusion was that teak wood from home garden is not inferior to that of forest plantation in its strength properties and heartwood proportion in similar age groups. This should be popularized among the farmers to get better prices for their teak wood.

Mr. Mayen Mohamed, India in his presentation explained the major wood processing activities of the Western India Plywoods, Ltd., Valapatanam, Kerala. He stressed the need for prudent use of raw materials and production of more and more innovative products of higher value addition, especially in the context of depletion and shortage of timber resources in the country.

Dr. Kishan Kumar, India presented a paper on the drying behaviour of teak under vacuum press drying. The experiment was conducted under three different vacuum level-temperature combinations. He attempted to analyse the combination that gave maximum drying rates in terms of moisture content reduction in two different initial moisture content ranges. It was found that the samples could be dried faster by employing combinations of 90^{o} C and 873 mbars of pressure. The study also indicated that drying rate under vacuum press drying is faster than that of conventional seasoning methods.

A case study conducted in Jabalpur Circle to assess the marketing efficiency of planted teak in Madhya Pradesh by Parag Dubey, India examined the pricing trends of planted teak in Madhya Pradesh. The State Forest Department (SFD) and Forest Development Corporation (FDC) are the two agencies which market teak in Madhya Pradesh and therefore, the authors compared the marketing efficiencies of these two agencies. One important conclusion was that the selling price of FDC is lower than that of SFD and the difference amounted Rs. 4300/- per m^3. This was mainly due to better quality of teak produced by the Forest Department (due to long rotation). Thus the timber merchant buys timber from the FDC and sell at par with existing timber price which gives a high profit to them.

In his paper on production, consumption and trade of teak in Kerala, Dr. Krishnankutty, India attempted to analyse the structure of timber market in Kerala. According to him, volume of the teakwood market in Kerala is to the tune of 96,000 m^3, 62 % of the teak wood production comes from forest plantations while only 2 % of the production of other timbers comes from forests. The net import of teak logs of larger girth was 7,100 m^3. The trend in import of timber is increasing whereas export is declining. Kerala, a traditional producer and exporter of teakwood in the past, is now a net importer. There is hardly any international market for Kerala teak wood due to non-availability of logs of larger girth. This may be due to shortening of rotation age of forest teak plantations to 50 years that has reduced the production of high value larger girth logs. A policy for growing logs of larger girth must be adopted by increasing the rotation age of forest teak plantations.

Dr. Sivaram, India made a projection of future availability of teak wood from forest plantations and its prices in Kerala State. He attempted to project the future availability of teak wood from forest plantations based on age structure under different scenarios and assessed how far forest plantations would meet the future teak wood demand. He used statistical models to predict the future availability of teak wood from forest plantations. The analysis of trends in current and real prices indicates that the price increase during 1990's has been low probably due to availability of substitute materials and increased timber import during the period. However, lately market for teak wood is picking up. The study also indicated that the high quality teak wood would fetch higher prices in the year 2007.

The presentation on Forest certification of planted forest based on the experience of Bhopal-India Process by Dr. Manmohan Yadav, India explained the need for managing the planted forests by following sustainable forest management practices. He also explained various initiatives on developing standards of SFM after Rio-Earth Summit on sustainable development. It was pointed out that the National Criteria and Indicators for SFM developed under Bhopal- India Process provide an opportunity to develop a national forest certification scheme for India.

Session: Project Elements from Partner Countries

The session was chaired by Dr. Daniel Bhaskaran Krishnapillay, Malaysia and co-chaired by Mr. Raymond Keogh, Ireland. The rapporteurs were Drs. K. K.N. Nair and Mammen Chundamannil, India.

Dr. K. M. Bhat, India was the first speaker. He introduced the concept of a Regional Project formulation among teak growing countries in Asia for joint submission to ITTO. He presented a project preparation format for listing the objectives, strategy, activities, the time schedule, the expected outputs etc for the guidance of those who were involved in drafting the different country components.

Mr. Sadhardjo Siswamartana, Indonesia, stressed the need for learning and applying the biopesticide Hyblaea puera Nuclear Polyhedrosis Virus (HpNPV) developed by KFRI for insect defoliation of teak trees as a project component and another to develop a "back to nature" management of teak as a mixed natural stand instead of the current monoculture plantations. He also emphasised the need for enlarging the genetic base of the planted teak in Indonesia.

Mrs. Chumnun Pianhanuruk, Thailand in her presentation called for research on pests problems of teak and for upgradation of the wood processing industry with more modern technology.

Dr. Kashio, FAO, Bangkok spoke for Myanmar as there was no delegate from Myanmar. The four themes he presented were: (i) improvement of the Myanmar Selection System of managing teak, (ii) plantation improvement, (iii) modernisation of the wood processing industry, which presently consists of very old machinery originally made to process huge logs that are becoming quite scarce and (iv) development of information services and connectivity which is extremely primitive in comparison with other teak growing countries.

Dr. Tan Tu-Eng from Malaysia pointed out that teak is not a traditional tree for farmers or the Forest Department of Malaysia. There are some shops selling teak furniture and handicraft items of teak from Indonesia. Teak farmers in Malaysia are unsure of who would be their buyers and what prices they can expect from the tree when it is harvested. Dr. Tan talked about harmonising the regional capabilities and strengths of the teak growing and marketing countries. The wood processing industry is very advanced in Malaysia which is their strength which can be utilised for processing teak from other countries to produce value added products.

During the discussion that followed, Dr. Kishan Kumar, India made remarks on the need for growing teak for the industries. Dr. Nagarajan, India wanted genetics of teak to be focused with programmes on hybridisation and cloning. Dr. Palanisamy stressed the management of seed orchards. Mr. Ricardo, Costa Rica wanted multi-country provenance trials to be carried out and research on the under story species in teak plantations for improving the cash flow from teak plantations. Dr. Manmohan Yadav, India called for information on prices and adoption of universally acceptable grading rules. Mr. Ramon Carrillo, ITTO suggested to arrive at the general consensus on the country to lead the regional project.

Mr. Kashio, FAO made the final comment touching upon the need to formulate a common approach integrating the needs of the participating Asian countries to make a regional programme. While developing the project, the preferences of the funding agencies have also to be kept in mind. He suggested the preparation of two or more projects, for example, bundling the market-oriented components in one, which will be definitely supported by ITTO as it is their priority area and another project focussing on the environmental aspects to place before the Global Environment Facility of the World Bank and genetic improvement of teak with DANIDA.

PANEL DISCUSSION: REGIONAL PROJECT FORMULATION

The panel discussion on regional project formulation was chaired by Dr. S. Chand Basha, India with co-chair Dr. Manmohan Yadav, India. Dr. S. Sankar and Dr. M. Balasundaran, KFRI were the rapporteurs.

At the outset, Mr. Jukka Tissari, Finland presented his views. He favoured 2-3 proposals encompassing not only the major Asian teak producers, but also Central and Latin American and African countries. He appreciated the Malaysian approach of technological evaluation for quality attributes. The other points he touched upon included development of new technology for quality product development from planted teak, harmonizing market with socio-economic aspects, the importance of Myanmar as the natural resource giant and China as the biggest emerging consumer.

In his presentation, Mr. Raymond Keogh, Ireland stressed the importance of taking projects on devising pricing policy, harmonizing grading rules and attaching price tag for quality and grade. In the discussion followed, the impact of sellers' ignorance of market price and the problems in formulating international grading rules were touched upon.

Mr. Peter Laming, Netherlands emphasized the market premium for quality product. He commented on the European buyers' willingness to buy the products, provided reliable quality and regular supply are assured.

Dr. Ichiro Nagame, Japan voiced importance of projects with global perspectives such as millennium development goal, addressing global warming and poverty alleviation. The other points touched upon were on the importance of partnership with stake holders and problems in international transfer of genetic material.

Mr. Hiroshi Nakata from JICA, Japan expressed his opinion on formulating grading rules. He stressed the importance of networking in processing and marketing aspects. He listed the important potential elements such as the transfer of genetic material for plantation activities, international pricing mechanism and timber grading system and cost of networking and revitalizing Teaknet. The necessity for unhindered movement of genetic material was elaborately discussed.

Dr. Daniel Bhaskaran Krishnapillay, presenting on behalf FAO Regional Office, Bangkok stressed the need for making Teaknet operational for information dissemination. Promotion of R & D activities on short rotation crop and a viable pricing mechanism were the other major points raised by him.

The process and steps involved in approval of projects by ITTO was explained by Ramon Carrillo, ITTO. How the project implementation will benefit the stake-holders would be a key point for consideration in sanctioning the projects.

While summing up, Dr. Manmohan Yadav discussed the issues addressing the IPR in particular.

Satellite Meeting of Teaknet

Chairman for the session was Dr. S. Appanah, National Programme Advisor, FAO, Bangkok; and co-chairman: Mr. Masakazu Kashio, Forest Resources Officer, FAO, Bangkok.

The Chairman in his opening remarks presented the agenda items for the meeting. The agenda items were as follows:

i) Brief introduction to Teaknet
ii) Decision to be taken for future of Teaknet
iii) Location, structure and function
iv) Steering committee
v) Financial and Physical support

Brief Introduction to Teaknet

Dr. Daniel Bhaskaran Krishnapillay, Advisor to FRIM, Malaysia gave a brief introduction to Teaknet with the presentations on why we need a Teaknet in the Asia Pacific Region, History of Teaknet, progress todate and the rules and functioning of Teaknet till late 1998. Since 1998, with the restructuring process in the Myanmar Government, regular activities of Network became difficult to implement and the Teaknet became inactive.

Dr. Krsihnapillay stressed the need for reactivating the Teaknet for the following reasons:

i) Teak is an important hardwood species
ii) Readily traded in the world market
iii) Suited and grown in countries in different agro-climatic zones
iv) Now grown in 36 tropical countries
v) Out of the total 187.1 million ha global plantations, 3% are teak
vi) Have new production technology
vii) Needs for definite grading rules and stable pricing
viii) Information to be disseminated to all those who are associated with teak

He informed the forum that during last many years, much information was generated with new findings. These findings with the current pricing practices and other information are to be collected, organized and disseminated. The possible option he put forth is to make a strong recommendation to FAO for assisting to effect necessary changes.

Options

- Retain the network in Myanmar and find out ways and means to reactivate
- Retain Myanmar as a referral Centre for natural teak management and move the secretariat to an already existing strong Network like APPARI or APAFRI which could co-host under FAO.
- Move the secretariat to a teak country, that is: a) currently active in teak management, research and trade and also willing to host the Network, b) to commit space, staff and funding and c) country which is easily accessible and is able to support information portal.

With these remarks Dr. Krishnapillay concluded the presentation.

The chairman requested the Steering committee members to express their opinion. All the steering committee members, Mr. Somaiya, Mr. Kashio, Mr. Nakata and Dr. Krishnapillay suggested to shift the Network to KFRI. Dr. Sadhardjo, Indonesia also endorsed the view and it was also suggested to retain Myanmar as a Referral Centre for Natural teak forest management and to move the secretariat to KFRI, India.

The Chairman went on record to express gratitude to Myanmar Government for supporting Teaknet in the past. He also asked the members to give their suggestions or disagreement for shifting the secretariat to KFRI. Chairman also asked the Institutions to come forward to express readiness to host the Network and the Director, KFRI expressed the willingness.

The Chairman sought the willingness from any Institution other then KFRI for consideration. Mr. Raymond Keogh upheld the decision and suggested that Teaknet need not be fixed to any country, but can move depending on the situation. Mr. Somaiya pointed out that KFRI is active and should host Teaknet since India is a major teak producing country in the world besides having natural teak forests. He also suggested that if any other country expresses willingness, an associate office could be activated in due course.

Structure and functioning

With regard to the structure and functioning of Teaknet, Chairman noted that APAFRI is functioning in Malaysia by the support from FRIM and Teaknet can function with the support from KFRI. Mr. Somaiya informed the forum that Teak21 in Ireland is active and can cooperate and work with Asian Teaknet in order to compliment each other.

Mr. Nakata informed that another project is submitted by Myanmar, which is same as that of India's and this can be sorted out through Teaknet. Mr. Ichiro Nagame asked whether Chairmanship of Teaknet could be rotated. It was clarified that Chairman of the Teaknet can be appointed from any member country and asked to fix the term for Chairmanship. Dr. Krishnapillay cited APAFRI's situation (having a Chairman from Sri Lanka) and pointed out that chairman can be replaced in 3-5 years.

With regard to regional meetings, Mr. Kashio pointed out that originally it was planned for two years but in reality meetings were conducted at 3-4 years interval. Dr. Mammen suggested that based on the periodic performance review, the host of Teaknet can be relocated. Mr. Keogh suggested a five year period and it was unanimously agreed. Director, KFRI suggested to include this issue in framing new Bye Law.

With respect to Functioning it was agreed that the present Steering committee members could continue. Dr. Appanah, Chairman recommended to expand the Steering Committee with the constitution of 9 members. Research institutions from Japan and from other countries can be included although currently it is for Asia Pacific region.

Regarding physical and financial support, Chairman suggested three points i) to bring more members to Steering Committee ii) to review the fee and make it uniform to developing and developed countries iii) to find out whether private companies can financially support Teaknet.

Mr. Ricardo from Costa Rica agreed to try his level best while others members from private companies also showed interest. As to the query from the forum, Dr. Appanah, Chairman also agreed for contribution of US$ 10,000 from FAO as seed money.

Next item for discussion was on the selection of a Co-ordinator at KFRI for the Teaknet. Dr. Bhat from KFRI was asked to give an account of the initiation of work. Dr. Bhat gave an account of the work initiated for a Global Teaknet at KFRI. He informed that FAO has already offered a consultancy to KFRI in this regard and KFRI has prepared a Website and a new Logo. The chairman and the members suggested to retain the old logo with few modification reflecting scope at global level. He also presented the strength and contributions of KFRI to Teak research and management. In response to a query, Mr. Keogh informed that Teak 21 would collect information and link it to Teaknet in future.

POSTER SESSION

Presentation of 20 posters covering various themes of teak productivity, wood quality and farming in a separate Poster Session promoted the scientific interactions of the Workshop.

The delegates also enjoyed one-day Field Excursion and cultural programme during the Workshop.

CONCLUDING SESSION

The concluding session was chaired by Mr. Ramon Carrillo, Projects Manager, ITTO and co-chaired by Dr. R. Gnanaharan, Director, KFRI. The panel drafted the recommendations for discussion and finalisation among the august audience.

Recommendations of the Regional Workshop

Preamble

Teak excites more interest among the general public than any other tropical hardwood for its versatile wood with sterling properties. The rapid expansion of the teak plantations, however, poses a risk of undermining its reputation in global market place because of questionable promises in terms of growth rates and economic returns and wide variations in wood quality with the net effect of reducing the prices and therefore the financial viability of teak planting programmes. To avoid this, teak growers, at the community and industrial levels, must ensure that the wood they produce is of the highest possible quality, which will mean choosing the right sites carefully, using good genetic stock, employing optimal rotation cycles and appropriate silvicultural, processing and marketing techniques.

Considerations

Knowledge of performance and behaviour of teak wood products of planted forests/clonal trees of shorter rotation including agroforestry and home garden forestry sectors is still inadequate in the context of sustainable tropical forest management (SFM). Appropriate steps need to be taken for refining and adopting up-to-date technology for application in realistic field conditions involving seed technology, tree genetics, silvicultural practices, agroforestry systems, protection, harvesting, processing, product development, value addition and marketing. These steps will help consolidate and strengthen the entire teak sector.

Recommendations

Policy & finance

1. Formulate appropriate (sub) policy on teak within the national forests, land use, industrial processing and socio-economic policies ensuring sustainability and the development of an enabling environment for the long term security of investments.
2. Establish and implement a comprehensive system of planning (involving long, medium and short term plans; and sites/locations, systems and market) for teak resource development.

Wood property analysis

3. Enhance the knowledge base of the wood properties and machinability of short rotation plantation teak - including those grown outside forests (ToF) - so as to ensure that they are processed within the acceptable tolerances of other tropical timbers.

Processing Technology

4. Develop new/innovative conceptual models for teak processing industries based on Best Available Technology (BAT) and the experiences from other industries.

Marketing

5. Develop common grading systems to support vibrant teak sector for the value-added processing of plantation teak wood. Develop market information system for collection, collation and dissemination of teak trading volume and price information

R & D and Training

6. Evaluate, document and disseminate R & D findings
7. Promote tree improvement through:
   - Globally coordinated R & D and
   - Facilitating process of exchanging genetic materials.
8. Appraise the processing technology in use in the context of the new developments in research and transfer to the field.

9. Conduct comprehensive socio-economic studies of teak under different technological systems as a means to attract investment flows.
10. Undertake growth and yield studies by consolidating data from international network of sample plots.

Code of Best Practices

11. Develop and promote sustainable practices for teak wood production and utilization codes (social, environmental and economic)

International Cooperation and Coordination/ Networking

12. Strengthen regional and international cooperation, collaboration and co-ordination in teak development with special emphasis on human resource development.
13. Support KFRI, one of the lead institutions, to host the secretariat of Teaknet and establish linkages with other national, international and NGO networks in collaboration with FAO and ITTO.
14. 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.
15. Prepare and submit the regional projects to international donor agencies in thrust areas, viz., processing and marketing, productivity / genetic improvement and social / ecological / policy issues.

Workshop Participants

Inaugural Session of the Workshop

Lighting of lamp by Mr. S. Regupathy Hon'ble Minister of State for Environment and Forests, Govt. of India (Left)

Welcome Address by Dr. E. P. Yesodharan, Executive Vice President, KSCSTE (Right)

Dr. R. Gnanaharan, Director, KFRI briefing about activities of KFRI (Left)

Mr. Rajaji Mathew Thomas, MLA delivering presidential address (Right)

Mr. Hiroshi Nakata, JICA, Japan giving addressing on behalf of ITTO representative (Left)

Dr. K M Bhat proposing vote of thanks (Right)

Glimpses of the Workshop

Satellite Meeting of TEAKNET

Chairman and Co-chair conducting a session

View of the audience

Cultural Programme- Traditional Dance of Kerala –*Kathakali*

Plenary Papers

Planted Teak: Policy Considerations and Sustainable Management

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ABSTRACT

The efficient management of land resources is *sine qua non* for all efforts aimed at overall growth, along with social justice and community welfare. In recent times, teak has attained maximum importance because of the entry of corporate sector and individuals in teak investment schemes in a big way with attractive claim of very high returns. Tropical forestry has got impetus by considering teak as the flagship of tropical hardwoods for throwing light on the potential of sustainable investments. Available technologies have also firmly established that teak is a viable tree crop in the tropics but have not succeeded in increasing productivity and quality over a period of time. Government of India's policy to increase forest and tree cover to 33 percent of the geographical area of the country by 2012 brought all stakeholders and policy makers together to strive hard for making forest plantation, a movement of the people as it will require additional 33.60 million ha under forest and tree cover. The policy interventions, initiatives and incentives are the key issues which can lead forward the pace of planting from the present 1.5 million ha per annum to the desired rate of about 3 million ha per annum. The production, consumption and trade including export and import and its role in the sustainable development of all stakeholders and thereby increasing the livelihood opportunities for the people are the critical areas where the participation of private individuals, growers, farmers and industries is essential. In the plantation of teak and its trade with economically viable and technically feasible sustainable forest management (SFM) approaches, the policy roadmap has to pass under crucial phase of economic and social ethos. The focus here is on policy considerations, initiatives, incentives and further policy interventions required to achieve large scale plantation of teak to bridge the gap between demand and supply with the commitment to SFM.

Keywords: Teak plantation, production, consumption, trade, sustainable management, initiatives, policy issues.

INTRODUCTION

Plantation forestry has emerged as a high yielding alternative to the traditional system of natural reproduction. Teak (*Tectona grandis* L.f.), a species of worldwide reputation as paragon among timber trees, is a component species of the tropical moist and dry deciduous forests of the South and South-East Asian Region. Troup (1921) judged teak as the most important timber tree of India. It is known for its strength, durability and maintaining attractive appearance. The ever increasing need for teak timber for its myriad uses has resulted in large scale plantations, both within and outside its range of natural distribution. Teak is used as a standard for quality rating of other timbers in India. From a policy point of view, apart from its physical properties, teak earns increased merit for the ecological, social and economic benefits it generates.

Teak occurs naturally in the Asia Pacific Region over an area of 23 million hectares in India, Laos, Myanmar and Thailand. It thrives best and reaches large dimensions in moist, warm and tropical climate. Its natural distribution ranges from sea level to mountainous areas of 800 m and in exceptional cases, up to 1300 m above. It can survive and grow under wide range of climatic and edaphic conditions in fragile eco-system. The rotation of crop takes place in 60-120 years. Shorter rotations of 20-30 years of teak for both veneer and sawlog production for relatively quick returns are now being employed in many countries (Ball *et al.*, 1999). Teak has good potential as plantation species (Loke, 1996) for quality products, which leads to strong drive for quality standards to guarantee sustainable forest and plantation management as well as user safety of end products. The policy interventions for large scale afforestation of teak are significant not only to bring large areas under forest and tree cover for sustainable management but to bridge the increasing gap between demand and supply of timber and timber products.

TEAK PLANTATIONS: GLOBAL SCENARIO

Teak is being grown in plantations in at least 36 tropical countries across the three tropical Regions. Of the estimated 187.1 million hectares of global plantations in 2000, about 5.7 million hectares (3%) were teak (FAO, 2001). Other species such as eucalypts (30% of hardwood plantations) and *Acacia* (12%) are grown more widely, but teak constitutes about 75% of the world's high-quality tropical hardwood plantations (Keogh, 1999). About 92% of the global teak plantations is found in tropical Asia including about 44% in India, 31% in Indonesia while 4.5% is found in Tropical Africa (mostly in Cote d' Ivoire and Nigeria) and about 3% in Central and South America especially in Coast Rica, Trinidad and Tobago and Brazil.

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. Laurie and Ram (1940) constructed a yield table for teak plantations in India. It indicates the early peak of mean annual volume increments (MAI) between 6 and 20 years. High MAI of above 20 m^3 per ha per year is reported from Indonesia, Trinidad and Tobago (Pandey and Brown, 2000). The rate of teak afforestation in India is one of the highest among the tropical countries. Teak plantations have become important to fill the gap between demand and supply of teak wood. To meet the global timber requirements in the context of reduced output from natural forests due to the practice of sustainable forest management (SFM), plantations of hardwood species such as teak in large areas have been done in many parts of the country and are being taken up at larger scale with private investments. Private investments on teak plantations have begun as a response to the growing demand in many parts of the country. High quality teak plantations thus have great potential for contributing to SFM by meeting the social needs and releasing pressure on natural forests for increased supply of forest goods and services. The area under teak plantations in India is estimated to exceed 2.5 million ha. (approximately 44% of the global teak plantations).

PRODUCTION, CONSUMPTION AND TRADE

The potential round wood supply from plantations is around 370 million m^3 per year, which is 25% of the global industrial round wood production (Whiteman and Brown, 1999). The practice of SFM and ban on logging in natural forests in many countries have reduced the production of teak wood from the natural forests and thereby increased the dependency of market on planted timber. Since the imposition of ban on logging in natural forests in Thailand in 1989, the timber production has declined from about 2 million cubic meter in 1988 to 20,000 cubic meter in 2003 (RFD, 2003). In India, currently, about 50% of the wood supply in the country is received from non-forest resources. A substantial portion is accounted for by imports and the balance is obtained from plantations. Timber products in India mainly comprise roundwood logs, sawn wood, veneer and plywood. The trend of production and consumption of forest timber products in India over the years 2001-2005 are shown in Table 1 & 2.

A comprehensive review of Indian consumption patterns undertaken by various studies shows that tropical hardwoods are commonly used for end products by a majority of consumers. However, convoluted procedures and high transaction costs on the one hand and paucity of requisite data and market diversification on the other could cause the loss of potentially high demand prospects for tropical hardwoods.

To meet the gap between demand and supply, plantation timber from the non-forest areas raised through agro-forestry and farm-forestry, etc. have played a significant role but the import of timber also raised simultaneously. The bulk of imports in India are in an unprocessed form, mainly as logs. Relatively small but sizeable quantities of sawn wood are also imported while veneer and plywood are almost negligible and limited to some specific categories. The Table 3 gives details of export and import scenario of timber and Table 4 gives the details of Export and Import of teak wood under the ITC (HS) Code 4403. Teak import is largely in log form whereas its export is in the form of sawn timber and value added products.

Most of the sawn timber in India is consumed in the domestic market but the fact remains that the worldwide demand of teak is much more than the available resources (Dupuy, 1990). The demand for high quality wood will continue to grow despite gains made in engineered timber and other

Table 1. Production of Timber Products ('000 Cu.m)

Item/Year	2001	2002	2003	2004	2005
Round wood/logs	13500	13500	13500	13500	13500
Sawn wood	6800	6000	6000	6000	6000
Veneer	55	235	246	258	258
Plywood	1300	1600	1760	1936	1936

Table 2. Consumption of Timber Products ('000 Cu.m)

Item/Year	2001	2002	2003	2004*	2005*
Round wood/logs	15914	15051	16293	16535	16535
Sawn wood	6806	6007	6010	5984	5984
Veneer	56	238	249	257	259
Plywood	1253	1551	1704	1911	1911

* Figures are rounded off.

Source: FAO Yearbook, "ITTO Annual Review and Assessment of World Timber situation-2005".

Table 3. Export-Import of timber

S. No.	Year	Total timber export (Million m^3)	Total timber import (Million m^3)
1.	2001-2002	6.7	5.7
2.	2002-2003	18.5	5.5
3.	2003-2004	0.6	6.0
4.	2004-2005	0.6	6.5

Source: Directorate General of Commercial Intelligence & Statistics, Ministry of Commerce & Industry, Government of India.

Table 4. Export-Import of Teak

S. No.	Year	Export		Import	
		Quantity (m^3)	Amount (Indian Rs. in million)	Quantity (m^3)	Amount (Indian Rs. in million)
1.	2001-2002	400	3.0	433,096	6364.7
2.	2002-2003	4,451	52.3	349,429	5173.1
3.	2003-2004	1,911	45.5	429,580	6585.8
4.	2004-2005	446	8.1	812,193	10502.9
5.	2005-2006	876	26.9	799,421	11948.7

Source: Directorate General of Commercial Intelligence & Statistics, Ministry of Commerce & Industry, Government of India.

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. To meet the global requirements of timber mainly teak, in the context of reduced output from the natural forests due to the practice of SFM, establishment of large areas of tropical quality plantations of teak is highly essential. The wood based industries in India requiring the wood from various sources estimate to the tune of about 81.67 million m^3 as per FAO estimate. The mounting estimate of wood to meet the gap between demand and supply is visible from the Tables 3 and 4 if the commitment is made from the policy point of view for SFM. As a major policy initiative, the Government of India permitted wood import by classifying wood under Open General License (OGL) in 1996 (which is called 'Free' now) with a view to ease out the wood shortage, as also to reduce pressure on natural forests. However, the tariff structure is biased in favour of imports of logs and conscious attempts have been made to keep out import of processed wood and products to protect the domestic wood processing industries. India does not have any export duties and encourages exports for which it also grants several concessions to the exporters. These concessions are in the nature of exemption on income tax, and refund of import duties if exported goods are processed from imported raw materials. Country has imposed complete ban on export of logs whereas export of wood based value added products are being encouraged.

According to an estimate, there would be a shortfall of about 121.5 million m^3 of commercial wood by the year 2015 (IPIRTI, 2003). Therefore, the mounting tree plantations and the Government policy to encourage such plantations will go a long way in having larger plantations in non-forest areas, as the natural wood properties, specifications and supply are three critical market factors which will continue to influence the domestic and international marketing potential of timber in general and teak in particular.

The domestic trade of timber and forest products is on large scale, but due to lack of available data for the same, the contribution of forestry sector towards the Gross Domestic Product (GDP) does not give a clear picture. The export/import of forestry products under the Foreign Trade Policy (2004-09) are governed by certain prohibitions and restrictions. 29 forestry species are prohibited to be exported under Chapter 12 and necessary mechanism for port restrictions have also been envisaged to ensure the export and import of legal timber and forest products. The tariff structure has been liberalized keeping ITC (HS) codes 4403 and 4406 in the Negative list with most of the trading blocks, largely to safeguard the interest of the growers and farmers of Agro-forestry and Farm-forestry.

SUSTAINABLE MANAGEMENT

Forests play an important role in social and economic development of any country. India is one of the 12 mega-diversity countries but losses due to deforestation are some of the vital concerns to the country. There are four important causes of deforestation in India (a) clearing the forestland for farming (b) demand for firewood and fodder (c) uncontrolled grazing in forests and (d) diversion of forest land for developmental activities. These factors are further aggravated by population growth both human as well as cattle and infrastructural and industrial development. Thus, there is need to understand the relationship between forestry and development. The developmental agencies must ensure the compatibility of their non-forestry development programmes with more specific forestry activities to compensate.

The SFM mainly emphasizes on the production of a continuous flow of desired forest products and services without undue reduction of its inherent values and future productivity and without undue undesirable effects on the physical and social environment (ITTO, 1992). In general, the following strategies are required for sustainable management of forests and teak plantations:

(i) Commitment to the national Forest Policy and programmes.
(ii) Conservation and protection of natural forests with the production of timber through silvicultural management.
(iii) Identification of the areas for production of timber to meet the demand for fuelwood, fodder and industrial wood.
(iv) Silvicultural management of natural forests and plantations for their growth and sustained yield.
(v) Involvement of the local communities in planning, development process and their management.

Joint Forest Management (JFM) in India, based on the concept of "Care and share" introduced in 1990, aims at the partnership between the State Forest Department and the Local Communities. As a result, about 22 million ha. of forest land at present are being managed by about 1,06,482 JFM Committees in India. The JFM is leading to regeneration of degraded forests, reduction in frequency of conflicts, vacation on encroached forest land and improved livelihoods. The involvement of people in the management of forests is thus, leading to creation of an efficient institutional framework for the protection of forests, apart from meeting the livelihood needs of the people. JFM Committee has been recognized as a vehicle of ensuring SFM and conservation with local community participation.

PLANTATION FORESTRY

Plantations are the alternatives to dwindling natural forests. They have profound implications in socio-economic and bio-diversity context of forests. They play a significant role in meeting the demands of the people for wood and non-wood forest products without affecting the natural forest eco-system. Moreover, they make significant impact on over all eco-system structure and functions. They help in rehabilitation of degraded lands, influence hydrological cycle, restore wildlife habitat and modify over all bio-diversity of eco-system.

One analysis had concluded that plantations are needed where: (a) natural forest is inadequate (b) natural forests grow too slowly to meet forest products' demand on a sustained yield basis (c) natural forests are too scattered to permit ecological harvesting, and (d) natural forest timber is too remotely located to be transported economically (Marsh, 1962).

But the farmers often hesitate in having plantations because of the following reasons:

(a) It is a long term investment. The farmers prefer the species which can give quick returns.
(b) No proper credit facility is often available.
(c) There is serious competition of forestry species with other cash crops.
(d) Registration problem for protected/ reserved species.
(e) Some species such as Neem etc. have no easy market.

Similarly, 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 SFM, new strategies have to be devised (Keogh, 2000).

Recent research findings indicate that short-rotation teakwood is not significantly inferior in density and strength compared to natural-grown teak, although with lower heartwood and extractive contents it is less durable and attractive. The findings of recent studies by Bhat (2000) offer the following hope to plantation-growers including smallholders:

(a) Without altering timber strength, plantation managers can aim to produce logs with higher yields of naturally durable heartwood per individual tree by accelerating tree growth in short rotations with judicious fertilizer application and genetic improvements on suitable sites;
(b) The MAI for teak plantations is generally relatively high in short rotations of 20–25 years. Teak yield tables indicate that MAI usually peaks within 20 years of plantation establishment;
(c) Teak can produce timber of optimum strength in relatively short (e.g. 21-year) rotations; and
(d) Fast-growing provenances/clones can be selected for teak management without reducing the wood's specific gravity. However, matching the provenances for specific site conditions and product requirements appears to be most crucial in tree improvement programs.

Table 5. Plantation through successive Five-year plans

S. No.	Plan Period	Areas Afforested in plan period (million ha)	Cumulative (million ha)
1.	First (1951-56)	0.05	0.05
2.	Second (1956-61)	0.31	0.36
3.	Third (1961-66)	0.58	0.94
4.	Annual Plans (1966-69)	0.45	1.39
5.	Fourth (1969-74)	0.71	2.10
6.	Fifth (1974-79)	1.22	3.32
7.	Annual Plan (1979-80)	0.22	3.54
8.	Sixth (1980-85)	4.65	8.19
9.	Seventh (1985-90)	8.86	17.05
10.	Annual Plan (1990-91)	0.75	17.80
11.	Annual Plan (1991-92)	1.15	18.95
12.	Eighth (1992-97)	7.95	26.90
13.	Ninth (part) (1997-98)	1.48	28.38

Source: Ministry of Environment and Forests, Government of India.

TEAK PLANTATION FORESTRY IN INDIA

Plantation activities have been one of the major focuses of Indian forestry programmes through successive Five-Year plans (Table 5). Earlier, plantations were intended primarily for industrial uses and were large scale monocultural but since 1970, plantations are raised to meet the people's various requirements such as fuelwood, fodder, building materials and to bring more geographical area under green cover for environmental purposes. These plantations have been undertaken under *social forestry*, *farm-forestry*, *agro-forestry* and energy plantation programmes.

The cumulative area of such plantations until the end of the 5th Five Year Plan was 3.32 million hectares. The annual planting rate ranged between 11,000 hectares to 244,000 hectares per annum (FSI, 1999).

The report of the National Commission of Agriculture (NCA) in 1976 led to increased investment in plantation establishments. In an attempt to enhance productivity and employment generation, the report recommended large scale replacement of mixed natural forests of low commercial value with fast growing commercially important plantation species.

As a result, the annual planting rate increased to about 1.0 million hectares during 1980-85. Plantation forestry received further impetus when the National Wastelands Development Board (NWDB) was established in 1985. The NWDB was given a target of afforestation of five million hectares of wastelands per annum. Although, NWDB did not quite achieve this ambitious target but it managed to give a further impetus to the social forestry programme by providing additional funds even to Non-Government Organisations (NGOs), for plantations. The annual rate of planting thus increased to 1.78 million hectares during 1985-90 (FSI, 1999).In the 7th Five Year Plan (1985-90), a record 8.86 million hectares of new plantations were established. The cumulative area of forestry plantations from 1951 until 1999 is 31.20

million hectares (FSI, 1999). The FAO report (FRA, 2000) estimates that India has 18% of the world's forest plantations or about 34 million hectares (IIED, 2003).

The Government of India aims to increase the forest and tree cover in the country to 33% of the geographical area by 2012. This target requires that additional 9.97% of the geographical area of the country i.e. 33.60 million hectares should be brought under forest and tree cover. It is a matter of great concern that how such a huge target can be achieved with the current rate of plantations of 1.2 to 1.5 million hectares per annum. Since almost 85% of the potential lands available for additional tree planting would fall outside the notified forest lands, involvement of non-government sector including private individuals is most crucial.

In India, Forest Development Corporations have taken up planting and sale of teak as commercial activity. During the last decade, many private companies ventured to raise teak plantations with investments raised from public. Teak being the most valuable timber species of the world due to its flexibility of use on land and also in water, its popularity and regular demand by the traders and consumers in India, there was a move to have lots of private plantations of teak in India. Many farmers prefer teak to fruit trees and other crops because of better market potential, cash income and wood for construction. Unlike the general trend of 'Rich becoming Richer' there is a common tendency of 'Poor becoming Richer' among small farmers, with regard to cultivation of teak and economic returns from agro-forestry system.

With increasing wood prices and teakwood demand, as well as the introduction of genetically improved planting material, there is a wide spread practice of teak growing in private lands. Premium teak is the most sought-after tropical hardwood for prestige furniture, ship-building and decorative use in construction. Teak has thus, come a long way from being a 'product' of forest to a dynamic plantation crop of ecological and socio-economic significance.

POLICY CONSIDERATIONS AND GAPS

'Policy' generally refers to the principle that governs and guides the actions directed towards given ends (Boulding, 1958). The National Forest Policy, 1988 envisages to bring 33% of the land area under forest and tree cover, and emphasizes upon the necessity of mobilizing stakeholders' participation and adequate financial support in the forestry activities. The Planning Commission of India has prepared a time bound programme to achieve the targeted forest and tree cover by the end of 11th Five Year Plan i.e., 2012 by involving all the key stakeholders in the Greening India Programme. The Forest Policies further 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 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. The large scale plantations could be possible where the funds are available either from the State Government, Central Government or other donor agencies. But inadequate fund availability remains a constraining factor in achieving the national goal of extending forest cover, which is possible only through large scale afforestation in non-forest areas. Similarly, the scope of plantations for carbon sequestration purpose in India is still in infancy due to lack of clear policies. Uncertainties in the evaluation of carbon budgets for forestry sector, e.g., lack of data and biases in the existing data and limited advantage about some components are some constraints (Adger *et al.*, 1996). These are applicable in India also where very few concrete attempts have been made.

In common with other plantation crops, teak suffers from several chronic constraints such as non-availability of suitable land, poor quality of planting materials, lack of financial assistance, market fluctuations, financial soundness of the firms / individuals to wait for longer rotation crops and strict transit rules for teak. Although many trees have been exempted from transit rules of State Governments but teak is still kept under this rule. Moreover, the market of timber including teak is not adequately organized and transparent.

One of the important lacunae in policies related to forest plantation is the lack of strategies to address the issues of market. Promoting forest plantations without concurrent efforts to find reasonable markets and without value added processing will be counter productive (Chandrasekharan, 2003).

Productivity of plantations needs to be enhanced to meet the growing demand and reduce imports. India has large areas as degraded forests/ wastelands, part of which can profitably be used for teak cultivation. Teak planting activity also provides employment opportunities. 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. Moreover, soils can be ameliorated with proper cultural practices to improve the teak growth (Krishnapillay, 2000). Research Papers suggests MAI of over 10 m^3 of average soils for genetically improved teak varieties, and feasibility of combined cultivation of teak with other available crops such as rubber and rattan for better profitability. Use of improved planting stock is an essential pre-requisite for substantial increase in productivity.

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. 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 dissuade private sector from investing on 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 (Chandrasekharan, 2003).

Existence of policy alone will not guarantee success of plantation programmes. Therefore, the implementation of policies plays a key role. Policy research involves scientific studies to support necessary development of policies. Thus, forest plantation development preferably teak requires suitable institutional and policy environment besides transparent financial and marketing mechanism & support.

INITIATIVES AND INCENTIVES

Incentives create artificial competitive advantages, and therefore, stimulate investments. Incentives for promoting forest plantations, among others, include: concessional credits, teak remissions, afforestation grants, price support, technical assistance and supply of cheap quality planting material.

Almost all significant national planting programmes appear to have been supported by Governments or with Government's participation. More than two thirds of Japan's land area is under forests, as a result of a State-sponsored afforestation drive. A number of Governments including China and India remain active participants in plantation establishment and management. In other words, Governments have dissolved their commercial forestry interest by privatising plantations (Chandrasekharan, 2003). Large scale plantation of teak requires sizeable funding support. Government of India (Central Government) and the State / UT Governments are taking the following steps for augmenting the financial resources towards the promotion of production of timber:

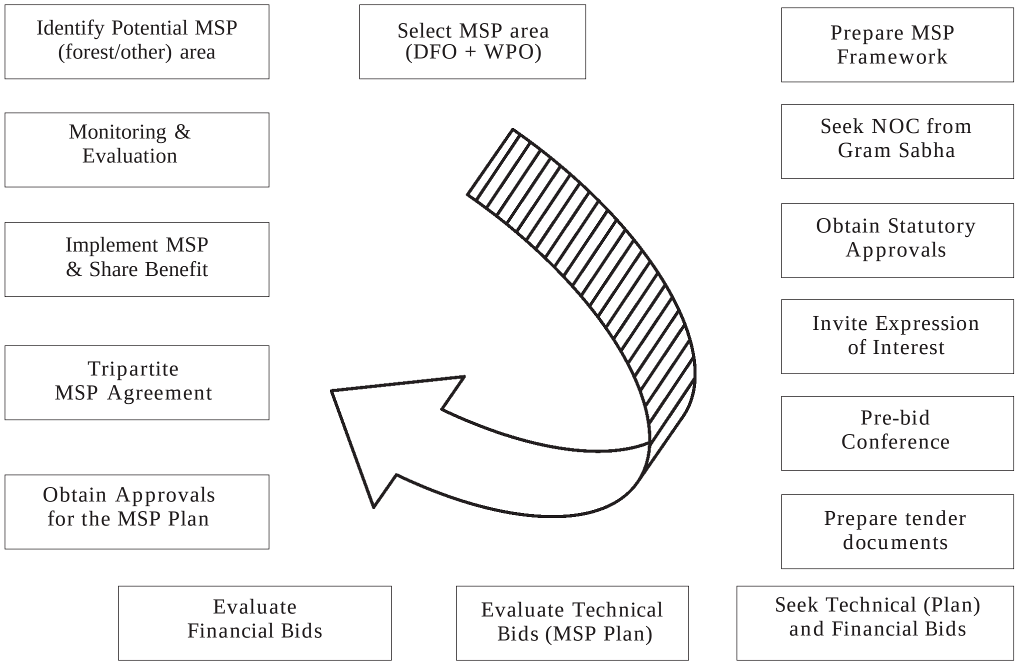
(1) Central Government

- Increased allocation for National Afforestation Programme (NAP)
- Greening India Scheme launched
- Expansion of Eco-Task Force battalions being considered
- New Panchayat Van Scheme being mooted
- Increased synergy with other ministries

(2) State/UT Governments

- Involve all land owning departments / agencies in tree planting
- 12th Finance Commission's Additional Grants

Government of India has prepared multi-stakeholder partnership document for resource mobilization towards afforestation of degraded lands. Endeavour is to provide feasible and detailed process of the Multi-stakeholder



Source: Draft document on *Multi-Stakeholder Partnership for Forestation* (IIFM, Bhopal).

Fig. 1. Global Approach for the MSP Process

partnership arrangement for engaging key stakeholders in the forestation activities. The scope of public- private partnership initiative is expected to increase plantation activities through the massive mobilization of resources and involvement of key stakeholders including the local communities and the forest-based industries who have economic interest in enhancing production of timber and timber products. Schematic approach for the *Multi-Stakeholder Partnership Process* is illustrated in Figure 1.

Global Approach for the MSP Process

National Bank for Agriculture and Rural Development (NABARD) is a development bank which also provides credit for promotion of sustainable agriculture including forestry, for integrated rural development. Teak has been considered a potential tree in rehabilitation of India's degraded forests and also raising farm forestry on wastelands, on a sustainable basis. NABARD has recommended rising of commercial plantations of teak by the farmers and the Forest Development Corporations on their lands. The recommended number of trees per hectare is 2500 and the unit cost is Rs. 40,000 in four years. Such teak plantations on wastelands have been found technically feasible and financially viable. The Internal Rate of Return (IRR) of the scheme is 28.69%. Teak plantations on degraded forest lands are also viable and the IRR varies from 17 to 18 percent (Haque, 2003).

SUPPORTING POLICY MEASURES

Besides facilitating for the financial resources for large scale plantation of teak, some policy interventions are inevitable not only to bridge the gap between demand and supply but also to achieve the target of 33% of forest and tree cover by 2012. Farm forestry and agro-forestry are the key areas in achieving this target and for these farmers have to be motivated. This will not only help them in getting good economic returns but will also reduce pressure on forests. A balance is therefore, required between regulatory mechanism and promotion of forestry in private sector. It is therefore, essential on the part of State / UT Governments to create an enabling environment by way of simplification of felling and transit regulations to encourage the tree plantations on private land. Ministry of Environment and Forests, Government of India, has therefore, issued guidelines for relaxing the felling and transit regulations of trees grown on non-forest private lands on 15 December 2004 to augment the pace of tree plantation on private land. The objective is to increase the forest and tree cover of the country from the present 23.68% to 33% of the geographical area as envisaged in the National Forest Policy, 1988 through the promotion of plantation of tree species on non-forest private lands. But, teak is still under the category of 'Restricted' tree species and therefore for the large scale teak plantation on private lands and in non-forest areas, there is an emergent need for the development of a mechanism to relax the harvesting and transit rules in respect of such teak plantations outside the forest areas.

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 thus, needs to be reviewed to get better quality of wood from teak plantations (Somaiya, 2003). The superiority of plantations as a source of timber rests primarily on their higher productivity of marketable wood. Commercial teak plantations should be developed and managed as a science-based enterprise following business management principles, to avoid damaging social and environmental impacts and to deliver sustainable economic benefits (Chandrasekharan, 2003). Standardised cost effective vegetative propagation/clonal multiplication techniques envisaged with the establishment of decentralized nurseries and clonal orchards to supply genetically superior planting material to teak growers including State Forest Departments and Development Corporations can boost the plantation activities under sustainable management principles.

The major supporting policy measures include:

(i) Rationalisation of *Felling and Transit Rules* for timber grown on non-forest private lands
(ii) Insurance for teak growers
(iii) Certification of forests and forest products
(iv) Rationalisation of tariffs/regulations for export/import of forest products to protect the domestic growers
(v) Promotion of Future Markets in forest commodities

Forest Certification has emerged as the market based mechanism in support of SFM. Certification initiatives rely on consumers exercising purchasing choice in favour of products labeled as originating from forests certified as being sustainably managed. Certification and Eco-labeling are the new slogans to enhance product positioning for a premium price on one hand and ensuring better forest management practices on the other. India and China have imposed ban on clearing primary forests for raising forest plantations. *Forest Stewardship Council* (FSC) guidelines for SFM, also require that plantations should not be raised by clearing natural forests. In view of the developing global scenario and to safeguard the interest of exporters, it has become imperative to have National Policy on 'Forest Certification'. From domestic (National) point of view also, certification is necessary to ensure the continuity of forest goods and services through SFM approach.

SFM and *Certification Mechanism* are the fundamental instruments leading towards organized market/future market of forestry value added items including plants, their products and derivatives. Ministry of Environment and Forests, Government of India has constituted three committees, namely, Committee for 'Certification Criteria', Committee for 'Certification Processes' and Committee for 'Accreditation Criteria and Processes' towards the development of forest certification mechanism in the country. For the sustainable management of planted teak forests, there is also need to have emphasis on research especially for getting quality planting material to increase productivity. The law of the country may be made more plantation friendly reducing pressure of demand on natural forests by meeting the same from outside forests.

CONCLUSION

Forest plantations have enormous potential to compensate for the deforestation and forest degradation, but it cannot compensate for environmental value of natural forest. These plantations can serve as complement to, rather than substitutes for natural forests. Considering the vast amount of wastelands in India and increasing demand of timber and timber products, the current annual rate of afforestation of about 1.5 million hectares need to be increased to 3 million hectares per year and therefore, enhanced budgetary allocation for forestry sector from all possible sources would be an important key factor for sustainable forestry management in the country in general and teak plantations in particular.

The new approach of facilitating the growers of teak by way of multi-stakeholders' partnership arrangement, loan facilities from banks and relaxed harvesting and transit rules will definitely give an impetus to the teak afforestation programme but more policy interventions are required towards further relaxation of harvesting and transit rules, development of future markets and organising an easy transparent trade thereby increasing the export potential of these products. The development of wood based industries and proper tariff structure can go further to help the growers for their better market and future management of teak plantations outside forests and therefore, increasing the present pace of afforestation of teak must be the paramount objective of all stakeholders and policy makers.

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Indonesian Teak Wood Marketing and Industries

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ABSTRACT

Teak is widely preferred due to its high commercial value, durability and suitability for heavy construction. Approximately, 50 percent of the teak plantations undergo unauthorized logging operations due to multidimensional crisis. Teakwood productivity has significantly increased by 75 percent as a consequence of improved planting material by way of the tree improvement programme of the Teak Centre. This calls for a paradigm shift in forest management from sustainable basis to environmental conservation and community based considerations.

Keywords: Forest destruction, teakwood productivity, National Rehabilitation Programme.

INTRODUCTION

Java Island is famous for homeland teak with recorded total teak area about 700.000 ha in the government land alone. It is sustainable managed as teak has economic value and is closer to the people's life due to its high value, durability and suitability for heavy and medium constructional work. Therefore teak forest management could not be separated from the surrounding communities. In the last two decades people also tried to plant teak in their home gardens for economic reasons and legal facilitations. Although there are no exact data on the private forest lands, 20 to 25 % of the government land is estimated to have private teak plantations.

TEAK FOREST DESTRUCTION AND REHABILITATION

The rampant illegal logging in the last decade has reduced productivity of the teak forestland significantly. Multidimensional crisis has resulted in almost 50 percent of the teak plantation suffering from illegal logging operations. The former forest regulation with strong repressive approaches suddenly had to be turned into community based forest management. Centralistic policy on forest management has to pursue demand of democratic system in bureaucratic policy.

Since 2002, the government made efforts to speed up the rehabilitation of the forest condition by introducing a national forest rehabilitation program. With respect to the teak forest in Java, forest rehabilitation will be completed in 2010. The sustainable plan of teak forest has to be adopted into 50 year rotation until the forest age class distribution and structure will turn back into normal condition. Consequently the timber product will slightly decrease in volume and quality with smaller diameter although no significant evidences are available in decreasing on wood quality.

Table 1. Comparison of wood properties of improved materials with conventional material at 12- and 16-year-old teak

Items	Improved plant material	Conventional plant material	Conventional plant material
Age (year)	12.0	12.0	16.0
Specific gravity g/cm^3	0.455	0.503	0.550
Tangential shrinkage (%)	3.88	4.25	4.74
Radial shrinkage (%)	2.91	2.95	2.83
Compressive strength parallel to grain (kg/cm^2)	18.02	15.49	19.6
Compressive strength perpendicular to grain (kg/cm^2)	133.54	150.48	179.25
Shear strength (kg/cm^2)	79.64	82.94	74.53
Cleavage resistant (kg/cm^2)	779.93	741.04	844.16
Hardness tangential	304.77	321.22	342.90
Hardness radial	297.09	278.22	316.07

THE USE OF IMPROVED PLANT MATERIAL

Meanwhile the *Teak Center* after 25 years' experience in tree improvement program has emerged with invention of improved plant material that significantly increased teak productivity of by 75 %. Based on observation in 12-year-old improved teak plantations, it is evident that physical and mechanical wood properties slightly decreased compared to the wood properties of conventional teak plantations of the same age. It is expected that this characteristic will get better as they are getting older (Table 1).

Clonal seed orchards and hedge orchards were developed in conjunction with the rehabilitations programme. Intensification on teak plantation has also been conducted to secure the better performance of plantation in relation with the community based forest management.

DEMAND ON MARKETING POLICY

Demand on legally imported wood in the consumer country has increased. New paradigm with certification on forest management is urgently needed. The big change in forest management on sustainable basis with environmental and community considerations are anticipated although sudden changes for betterment are not feasible. The fact is that the forest management is a social process as it is always related to the attitude of communities.

It is expected that by 2010 there will be more than 15 forest districts in Java under certified forests. Those forest districts will produce approximately 150,000 m3 of certified wood annually. The production of certified wood may gradually increase in line with certification process of other forest districts with the outcomes of forest rehabilitation program.

Although application of Chain of Custody (COC) is now likely to be adopted easily in the industrial sectors almost all of the wood based industries in Java are preparing COC mechanism in their production processes. The strong effort in elimination of illegal wood has also come from the consumer country. The programmes such as voluntary partnership agreement will be initiated involving producer and consumer countries to guarantee that only legal wood will be exported from the producer country to the consumer country.

Policy and Status of Teakwood Production, Processing and Marketing from Planted Forests in Thailand

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ABSTRACT

Rich in teak forest, teak trade used to earn Thailand revenue second only to rice when teak was exploited in mid 1900. The Royal Forest Department (RFD) was established in 1896 and further exploitation was carried out under selective cutting and appropriate marketable size limits. The RFD started its first teak plantation 1906. The plantation was sporadic until 1961 when the first policy was drafted and the teak planted areas were stated clearly in the first and Second Forest Development plans. Policy and legislation clearly facilitate teak plantations but there are some restrictions to teak exploitation and trading. The laws and regulations that adversely affect plantation activity were the logging ban in 1989, the Forest Plantation Act of 1992 and the forest plantation promotion project in 1994. Teak planting agencies are Government, Forest Industrial Organization (FIO), the Thai Plywood Company and private sector whose accomplished areas up to 2006 were 1,273,211, 183,985.85, 7,540 and above 155,708 ha respectively. After the logging ban Thailand turned from teak exporter to importer. During 2002-2006 Thailand had imported teak timber up to 340,816, 128,497, 120641, 143,668 and 146,758 m^3 and exported only 8,803, 5,445, 7,678, 12,921 and 7,116 m^3 respectively. Exporting of teak timber is restricted to only FIO due to the lack of raw materials for domestic use. Production of timber is obtained from the FIO's logging and thinning activities and from licensed or confiscated timber. Teak timber productions were 7,761, 1,554, 40, 2,737 and 2,037 m^3 during 2002-2006 respectively. Wood processing still uses low technology and immature wood. Poor design and coarse work make the products unacceptable to international market. Training programmes to improve skills and productivity are needed. Inferior in its appearance, durability and wood figure, the teak growers and manufacturers need to find new technologies, products and markets.

Keywords : Teak, plantation, policy, marketing, import, export, production.

INTRODUCTION

The kingdom of Thailand is located in Southeast Asia, bordered by Myanmar, the Lao People's Democratic Republic, Cambodia and Malaysia. It has land area of 51.3 million ha and population of 62 million (RFD. 2006). Situated in tropical climate the country is home to the most bio-diverse forms of forest with 1,715 known species of amphibians, birds, mammals and reptiles, of which 5.1 percent are endemic and 5.8 percent are threatened. Thailand has 11,625 species of vascular plants and at least 1,190 tree species. The most valuable timber tree species is teak.

Commercial teak exploitation was started in mid 19^{th} century by foreign companies (Borneo Co., Anglo-Thai Co., and Bombay Burma Co.). There were no regulations to control timber harvesting and the right to exploit forest areas was conceded by the local provincial suzerain. In 1896, the Royal Forest Department (RFD) was established to manage all forests in the country. Since then, timber exploitation has been carried out under the selective cutting system, on the basis of the growth rates of each tree species and its appropriate marketable size (Sumantakul and Sangkul unpubl). Teak trade used to make the revenue for the country second only to rice. The figure however has been changed since the logging ban in 1989.

The increasing domestic wood consumption and the diminishing of the teak forests forced Thailand to consider initiating large-scale reforestation projects. activity was sporadic at the early stage but exact target was set up in 1961. When the first policy in forest plantation was documented. As Thailand is rich in forest tree species, the number of species recommended for plantation programmes has been increased to 53 (Sumantakul and Sangkul unpubl.). Teak is a highly recommended species and its planting targets are clearly stated in the first up to the third National Social and Economic Development Plans (NSEDP) (1961-1976) as shown in Table 1. In the Fourth and the Fifth Plans (1977-1986) only, the total area was set for planting mixed forest tree species. The Sixth to the Ninth Plans (1987-2006), however, only aimed to increase forest area to cover 40 % of the total land area with 25 % for conservation and 15 % for production. At the same time, more private activity in forest plantation had been encouraged. In 2007, the government revised the National Forest Policy in the Tenth NSEDP (2007-2011) and lowered its expectation on forest cover down to reality at only 33 % with conservation forest not less than 18 percent (National Economics and Social Development Board).

Table 1. Forest plantation programs in Thailand based on the NSEDP

NSEDP	Years	Productive plantation area (ha)		Protective plantation area (ha)	Total areas (ha)
		Teak	Non-teak		
1st	1961-1966	4,800	7,600	-	12,400
2nd	1967-1971	12,800	8,000	-	20,800
3rd	1972-1976	16,000	8,000	14,800	38,800
4th	1977-1981	-	-	-	400,000
5th	1982-1986	-	-	-	240,000

Source: National Economics and Social Development Board.

It is documented that the country started its first forest plantation as early as 1906 (Phothai, 1995). After the logging ban, teak wood product has been then relied entirely on wood from plantation. In order to secure wood supply, there is a need to investigate the important aspects such as status of wood production, processing and marketing of teak wood from plantations. This paper, therefore, aims to compile data available on policy, status of wood production, processing and marketing of teak wood from plantations in Thailand.

National Social and Economic Development Plan and Teak Plantation Policy

The Thai National Forest Policy was implemented in 1961, but has periodically been revised to change its focus to suit changing situations. Forest plantation

THAI LEGISLATIVE AND TEAK PLANTATION

Thai forestry is regulated by a number of legislative instruments: the National Forest Act of 1941, the Wildlife Preservation and Protection Act of 1960, the

National Parks Act of 1961, the National Reserved Forests Act of 1964 and the Commercial Forest Plantation Act of 1992. The laws and regulations that affect forest plantation activity most were the logging ban in 1989, the Commercial Forest Plantation Act of 1992, and the forest plantation promotion project in 1994.

The National Forest Act of 1941, was issued with focus on timber production and dealt solely with the management of plantations and logging concessions in natural forests. The 1985 forest policy sought to establish the long-term coordinated management of forest resources, envisaging increasing the area of forest to 40 % of the land area. With the imposition of the logging ban in 1989 the focus of forestry moved clearly towards conservation. Following the logging ban in 1989, attention was focused on how Thailand would acquire adequate wood for domestic consumption. The concern was reflected in a flurry of legislation, policy and cabinet resolutions made in the years following the ban. Perhaps the foremost among the legislative documents is Commercial Forest Plantation Act 1992. The main purpose of the Act is to support planting of restricted tree species such as *Tectona grandis* and *Dipterocarpus alatus* by the private sectors on their own land. The Act describes the types of land on which forest plantations may be registered and established. Of particular note are Sections 10-13, which cover harvesting and passage of timber through checkpoints, and Section 14, which indicates that all royalties shall be waived (FAO, 2007a).

In 1994, the RFD launched a forest plantation promotion project to encourage and support private landowners and local farmers to establish forest plantations of commercial tree species and to help the country become more self-sufficient in timber. With the intention to attract more attention from the private sector and small farm holders, the Government was willing to pay a subsidy of up to US$ 780 per ha within 5 years to the tree planters without conditions. This measure was expected to stimulate interest in commercial tree farming. The forest area of Thailand, and of course teak planting, were encouraged and expanded by the scheme. The promotion of reforestation was activated by the government through the RFD (Sumantakul and Sangkul, unpubl). The project lasted up to 2002. To endorse and strengthen national forest policy and to reflect Government's acknowledgement of the role the private sector plays in reforestation, land policy changes have been considered. The Government considered adoption of a progressive land tax policy to encourage conversion of uncultivated land to productive land. Some indication of the level of involvement of the private sector can be obtained through assessment of the area of land rented for forestation in National Reserve Forest under the National Reserve Forest Act 1964 (Article 20) (FAO, 2007a). The present forest policy was adopted in 1997, based on suggestions contained in the forest sector master plan, which was completed in 1995. Reforestation and afforestation were seen as initiatives for the future supply of wood. Implementation of the plan has, however, been hindered by several constraints, institutional misinterpretations (ITTO, 2007c). Further to the keystone legislation, a number of resolutions have been passed by the Cabinet concerning economic reforestation. Notable resolutions include (FAO, 2007a):

- Classification of the National Reserve Forest Area: The Council of Ministers agreed to conduct land-use zoning of the National Reserve Forest area. Based on zoning, about 14.12 million ha (25 percent) of the country have been approved by the cabinet for conservation forest, 8.30 million ha (16 percent) for economic forestland, and 1.15 million ha (2 percent) for land reformation.

- Renting of degraded forestlands by the private sector (not exceeding 8 ha / holder): The Council of Ministers agreed that the Minister of Agriculture and Co-operatives should be permitted to authorise the rent of degraded forest land, within the National Forest Reserve, to private individuals for the purpose of plantation establishment.
- Reorganisation of the State Enterprise, Forest Industries Organisation (FIO). The Council of Ministers agreed that the Forest Industries Organisation should play a role in encouraging the private sector to invest in plantation development.

Regardless of these changes, the remaining forests would neither be protected nor new forests established, without solving the problem of occupation of forest reserves by 12 million people. To solve the problem, the RFD issued a four phase policy in 1998, which included (i) zoning to separate conservation and economic forest; (ii) demarcation of forest boundaries on the ground; (iii) land reform, to reverse degradation of areas by local people, re-establish agricultural land and legitimise occupation of state land designated for agricultural processes; and (iv) protection and management to prevent further encroachment on forest lands and to promote forest plantations, agroforestry and other sustainable land use practices (FAO, 2007a).

Development of forest plantations in Thailand

The first forest plantation incuding that of teak in Thailand was reported 1906. The first plantation was on an area of less than one hectare under the taungya system. The system proved to work well and then extended to larger area when the real teak plantations were established in 1910 in Phrae province. At that time, planting method was direct seeding. In 1935 the method of planting was changed to stump planting which performed better (Phothai 1995), has been continued until now. Teak plantation from the beginning up to 1967 was solely done by the RFD. Most of the plantations are located in the northern and northeastern region. The Forest Industries Organization (FIO) started its first plantation in 1968. Later on, a state owned enterprise, the Thai Plywood Company, and other private concessionaires joined in (Anon. no date (b), 2007).

Teak planting agencies

There are four main agencies involve in teak plantation activity in Thailand: the Government (RFD), Forest Industries Organization (FIO), Thai Plywood Company, private concessionaires and farmers.

The RFD was established in 1896 as the sole agency for administration and management of forest resources. The RFD is also responsible for reforestation. The first forest plantations were reported in 1906 under taungya system. Teak is the only species planted at the beginning of the reforestation program, until 1919 some non-teak species were then planted in various sites. The establishment of plantations at that time remained a sporadic activity with a total area of 8,500 ha. Regular planting started in 1961 when the government realized the importance of reforestation. An area for teak reforestation was clearly documented in the first three National Economic and Social Development Plans (1961-1976). Three divisions of the RFD involve in forest plantation–Nation Forest Land Management, Silviculture and Watershed Management. They had been working in three different types of areas. The Silviculture Division concentrates on establishing industrial plantations whereas other two divisions establish plantations on denuded and watershed areas, mainly for non-industrial purposes (FAO, 2007b).

Total industrial plantations by the Silviculture Division reported in 1980 were 133,800 ha of which

Table 2. Total areas of forest plantation (ha) by RFD from beginning to 2006 by objectives

Item	From beginning to 1999	2001	2002	2003	2004	2005	2006	Total
Afforestation by Government budget	672,739	4,208	5,592	3,936	5,600	13,200	9,424	714,699
The reforestation campaign in commemoration of the Royal Golden	368,684	16,005	16,831	2,386	4,990	26,281	9,718	444,895
Jubilee reforestation according to Ministry's regulations	16,584	1,914	450	468	566	1,400	1,013	22,395
Reforestation by concessionaire budget	22,512	138	2,400	4,869	2,906	5,400	6,512	44,737
Total	**1,080,519**	**22,265**	**25,273**	**11,659**	**14,062**	**46,281**	**26,667**	**1,226,726**

Source: RFD 2006.

55% were Tectona grandis (RFD, 1980). Up to the year 2006 the RFD had accomplished in forest plantation divided into different activities as summarized in Table 2. The total planted area by RFD up to 2006 was 1.2 million ha.

After the reformation of government offices through out the country in 2002, the RFD has been divided into three departments as RFD, National Park, Wildlife and Plant Conservation Department (DNP) and the Department of Marine and Coastal Resources (DMCR). The plantation activity therefore divides into 3 categories accordingly. The RFD was then responsible for economic plantation while the DNP responsible for protective and conservation plantation, and the DMCR responsible for mangrove forest plantation along the coastal lines.

Teak planting by FIO

The Forest Industries Organization was established on the 1st of January 1947 as a section under the RFD. Its main activity involved logging. Later when the government had a policy to increase teak logging activity, the FIO was then issued to be an enterprise which directly under the administration of the ministry of Agriculture and cooperatives in 1956. The FIO started its plantation activity in 1968 in the Northern part of the country. The only species planted then was teak. Later the plantation programs were extended to other part of the country where non-teak species were also planted. Total planting area reported in 1992 was 69,390 ha (Phothai, 1995). The latest reported on FIO plantation area shows in Table 3.

Teak planting by Thai Plywood Company Ltd.

The Thai Plywood Co. Ltd., established by the Forest Industries Organisation, initiated plywood manufacturing in 1957 (FAO, 2007a). The Thai Plywood Company was approved by the national economic and social development congress to start its plantation project under the company budget at

Table 3. FIO Plantation areas (ha) in different regions classified by tree species.

Regions	Tree species				Total
	Teak	Eucalyptus	Rubber	Others	
Upper northern	48,107.85	1,665.28	107.84	4,128.22	54,009.19
Lower northern	33,138.67	1,811.96	-	989.60	35,940.22
Central	10,353.84	4,686.43	1,239.57	5,281.75	21,561.59
Northeastern	2,390.02	20,040.66	1,989.13	21,255.64	45,675.44
Southern	233.28	3,776.27	6,814.16	15,975.69	26,799.40
Total	**94,223.65**	**31,980.60**	**10,150.70**	**47,630.91**	**183,985.85**

Source: FIO July 1 2007 (personal communication).

Table 4. Forest plantation area registered with the RFD, under the 1994 forest plantation promotion project from year 1994 to 2002.

Regions	Planting area (ha) in different year								Total
	1994	1995	1996	1997	1998	1999	2000	2002	
Northern	33,391	24,551	6,252	6,886	1,648	2,101	3,877	1,480	80,188
Northeastern	2,922	23,499	1,7072	4,171	710	482	512	36	49,405
Central	9,861	4,585	1,728	715	94	64	273	106	17,426
Southern	618	163	9	47	7	0	2	0	845
Total	**46,793**	**52,799**	**25,060**	**11,819**	**2,459**	**2,647**	**4,664**	**1,623**	**147,864**

Source: Forest Economic Group. RFD 2006 (personal communication).

Bang-Krak Thungpo plantation in 1963. The first plantation was then started in 1964. A year later another plantation was set up at Lad Krating and aimed to plant 160 ha annually. The objective of the project was to provide raw material for its plywood industry within 20 years. The project however, did not work well due to the conflict in land use with local people. The project, therefore, lasted at the end of the second phase in 1976. The remained forest, however, were very well managed and kept. Total forest area planted by the Thai Plywood Company was 7,540 ha (Phothai 1995).

Teak planting by private sector

Prior to 1992 before the government passed the Commercial Forest Plantation Act, and 1994 to 2002 when the RFD launched a forest plantation promotion project, private plantations, woodlots and agro-forestry plantations were reported to have been widely established in Thailand but the extent of these was not known (FAO, 2007b). Following the 1989 logging ban, there has been greater planting activity in private plantations for which the Office of Private Reforestation and Extension (OPRE), established in 1986 is responsible (FAO, 2007a).

Summary of plantation areas under the promotion project in 1994-2002 is in Table 4. Although there is no classification of species planted, teak presumably 90 % of all especially in the Northern and the Northeastern regions. An overview of forest plantation area and number of planters as stipulated under the Commercial Forest Plantation Act 1992 is given in Table 5. There are a number of reasons for the low figures for registered plantations: (i) the Forest Plantation Act does not stipulate registration

Table 5. Forest plantations registered with the RFD, under the 1992 Commercial Forest Plantation Act (data collected up to September 30, 2006)

Regions	Number registered	Area (ha)
Northern	26,363	101,665
Northeastern	5,052	18,419
Central	3,916	35,311
Southern	109	313
Total	**35,440**	**155,708**

Source: Private Reforestation Division, RFD 2006 (personal communication).

of forest plantation for tree species other than teak *(Tectona grandis)* and *Dipterocarpus alatus*; (ii) farmers and other plantation owners are unfamiliar with this new piece of legislation; (iii) Government officials offer poor service to the general public; several thousand registration forms have to be processed; (iv) it is not necessary to register until it is needed for felling the trees.

Status of wood production from teak plantation

At present, production of hardwood timber from national forest areas is obtained from the FIO's logging and thinning activities in their reforested area. According to the RFD, timber (logs and sawn timber) production (legally licensed timber and confiscated timber) during 2002-2006 was 33,634; 20,184; 2,115; 8,938 and 12,227 m^3 of which teak wood production was 7,761; 1,554; 40; 2,737 and 2,037 m^3, respectively (RFD, 2006). The teak wood production continued to decline to around 40 m^3 in 2004, compared to 1,554 m^3 in 2003, which reflected from the lack of mature reforested trees. The commercial forest plantations by private sector in reforested area will take several years to mature. Some farmers prefer to harvest their trees whenever it is marketable in believing that waiting until maturity of the trees the planters might die before earning anything. Although there is quite large area of mature teak plantation by RFD, the lack of mature tree in wood industry still occur due to illegally cutting for personal use. Some of the commercial plantations planted by RFD had been converted to conservation plantation after the land-use zoning of the National Reserve Forest areas have been implemented if the plantations located in conservation zone. The plantations outside conservation zone were given to FIO to be registered as its own plantation. In 1990 the FIO received plantation area from RFD and from private concessionaire under the ministry policy about 68,577 ha. These areas may contain some mature teak plantations from which timber could be harvested.

From the reasons above, teak timber production from mature forest will likely remain flat as the government plan to expand commercial forest plantations will take several years for the teak wood to be commercialized. Even though teak plantation has been taking place long time ago by government, but to allow logging or harvesting is not an easy decision for any government to make. It is due partly to fast reduction of forest area. The aim to keep forest cover to 40 % of the whole country area is still far reaching. Therefore none of the teak plantation planted by government shall be allowed to harvest in the mean time.

Processing of teakwood from plantation in Thailand

After the Government banned all logging operations in over 300 forest concessions in January 1989, the supply of domestic timber ceased. As a direct impact of this decision, numerous sawmills had to close down because of the shortage of timber supply. This also affected the plywood and veneer industries, who now have to rely mainly on imported logs and have therefore cut mill capacity to as low as 50-60% (Sumantakul and Sangkul, 2007).

Processing of teak wood as veneer and plywood

Veneer and plywood manufacturers in Thailand have faced raw materials scarcity and high prices that have resulted in reductions in output. This has been partly due to the fact that many log-exporting countries, such as Indonesia and Malaysia, have policies to export sawnwood instead of roundwood in order to add value within the country of origin. The shortage of large logs has forced some factories to re-equip with peeling machines of 4ft rather than 8ft length and with slicing machines cutting the thinnest veneer at 0.1 mm. Some factories, however, import logs for veneer production and then re-export. Thailand also imports finished plywood and overlay to supply local markets and many plywood industries use overlay on particle board or MDF to compensate for the lack of plywood (FAO, 2007a). Unfortunately, plywood production records are not available because of the shortage of raw materials. Using teakwood as veneer should be the most economical way of teak utilization. Sadly enough that from personal communication with a Thai Plywood Co. Ltd. staff revealed that none of teak from plantation ever been use as raw materials in the company's veneer production due to its small size and immaturity of trees.

Processing of teak wood by sawmills and wood products factory

In 2006, data from the Office of the Permission Division, RFD revealed that, number of remaining sawmills and wood product factories were as appeared in Table 6. These include FIO's 2 teak sawmills, 1 wood producing factory, 1 house construction factory and 1 vacuum and pressure treatment factory. The FIO's factories produce wood processed product under brand name "Fioline". The products are exported to Europe and other countries. After the logging was banned in 1998 raw material for the factories has been changed from natural teakwood to plantation teakwood. The FIO then set up policy to encourage the use of wood from plantation instead of from natural forest. Unfortunately, wood supplies from teak plantation were usable in only some of these factories such as saw milling by man-power, wood working by man-power and wood products shop where located in the northern region only. In other regions rarely teak plantation wood producing factories or shops can be found.

At present, wood processing by these factories or saw milling by man power is still using low technology. It produces too much waste in wood processing which results in higher cost per unit, thus lessen

Table 6. Sawmills and wood products factories in 2006

Item	Total	Classified by Region					
	mills	Bangkok	Central	North	North-east	South	East
Sawmills	971	90	244	104	81	321	131
Sawn milling by Man-power	71	19	11	24	6	2	9
Wood Working by Machinery	7,270	2,995	2,229	594	510	485	457
Wood Working by Man-power	944	35	312	191	307	59	40
Pulp and Paper Mills	1	1					
Sawn Timber Shop	5,239	1,425	1,547	638	843	447	339
Wood Products Shop	6,890	2,362	1,841	1,200	945	247	295

Source : Office of the Permission Division. RFD 2006.

competitiveness. The other problem found in utilization of teak wood from plantation which causes exporting processed product less opportunity is that most farmers harvested immature trees from the plantation which, inevitably, resulted in lower quality products than from natural wood. Even though there is a research indicates that short-rotation teakwood is not significantly inferior in density and strength compared to natural-grown teak, with lower heartwood and extractive contents it is less durable and attractive (Bhat and Ma, 2004). Mentions made by Bhat and Ma (2004) are that even with genetic and silvicultural improvements, the appearance of the teakwood produced by fast-grown trees is likely to continue to be different from slow-grown natural-forest teak in terms of colour, grain and texture. Given that one of the main criteria for the market price of a timber is its appearance while another is durability, the fast-grown teak is therefore unlikely to ever fetch the sorts of prices commanded by old-growth teakwood. Today's plantation teak sells at a significantly lower price than does natural-forest teak. To worsen the problem, poor designed and coarse work makes the products unaccepted in international market. Most of products have to be sold in domestic market with lower price. These same problems may be faced in other teak planting countries. Bhat and Ma (2004) made some suggestions that training programmes are needed to improve skills and productivity and to reduce waste in the processing of teakwood, including sawing and drying but also in other value-adding processes such as the design and manufacture of fine furniture. Moreover, given the changing nature of the teak resource from one that is generally slow-grown and large-diameter to one that is fast-grown and small-diameter, teak-growers and manufacturers will need to find new technologies, products and markets.

TRADE AND MARKETING

Thailand was once classified as a major timber-producing country with rich forest resources. It is recorded that export earnings from teak trading were second only to rice for many decades. The net effect of illegal logging, ineffective forest management, expansion of agriculture and livestock breeding, and shifting cultivation, accompanied by the continuously increasing demand from wood-based industries, has resulted in a timber scarcity. Currently, Thailand has to import logs, sawn wood, and other resources from neighboring countries to meet the domestic demand, which has turned Thailand from a timber exporting to an importing country (Sumantakul and Sangkul, unpubl.). Even though there are some wood productions from plantations available, most of teakwood from plantation is used within the country due to lack of raw materials for domestic use.

Teak import

Teak log and lumber imports amounted to more than 200,000 m^3 / year as raw material for export products, as well as for domestic consumption (Moonrasarn, 1992). Statistics of the RFD indicated that Thailand imported teak timber (logs and sawn timbers) during 2002-2006 were 340,816; 128,497; 120,641; 143,668 and 146,758 m^3, respectively. The values of these timbers were 2,702,993; 2,928,224; 2,844,404; 3,218,066 and 3,210,460 thousand baht, respectively. This figure is very high compare to the grand total of importation value of major wood products to the country in 2006 of which was only 4,824,898 thousand baht. The most teak exporters to Thailand were Myanmar, Laos, and Indonesia (RFD, 2006).

Teak export

After heavy exploitation for many years, production has been substantially reduced. However the imposition of a logging ban in 1989 prohibiting teak harvesting from natural forests, except from areas with land titles, as well as from dams and reservoir construction, has sharply reduced the teak harvest. Lack of wood supply for domestic use then occurred. Since 1991, export of teak logs and lumber had then been prohibited, except in the form of processed products or veneers (Sumantakul and Sangkul, unpbl). The regulation, however, has then been changed since January 11, 2000 when the cabinet made an approval on exporting teakwood from plantation. In the regulation only FIO is allowed to export logs and sawn timbers teakwood from plantation after an approval of the RFD. Data from the Customs Department revealed that Thailand has exported teak timbers (logs and sawn timber) during 2002-2006 was 8,803; 5,445; 7,678; 12,921 and 7,116 m3 with values of 566,715; 577,635; 675,599; 713,760 and 793,669 thousand baht, respectively (RFD, 2006).

Exporting of teak logs from plantation by FIO, however, had been protested by local wood factories due to the lack of raw materials supply in the country. In 2006, only sawn timber was then exported. From this figure it reveals clearly that teak export is not any more important to Thailand economic. It is not because of its low valuableness but because of its so high valuableness till too many restriction laws and regulations have been issued to protect it. Compare to its exotic invaluable friend, parawood, with no restriction regulation at all, its exported value during 2002-2006 were up to 4,893,492; 6,901,473; 9,276,386; 8,939,664 and 10,525,279 thousand baht, respectively. Grand total exportation value of major wood products in 2006 was 35,400 million baht. The most importers were U.S.A. and Japan (RFD, 2006).

Another factor that causes less competitiveness of planted teakwood from Thailand in the international market is improper legislation with official practices which involve in natural wood, planted wood and imported wood. The laws are still emphasizing on controlling rather than supporting wood industry.

CONCLUSION

Rich in its natural forest, Thailand was once classified as a major timber-producing country, especially teak timber. Thailand has been changed from teak exporter to be importer since the logging ban has been imposed in 1989 after big flooding in the South. Since then teak wood product has been then relied entirely on wood from plantation. Most of teak in plantation is, however, still immature. Thailand has a clear policy to support teak plantation but for exploitation, however, there are some strict regulations on harvesting and trading due partly to fast reduction of forest area and lack of supply in the country. At present, wood processing is still using low technology and low wood quality from plantation with lesser opportunities in the international market. Training programmes are needed to improve skills and productivity. For trading and marketing issues, Thailand imports raw materials from neighbour countries such as Laos, Myanmar, and Indonesia. Only FIO is allowed to export logs and sawn timber. For other traders only wood processed products are allowed to export. The most importance importers are U.S.A. and Japan.

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Processing and Marketing of Teak Wood Products of Planted Forests pp 56 - 70

Policy and Status of Planted Teakwood: Its Properties and Processing in Malaysia

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ABSTRACT

Even though Malaysia has planted teak since 1800s, commercial scale planting began only since 1990s. By 2001, there were about 5,970 ha of teak plantations in Malaysia. However, the technology for processing and marketing of planted teak products is yet to develop. In general, the planters and wood-processing industries believe that there is a market potential for planted teak products. Studies highlighted that: (a) of the six companies and 21 individuals who planted timber species, 45 percent stated their target market to be within Malaysia while 22 percent of them aimed at foreign market while 33 percent were not sure of their perceived market, (b) 58 percent of the total 40 industries interviewed perceived that planted teak has market prospects, and (c) among a total of 35 highly sought-after species by the industries, planted teak ranked 14 in the list. With strong support from government for the development of forest plantations, some companies are expected to plant teak on a big scale. If teak plantation forestry is to be, we can expect it to be followed by a significant improvement in processing and marketing of products in the future. To make this happen, more information on potential markets and end-uses of teakwood need to be disseminated widely to the planters, potential planters and wood-based industries.

Keywords: Planted teak, processing and marketing, market prospects, forest plantation.

INTRODUCTION

In 2006, the total area of forests in Malaysia was 19.52 million hectares or 59.5% of the total land area of 32.82 million ha. Of the total forested area, 14.39 million hectares (74%) have been designated as Permanent Reserved Forests (PRFs) and these are under sustainable management. A total of 10.63 million hectares (74%) of the PRFs are production forests with the remaining 3.81 million hectares (26%) being protection forests. The Malaysian forestry sector plays an important role in nation building, especially in terms of income generation and employment. The export value of all timber products increased from RM8.6 billion in 1990 to RM21.5 billion in 2005 (or 4.7% of the total export earning). About 360,000 people (3.2% of national labour force) are employed in the forestry sector.

The forestry sector in Malaysia faces challenges in terms of achieving sustainability and conservation of forest resources on the one hand and the development of forest-based industries (FBIs) for national income generation. In the midst of international demand for sustainable forest management and consumers' demand for certified forest products, efforts have been taken by the Malaysian government to reduce the harvest of logs from natural forest. Log production in Malaysia declined from 40.1 million m^3 (1990) to 21.8 million m^3 in 2005 With the effort of managing the natural forests in a sustainable manner, the medium term log production from the natural forests for Malaysia is estimated at 18.7 million m^3 per annum (Woon and Ab. Rasip, 2006).

On the other hand, the FBIs in Malaysia are developing rapidly. This gives a pressure on the ability of the natural forest to supply enough resources for the industry. In an effort to reduce this pressure, the production of wooden furniture had been using rubberwood obtained from the rubber estates throughout Malaysia since 10 to 15 years ago. To date about 80% of the Malaysia furniture are produced from rubberwood. Despite all these, it has been projected that Peninsular Malaysia would still face a deficit of 3.85 million m^3 of log between 2006 and 2010 to meet the industrial demand for logs as log production (from natural forest, forest plantation and rubber plantation) totalled 16.75 million m^3 while domestic demand amounted to 20.6 million m^3 (Lunjew, 2005).

It is in this light that the planted forests are becoming more important to Malaysia as there is a shortage of timber supply from the natural forest to meet the needs of the local wood-based industries, particularly those in Peninsular Malaysia. The aim of this paper is to examine forest plantation development in Malaysia in general and teak planted forests in specific. It also outlines planted teak wood's properties and its utilization. The marketing of teak wood products is not examined because this aspect is insignificant at this stage of time. The planters' perceptions on potential markets and perceived end-usage of planted timber in general were outlined. Industries' perceptions on market prospects of planted teak were also examined.

Forest plantations in Malaysia

Even though Malaysia has a relatively long history of forest plantation establishment (Table 1), commercial planting only took place actively since 1980. As early as the 1980s, it was forecasted that there would be timber shortage of about 4 million m^3 between 2006 and 2010 (Thang, 1985). Consequently, forest plantation is being promoted in anticipation of the shortfall in log supplies to cater to the need of the fast growing timber-based industries. The Compensatory Forest Plantation Program (CFPP) implemented in 1982 as well as plantations in Sabah have contributed to supplying logs to the timber-based industries.

By 2006, a total of 321,115 hectares of forest plantation had been established in Malaysia. Of this total, 75,807 hectares (23%) were established in Peninsular Malaysia, 185,308 hectares (58%) in Sabah and 60,000 hectares (19%) in Sarawak (Woon and Ab. Rasip, 2006). Production is projected to increase when these plantations are ready for harvest. Besides natural timber species, rubber plantations are now an important timber resource especially for the production of panel products and furniture. Rubberwood (*Hevea brasiliensis*) from the rubber trees is used mainly by wood processing industries in Peninsular Malaysia.

History of teak plantation

Teak (*Tectona grandis* Linn. f) from the family Verbenaceae, is predominantly tropical or sub-tropical and not indigenous to Malaysia. The natural distribution of teak extends from the Indian sub-continent through Myanmar and Thailand to Laos. In addition to its natural distribution, teak has been widely cultivated in many parts of the tropic especially in South East Asia, Africa especially in Nigeria, Ghana and Ivory Coast, the Caribbean, south and central America (Phengklai *et al.*, 1993, Ola-Adam, 1990; Tewari, 1992).

Table 1. A summary of notable events in the history of forest tree planting In Peninsular Malaysia

Year	Event
Before 1877	Villagers planting forest fruit trees in shifting cultivation areas, orchards and around houses. This continues until today even though some villagers have given up shifting cultivation.
1877	Rubber tree (*Hevea brasiliensis*) in Kuala Kangsar, Perak.
1880 - 1900	Small-scale planting of species such as nyatoh taban (*Palaquium gutta*), rambong (*Ficus elastica*) and rubber tree (*Heave brasiliensis*), Ru (*Casuarina equisetifolia),* kelat (*Eugenia grandis),* kapur (*Dryobalanops aromatica*), mahogany (*Swietenia macrophylla*), and tembusu (*Fragraea fragrans*).
1901 - 1913	Regular plantations of gutta percha (*Palaquium gutta*), and rubber tree (*Hevea brasiliensis*); line-planting of chengal (*Neobalanocarpus heimii*) in forest reserves; experimental planting in abandoned mining land. Species trials with teak were first tried by a rubber planter in Langkawi Island, Kedah.
1927 - 1941	Forest Research Institute set up in Kepong, and experimental plantations in lowlands were started; plantation experiments in Cameron Highlands (ca. 1,500 meter above sea level), Pahang; Rantau Panjang and Bukit Sungai Puteh Forest Reserves, Selangor; teak planting in Langkawi Island.
1945 - 1950	Experimental teak plantations in northwest Malaya; plantings in forest clearings resulting from disturbances during the Japanese Occupation (1942-1945).
1954 - 1958	Experimental teak plantations in northwest Malaya were stepped up. Some exotic species (such as pines, yemane and eucalypts) were tried on experimental plantations.
1959 - 1962	Large-scale experimental planting with *Pinus caribaea* and *Pinus insularis* in the lowlands. Experimental plantings in shifting cultivation areas; line-planting and small-scale plantings of secondary growth of *Dryobalanops aromatica, Eusideroxylon zwageri, Flindersia brayleyana, Fagraea fragrans, Khaya* spp., *Pentaspadon officinalis* and *Shorea macrophylla.*
1963 - 1965	Bigger trials of *Pinus* spp. conducted in Selangor.
1966 -1970	Under UNDP, pilot plantations of quick growing industrial tree species were initiated, mainly for production of pulp; plantations of pine were expanded in Selangor, Johore, Pahang, Negeri Sembilan and Kedah; *Shorea* and *Drybalanops* spp. planted under the taungya system in Negeri Sembilan; jelutong (*Dyera costulata*) plantations were expanded in Sungai Buloh Forest Reserve.
1971 - 1976	Mixed plantations of *Pinus* and *Araucaria* were tested on poor soils in Bahau; enrichment planting using indigenous species became an important forestry species.
1981 - 1992	The Compensatory Forest Plantation Project through Asian Development Bank loan was initiated; quick growing tropical hardwoods like *Acacia mangium, Gmelina arborea* and *Paraserianthes falcataria* were chosen for producing general utility paper. Trial planting of rubber trees for the production of timber alone took place between 1987 and 1991.
1992 - 1996	Planting of teak began earnestly in wetter sites; sentang (*Azadirachta excelsa*) was also given importance as a plantation species.
1996 - now	Government encourages big planters and smallholders to plant forest tree species, such as teak (*Tectona grandis*) and sentang (*Azadirachta excelsa*).

Source: Appanah and Weinland (1993), Krishnapillay and Appanah (2002).

Trial planting of teak in Peninsular Malaysia started in the 1800s but without much success (Burkill, 1966). Prior to 1941, the growing of teak in northern states of Peninsular Malaysia, particularly in the state of Kedah, was restricted to roadside or garden trees with the exception of a small plantation at Sungai Raya Rubber Estate in Langkawi Island (Wyatt-Smith, 1957). After the Japanese occupation of Malaya (1941-1945), plots of teak were set up between 1945 and 1950 in northwest of Peninsular Malaysia. From 1949 onwards and probably until late 1970s, several small scale experimental plantations ranging from 0.24 ha to 12.42 ha were established in the states of Perlis, Langkawi Island, Central and North Kedah.

More planting of teak was initiated in 1980s and through 1990s. By 1990s, a total of 1546.4 ha of teak were planted, mainly in the northern states of Perlis, Kedah, Perak, and Kelantan as well as in southern state Negeri Sembilan in Peninsular Malaysia (Aminah and Amir Husni, 1996). Even though relatively large-scale forest plantations started only in the 1980s where under the CFPP, the key species planted were *Acacia mangium*, *Gmelina arborea*, and *Paraserianthes (Albizia) falcataria*. Consequently, the development of teak plantation did not take place on a large scale compared to the other timber species. In Peninsular Malaysia, of the 74,052 ha of forest plantation in 2000, 2,433 ha (3%) was under teak (Table 2). In the East Malaysian state of Sabah, a total area of 2,362 ha was planted with teak (Trockenbroth and Josue, 1999).

By 2001, the total planted teak area increased to 3,608 ha in Peninsular Malaysia (Table 3), after road shows were held by FRIM with support from the other government agencies such as the Forestry Department of Peninsular Malaysia, Rubber Smallholders Industry Development Authority (RISDA). Peninsular Malaysia and Sabah thus totalled 5,970 ha of teak plantations in 2001.

Table 2. Areas of forest plantation projects, Peninsular Malaysia, 2000

Project	Area (ha)	% of total area
Compensatory Forest Plantation Projects (CFPP)	56,107	76
State projects	6,272	8
Teak	2,433	3
Pine	3,555	5
Hevea	1,313	2
Sentang	2,235	3
Others	2,137	3
Total	**74,052**	**100**

Source: Forestry Department Peninsular Malaysia, cited in Lim *et al.*, 2002.

Table 3. Distribution of teak plantations in Peninsular Malaysia, 2001

Species	Total area (ha)	% of Total
Teak	3108	79.6
Teak x rubber trees	430	11.0
Teak x sentang	70	1.8
Total	**3,608**	**100**

Source: Forest Plantation Division, FRIM (2002), cited in Lim *et al.*, (2002)

Slow development of teak plantation

In general, teak plantation is relatively less developed in Malaysia compared to other timber species (Table 2) for a number of reasons.

Firstly, teak occurs naturally within the latitudes of 10°N and 25°N. Hence, region such as the Indian subcontinent and mainland of Southeast Asia (Myanmar, Thailand, Cambodia and Laos) fit into this category of teak area (Krishnapillay *et al.*, 1998). Malaysia, a country south of 10°N was introduced with teak during the British colonial period in the early 20th century.

Secondly, it was believed that not all parts of Malaysia have the conditions suitable for teak's planting and growth. Teak tolerates rainfall from 1250 mm to 3800 mm and thrive in optimum temperature varies from 15° C to 40° C. Even though it is rather flexible to soil requirements as it grows on a variety of soils of different geological formations, the quality of its growth depends on depth, structure, porosity, drainage and moisture holding capacity of the soils. In general, deep soils with free draining properties are most desired (Krishnapillay *et al.*, 1998). It appeared that only the northern states of Malaysia fulfil all these conditions for the planting of teak.

Thirdly, the British colonial government did not promote the planting of teak on a large scale. The reason being teak was believed to thrive best in the drier zones like in the northern states (i.e. Kedah and Perlis) of Peninsular Malaysia, bordering the Southern Thailand where teak is a native species. Consequently, teak was not seriously promoted to the other parts of Malaysia (Wyatt Smith, 1957).

Fourthly, there was a lack of information on planting of teak in wetter areas in Malaysia. By the 1990s, more research information was available on teak plantation establishment. Teak growing areas in India show that teak responds very well in terms of growth and girth increment in areas where the trees received sufficient moisture at least for most part of the year when compared to those growing in the monsoonal areas (Kondas, 1995). It simply means that as long as there is adequate rainfall, teak could be planted in areas near to the non-native areas. Moreover, it has been shown that the relationship between growth rate and strength was not significant (Sekar, 1972, Nair and Mukerjee, 1957). Studies by Sanwo (1987) based on dominant, co-dominant and sub-dominant trees from a 27-year-old teak plantation in Nigeria showed that the rate of growth has no significant influence on specific gravity. Strength is, in general, higher at the bottom and top regions and comparatively lower at the intermediate height. The teak trees from 20-year-old plantation that has been grown in the wet areas in India also showed similar results (Kondas, 1995).

Based on this understanding, in the 1902, various small trials of teak were established in other southern states of Peninsular Malaysia such as in Perak (Lenggong-rainfall 2800 mm), Selangor (Kuala Selangor-rainfall 2500 mm) and Johore (Yong Peng-rainfall 2700 mm). The planting shows 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 was also remarkable. This has sparked off the interest to promote teak on a large scale within Malaysia in the 1990s and early 2000s.

In Malaysia, the planting of teak is economically motivated. The price of sawn teak timber on the world market fluctuates between US$1,500 and 2,000 per tonne. Such a high price is because of teak wood reputation in its durability, beauty, workability, strength and dimensional stability. It is resistant to termite and fungal attack. The colour of the wood is attractive to many consumers. The sapwood is yellowish or straw-coloured while the heartwood yellowish brown turning golden brown. The planed surface of teak wood has a velvety feel due to the oily substances and smells like old leather. These characteristics make teak suitable for many purposes. Heavy duty uses include structural beams, bridges and boat building. Light duty uses include furniture making, parquet and strip flooring, staircase, interior joinery, decorative work, sculptured and carved woodwork, door and window. Despite this high world market price for planted teak, its planting has slowed down in the last few years due to the long gestation period. In some cases, due to slow growth, some teak farms established by small farmers were converted to other crops such as oil palm after planting teak for a few years.

National development policies

The Malaysian government's promotion for timber species plantation establishment since the 1990s has much to with national development policies.

Recognizing the dire need to rationalize land use policies in relation to the conservation of forest resources and their management on a sustainable basis, a National Forestry Policy (NFP) for Peninsular Malaysia was formulated and approved for implementation in 1978. When the policy was revised in 1992, among the spheres emphasized were forest plantation development, community forestry and agro-forestry (Salleh and Lim, 1996). Another Malaysian policy that promotes the development of forest plantation in general is the Third National Agricultural Policy (NAP3), 1998-2010. The overriding objective of NAP3 is the maximization of income through the optimal utilization of resources (Malaysia, 1999). The specific objectives are to enhance food security, to increase productivity and competitiveness of the sector, to deepen linkages with other sectors, to create new sources of growth for the sector, and to conserve and utilize natural resources on a sustainable basis. With the implementation of NAP3, new sources of growth will emerge in the areas of agroforestry, specialty natural products, bamboo and rattan, biotechnology products, floriculture and aquarium fish.

It is in this context that agroforestry practices could be further promoted to uplift the living standards of the Malaysian rural population. The NAP3 has adopted an agroforestry strategy to integrate agriculture and forestry development. The agroforestry approach is expected to optimise resource utilization and enhance the income generating activities.

Government incentives for tree planting

Since 1990s, the government has taken steps to encourage private forest plantations in the country. Subsequently, incentive packages were introduced under the Promotion of Investment Act (PIA) 1986 and the Income Tax Act 1967. Under the PIA 1986, the two incentives offered were pioneer status and an investment tax allowance (ITA). Those planting timber, rattan, and bamboo, which were designated promoted activities under the PIA 1986, were granted pioneer status. For instance, a company granted PS would be eligible for the 100% exemption for a period of 10 years from the date of its first sale. The ITA provided an agriculture allowance (100% of the qualifying capital expenditure incurred within 5 years from the date of approval of the project) to those who invested in forest plantations.

Under Income Tax Act 1967, Schedule 4A allows for qualifying farm expenditure incurred for the purposes of an approved agricultural project on the followings:

- The clearing and preparation of land;
- The planting (but not replanting) of a crop relating to an approved agricultural project;
- The construction on a farm of a road or bridge;
- The construction on a farm of a building used for the purposes of an approved agricultural project which is carried out on that farm or the construction on that farm of a building provided for the welfare and accommodation of persons employed in that project and which, if that project ceased to be carried out, is likely to be of little or no value to any person except

in connection with the working of another farm; or

- The construction of a pond or the installation of an irrigation or drainage system which is used for the purposes of an approved agricultural project.

The above is subject to the following conditions (Income Tax [Approved Agricultural Projects] Order 2002):

- The forest plantation project is at least 50 hectares;
- The period / rotation age is 6 to 50 years depending on the type of species specified in the Second Schedule (73 species of tree, rattan (*Calamus)* and Bamboo poring *(Gigantochloa levis*).

RESEARCH, DEVELOPMENT AND PROMOTION ON TEAK

The planting of teak is strongly encouraged by the government. Consequently, special research and development activities were carried out by related government agencies. Nurseries were established by both the public and private sectors. The research aspects of teak are mainly done by the Forest Research Institute of Malaysia (FRIM). Since 1997, FRIM undertakes research on the following aspects of teak (Krishnapillay *et al.,* 1998).

1. Tree improvement – to make available elite planting materials for mass propagation.
2. Tissue culture – to develop large scale in-vitro propagation techniques for the production of uniform true to type plants for the plantation industry.
3. Genetic evaluation and finger - printing of teak clones using isozyme and DNA molecular markers.
4. Detailed studies on species site matching.
5. Planting trials relating to optimum thinning regime, fertilizer requirement and sound silvicultural practices.

Besides government incentives for companies to plant forest trees, efforts were also made by forestry agencies to encourage forest tree planting by the smallholders. Road-shows were held by Forest Research Institute Malaysia and the Forestry Department Peninsular Malaysia, supported by Rubber Industry Smallholders Development Authority (RISDA), has been instrumental in encouraging smallholders to plant tree species. The planting of teak (*Tectona grandis*) and sentang (*Azadirachta excelsa*) became a hot issue among the smallholders immediately after FRIM organized road shows on these two species in 1996 and 1997. In the mean time, there was also a private syndicate encouraging smallholders to plant forest tree species. Even though the role of the syndicate is economically motivated (i.e. the sale of seedlings), it helped raised the interests in forest tree planting among smallholders.

The research in FRIM and its road shows in various parts of Malaysia led to the promotion of teak planting among the public and private sectors as well as the smallholders in the mid-1990s.

Tree planting by the private sectors: a case study

Other than the government agencies and private sector, teak is also planted by the individual farmers. Tree planting among smallholders is not new in Malaysia. The indigenous peoples (14% of Malaysia's population of 27 million in 2007) and rural villagers have been planting fruit trees and rubber trees for a long time to meet their subsistence food need, to generate cash income and to provide shade to their living environment.

The tradition of planting forest trees and hill paddy (in remote areas) persists among the indigenous peoples in Malaysia. After a number of years of planting hill paddy in an area, the indigenous farmers normally shift to a new area. Fruit trees such as durian (*Durio zibethinus*), rambutan (*Nephelium lappaceum* L.), petai (*Parkia speciosa*), duku/langsat (*Lansium domesticum* Jack), nangka (*Artocarpus integrifolia*) and mangoes (*Mangifera indica* L) are normally planted in the abandoned area. This serves a few purposes. Planted trees are used as traditional boundaries, which decide land and forest resource utilization. After a number of years, the household concern would return to this same area to harvest the fruits or plant hill padi again.

Other than the indigenous people, other rural villagers (mainly Malays, Chinese and Indian) also planted fruit trees in their orchards and near their houses. There is yet to be a big scale planting of forest trees among these rural farmers.

In 2002, a study on the planting of forest tree species among the planters in the private sectors (Lim *et al.*, 2002). A total 21 smallholders and 6 companies were interviewed on various aspects of forest tree planting. Highlights of the study are as follows:

1. The role smallholders played in planting forest species is as important as that of the private companies. The total area planted by individuals in 2002 was 11,823 ha (15.6%) while the area planted by various companies was 11,404 ha (15.1%) as indicated in Table 4.
2. Probably what differentiates the two groups is the area planted individually, which usually is much larger for a company than for an individual planter. The average size of forest tree area was about 2 hectares per smallholder (Table 5) while it averaged 75 ha per company for six companies.
3. Two-thirds of the 21 smallholders planted on land less than 2 hectares (Table 5).
4. About half of the smallholders planted mono crop (i.e. either teak or sentang) while the rest preactises agroforestry where teak or sentang

Table 4. Distribution of forest plantation areas by private entrepreneurs, government agencies and individual planters, Peninsular Malaysia, 2002 (in ha)

State	Private companies	Various government agencies	Individuals	Total
Johore	6,599	12,069	2,020	20,688
Kedah	95	1,003	441	1,539
Kelantan	15	3,866	650	4,531
Malacca	40	12	126	179
N.Sembilan	723	4,314	554	5,590
Penang	7	4	11	22
Pahang	2,129	16,571	3,606	22,306
Perak	396	3,219	1,079	4,694
Perlis	78	311	407	795
Selangor	304	9,025	831	10,161
Terengganu	1,017	2,053	2,098	5,168
Total	**11,404**	**52,445**	**11,823**	**75,672**

Source: Forest Plantation Division, FRIM (2002), cited in Lim *et al*., 2002.

Table 5. Smallholders' forest tree planted areas, 2002

Land size (ha)	No. of smallholders	%
Less than 1	9	43
1 – less than 2	4	19
2 – 4	5	24
7 – 8	3	29
Total	**21**	**100**
Average land size = 2.2 ha		

Source: Lim *et al.,* 2002.

Table 6. Type of forest tree species planted by smallholders, 2002

Type of tree	No. of smallholders	%
Teak only	5	24
Sentang only	5	24
Teak and oil palm	2	10
Teak and banana	1	5
Teak and tongkat ali	2	10
Sentang and rubber	6	29
Total	**21**	**100**

Source: Lim *et al.,* 2002.

Table 7. Previous crops planted by smallholders, 2002

Previous land use	No. of smallholders	%
Oil palm	2	10
Rubber	15	70
Fruits	1	5
Coconut	2	10
Residential land	1	5
Total	**21**	**100**

Source: Lim *et al.,* 2002.

Table 8. Planting year of forest trees by smallholders, 2002

Land size (ha)	No. of smallholders	%
1993	1	4
1994	2	10
1995	2	10
1996	2	10
1997	3	14
1998	2	10
1999	8	38
2000	1	4
Total	**21**	**100**

Source: Lim *et al.,* 2002.

is mixed with other crops such as rubber, oil palm or tongkat ali (*Eurycoma longifolia)*, the most popular medicinal plant in Malaysia as indicated in Table 6.

5. Of the 21 smallholders, 70% previously planted rubber (Table 7).
6. All the 21 smallholders planted forest trees between 1993 and 2000 (Table 8).

Why commercial forest plantation not taking off?

Malaysian experience showed that forest plantation can produce as high as 10-30 m^3/ha/yr of commercial hardwoods compared to 1-3 m^3/ha/yr from natural forests (Awang Mohdar and Ahmad Zuhaidi, 2005). We would then expect forest plantation development in Malaysia to take place in a bigger scale. However, despite the incentives given by the government (through Pioneer Status and the Investment Tax Allowance [ITA]), the establishment of forest plantations have been very slow and far short of expectation. In this case, while the research findings may be technically sound, the economic case may not be so, in spite of the fiscal incentives given. Investors in the private sector are reluctant to invest in forest plantation because it has a long gestation period and involves higher risks, thus making the fiscal incentives provided less attractive. The Pioneer Status is only useful at the harvesting stage, which is 15 years or more down the road. Under the ITA, qualifying expenditure is only allowed for the first five years and can be carried forward until it is fully offset against future incomes. If the company is not making any profit or does not have any other business incomes, it will also have to wait until the harvesting stage as mentioned earlier.

For the smallholders, teak planting has slowed down after 2002. Smallholders were basically motivated by the high expected economic returns when they planted teak. After a decade of planting, it has been observed that the expected economic return has yet to be seen. Consequently, interested smallholders have to put on hold their plans to plant teak and other timber species.

A new approach to forest plantation establishment

Despite slow development of the forest plantation in Malaysia, the Malaysian government continues to find new way to promote its development. Simply, forest plantation is an important supplementary source of raw materials in order to sustain the vitality of the wood-based industries as well as to reduce pressure on over-harvesting of the country's natural forest. A new approach is now adopted in forest plantation development. A big-scale tree planting program is now funded and implemented. For this purpose, a Special Purpose Vehicle (SPV) in the form of a new company, Forest Plantation Development Sdn Bhd (FPDSB) was formed in 2006 (Maskayu, May 2006) to be accountable for loan management and will recoup all payments from borrowers undertaking the forest plantation projects.

With this new approach to forest plantation establishment, the following two new mechanisms are being implemented, i.e. soft loan facility and tax incentives

(a) Under the soft loan facility, a borrower is charged an interest rate of only 3.5% per annum and a grace period of 15 years is given before repayment of both loan and interest incurred. Among the species recommended/ considered under this facility are rubber, Acacia hybrid, teak, kelempayan, batai, binuang, khaya and sentang (Woon and Ab. Rasip, 2006).

(b) In 2006, the government has allocated an initial sum of RM200 million to finance the establishment of forest plantation. The allocation signifies a bold step taken by the government towards the implementation of a big scale forest plantation programme on a commercial basis (Maskayu, May 2006).

It is projected that more than 5 million m^3 of sawn timber are required from 2020 onwards. The forest plantation development program is targeting to develop 375,000 hectares of forest plantations nationwide with the 15-year cycle to ensure the sustainable growth of the timber sector and continue to contribute towards the growth and development of the Malaysia's economy. Beginning 2006, an average of 25,000 hectares will be planted per year for 15 years (Maskayu, May 2006). The planted areas are expected to meet the shortage of wood supply from natural forest and rubberwood from the traditional rubber plantations.

The availability of planting materials is essential in ensuring the successful implementation of this new approach. FRIM is responsible to develop sufficient planting materials for teak and other timber species under this programme. The new approach enables the private sector nurseries to work closely with Malaysian Rubber Board and FRIM for commercial production of planting materials for future development of forest plantations in Malaysia.

The implementation of this new approach has been encouraging. In 2006, a total of 26 companies have been short-listed under the loan programme (Makskayu, May 2006). By July 2007, according to FPDSB, a total of 10 companies were approved a total loan of RM140 million to establish 28,000 ha forest plantation in Malaysia (Mohamad Rosde, 2007).

PROPERTIES AND UTILISATION OF PLANTATION - GROWN TEAK

There is no major utilization of plantation-grown teak in Malaysia since the earlier planted stock was mainly for research purpose while commercial cultivation took place only since mid-1990s, which is yet to be harvested for use. However, some studies have been carried out on their properties below.

Decorative veneer

Wong (1980) studied materials from five 25 years old teak trees harvested from the Mata Ayer Plantation in Perlis for use as decorative veneer and found that the colour of the locally-grown teak veneers was light brown with a pronounced greenish tinge and upon drying, the greenish tinge became less pronounce. The colour of the veneer is lighter when compared with the veneers imported from Myanmar. Recovery of the veneer was reported to be around 25%. The low recovery was attributed to the rejection of defects such as knots, splits and the 'boxed heart' portion. Slicing and gluing were easy and good.

Processing and recovery studies

Sim *et al.* (1979) reported good sawing properties of 25 years old teak from Perlis and reported 55% recovery despite unfavourable smaller logs diameter. Tse (1999) studied fourteen 70-year-old trees from Sabah reported that logs of sawmill quality and millable quality produced lumber with mean recovery rates of 30 and 23% respectively. Majority of the output was classified as 'Prime Grade' with others classified as standard, serviceable and utility grade. Common defects detected include sloping grain, stain, shakes, unsound knots and large percentage of sapwood. Lee and Lopez (1980) reported that sawing, planning, boring, moulding, turning and sanding of teak were easy with smooth surfaces. The resistance to splitting in nailing is rated as 'excellent' (Lopez, 1992).

Mechanical properties

A total of nine trees were obtained from the states of Kedah and Perlis for evaluating their mechanical strength properties (Lee *et al.,* 1979). The results of the test are shown in Table 9.

The overall strength results are probably very similar to the Malaysian timber of nyatoh (*Palaquium gutta*).

Density variation

Lim and Gan (1998) tested on five trees each of 8, 16 and 28-year-old teak from the Mata Ayer Forest

Table 9. Mechanical strength properties of plantation-grown teak in Malaysia

Test condition	Modulus of elasticity (MPa)	Modulus of Rupture (MPa)	Compression parallel to grain (MPa)	Compression perpendicular to grain (MPa)	Shear strength (MPa)	Side hardness (N)
Green	9400	73	35.7	5.38	13.0	5430
Air-dry	10300	86	45.8	5.79	10.6	4850

MPa = Mega-Pascal, N=Newton

Reserve, Perlis. The density was found to range from 515 to 805 kg/m^3 for the 8-year-old, 514-893 kg/m^3 for the 16-year-old and 534-961 kg/m^3 for the 28-year-old. There was a tendency for the density to increase as the trees aged. On the radial variation, the 8 and 16-year-old teak showed an increase of density towards the bark. Generally, the density of the Malaysian-grown teak was comparable to teak grown elsewhere.

Market prospect of planted trees

Even though teak planting since the early 1990s has yet to be harvested for market use, the issue of market is of real concern to the planters. Unlike the commercial crops such as rubber and oil palm where markets are readily available, the potential market for planted forest timber is yet to be established. A study (Lim *et al.*, 2002) among six companies and 21 individual planters showed that even though some planters were not sure of future market situation, they are generally aware that there would be markets for their timber. The study showed the following notable findings.

- Of the total respondents, 45% stated their perceived market to be within Malaysia, 22% foreign market while 33% were not sure of their perceived market.
- A slightly bigger proportion of individual planters (48%) viewed domestic market as their perceived market compared to companies (33%).
- A higher percentage of companies (50%) viewed their markets in foreign countries than individual planters (14%). One possible reason for this is that companies have more access to information on foreign markets than individual planters.
- All six companies felt that they could sell their timber to either trading agents (50%) or furniture mills (50%) in the form of sawn timber. For 21 individual planters, 10% would sell their timber to agents, 43% to furniture mills while 47% did not know to whom they could sell their timber.
- Of the six companies, 83% were aware that the timber produced would be used in furniture making while 17% perceived the timber to be used as sawn timber. For the 21 individual planters, 53% were aware of usage of the timber tree planted.

In another study (Norini *et al.*, 2002), a total of 18 sawmills, 6 plywood/veneer mills, 5 moulding mills and 13 furniture mills throughout Peninsular Malaysia were surveyed on the market prospects of fast growing timber plantation species. With regards to market prospects of planted teak (categorised as medium hardwood), the study showed that 58% of the total 40 industries responded to this question perceived that planted teak has market prospects while 42% were not sure of its market prospects (Table 10).

In the same study (Norini *et al.*, 2002), the respondents were asked to list the highly sought-

Table 10. Market prospects of planted teak from the industries' perspective

Industry	Has prospects	Prospects "not sure"	Total
Sawmills	10	8	18
Plywood/veneer Manufacturers	4	2	6
Moulding mills	4	1	5
Furniture manufacturers	5	6	11
Total	**23 (58%)**	**17 (42%)**	**40 (100%)**

Source: Norini *et al.*, 2002.

after species. A total of 35 highly sought-after species were provided and planted teak ranked 14 in the list. This shows that the industries are prepared to process and market planted teak products.

What are the conditions required for the market development of planted species? The industries were of the view that three main factors required for market development are sufficient supply, attractive prices and good characteristics (Norini *et al*., 2002). Good characteristics of the timber include easy handling and sawing. For the 18 sawmillers, ranking of factors affecting the price of logs are in the order of availability (83%), timber species (67%), quality (61%), density (56%), process-ability (50%) and colour (33%).

CONCLUSION

Total planted areas of teak are over 3,600 ha in Peninsular Malaysia and over 2,000 ha in the east Malaysian state of Sabah. Out of the total areas planted, at least 50% of them are below 15 years of age. It is envisaged that there will not be a large scale utilization of teak in the near future. In the case of Sabah, some teak plantations are managed privately and perhaps, the possibility of early harvest and utilization of the timber will be carried out in the near future.

Unlike other teak producing countries, since commercial teak planting is still in its infancy, teak processing is currently regarded insignificant in the wood-based industries in Malaysia. Be that as it may, teak is a potential timber species that researched, developed and promoted by the Malaysian government. In general, the planters and wood-processing industries perceived that there is market potential for planted teak products. The financial return expected from teak plantation appears attractive. A study in 2002 showed that the net present value (NPV) discounted at 10% and internal rate of return (IRR) values are RM 10,577 (US$ 3,205) and 15.96% respectively for 1 ha of teak with 15-year rotation; the corresponding values for 20-year rotation are RM6,034 (US$ 1,828) and 13%.The NPV and IRR values for 1,000 ha of teak with a 15-year rotation are almost RM 14.9 million (US$ 4.5 million) and 18.49% respectively (Lim *et al.*, , 2002). Some companies are expected to plant teak in a bigger scale, with strong government supports. If teak forest plantation is successfully developed in a bigger scale, we can expect it to be followed by a significant scale of processing and marketing of teak wood products in the future. To make this happen, more information on potential markets and end-uses of teak wood need to be disseminated widely to the planters, potential planters and wood-based industries.

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Processing of Planted Teak in Producer Countries: Problems and Prospects

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ABSTRACT

Teak is the longest-planted commercial hardwood in world's plantation forestry. In spite of its long history, plantation teakwood is normally inferior to natural teak and exhibits more frequent defects that necessitate the use of finger-jointing and edge-gluing prior to further processing. This results in higher processing costs, and importantly, pre-processing does not guarantee that finished products meet the quality requirement, needed in refined applications. Hence, plantation teak is directed to utility applications where it competes with many other tropical hardwoods at lower price points. This is a challenge for the private investors who have planted teak, particularly in Latin America, aiming at high returns with short rotations. Development of domestic processing of teak into high-quality end products is a desirable policy objective for the producer countries. Processors are typically small and medium-sized enterprises (SMEs) operating on challenging conditions. It is the task of the governments to create conducive and stable macro-economic conditions, which act as incentives for private sector to harbor industrial development. According to the World Bank (WB) "Ease of Doing Business" indexes, teak producer countries face formidable challenges in creating such an enabling environment. Provenence selection, improvement, plantation management for intended end-use, and processing technology innovations will provide means of achieving improved teak qualities in future. There are currently new techniques to overcome the common problems of planted teak, i.e., color variation, defects and high proportion of sapwood. Three leading heat-treatment systems, all European-based and focused mostly on softwood, promote their systems also in the tropical plantation woods. The technology is in use in Thailand and Malaysia on an industrial scale. Another innovation comes from a combination of camera vision and CAD (computer-aided design) technology. The CAD system transmits the exact shape and size of the desired final component into camera grading system, which accurately optimizes defect-free parts on a piece of sawn wood.

Keywords: Plantation teak, utility applications, private investors, domestic processing, incentives, enabling environment, processing technology, heat-treatment, camera grading, CAD.

INTRODUCTION

Plantations in the world forestry context

The trend towards the utilization of semi-natural and plantation forest from the use of natural forests is driven by several fundamental factors, of which the most important ones can be identified as being:

- Destructive forest resource use in certain areas in the 1950s -1990s, leaving those regions with inadequate forest resources for the processing industry
- Governmental subsidies for the plantation forestry investments especially in Latin America and New Zealand in the 1960s-1990s
- Poor sustainability and image problems of natural forest utilization

- Cost and quality competitiveness of plantations as roundwood sources when compared to natural forests

The use of natural forests is considered as being less sustainable than the use of planted forests. This is reflected in the demands from the consumer industries that the wood sources should be managed sustainably and preferably certified according to recognized standards such as PEFC (Programme for the Endorsement of Forest Certification Schemes, formerly Pan European Forest Certification Scheme) or FSC (Forest Stewardship Council). These aspects also drive the companies to look for alternatives for the wood from natural forests.

The plantation forestry in large scale is still a young sector and much research and development (R&D) is ahead. Yet already now the benefits in the harvesting and transportation costs, wood growth and quality as well as the efficiency of land use can be seen in the large-scale plantation projects when compared to wood sourcing from natural forest.

In the global scene, the plantations have more crucial role when serving the pulp and paper industry than the mechanical wood processing (sawmill, plywood, veneer, etc). In some countries / regions, especially Brazil, large plantations are also supporting wood-based panel industry and even charcoal manufacturing for steel industry's blast furnaces. Advanced plantation regimes are combining pulpwood and sawlog production in areas where attractive markets are available for both.

Pioneer role of teak plantations

Teak *(Tectona grandis)* was one of the first tree species used in plantations projects in the tropics. Furthermore, the plantations designed for teak growing are dominantly aimed to supply wood for the mechanical wood industry. In global scale, timbers like teak, mahogany (Swietenia macrophylla) and rubberwood (Hevea brasiliensis) are the most important hardwood species planted especially for the mechanized forest industry use. Teak is one of the most coveted timbers in the world. Its appearance is attractive with a golden color, it is durable, easy to work, termite resistant, neither light nor heavy in weight and proven to be suitable for every conceivable form of end use (Wint, 1995).

A shift from using natural old-growth trees to the plantation-grown wood is taking place also in the teak processing in global scale. There are several simultaneous trends impacting this shift. Most significant ones are the following:

- Increased availability of plantation grown teak in the global markets
- Declining or anticipated decline in the supply of natural teak from Myanmar, i.e. declining supply of natural teak
- Image problems related to the use of natural teak from Myanmar in the processing industry, i.e. declining demand for natural teak
- Image benefits related to the use of plantation grown teak in the processing industry, i.e. increasing demand for plantation teak

The increased supply of plantation teak will be targeted to slightly different markets than the supply of natural old-growth teak. As the wood quality from these two sources differs, plantation teak and natural teak are not direct substitutes.

Plantation teak's value-adding potential is considered lower than the one of natural teak. When plantation teak supply is increasing, its price settles to a significantly lower level than that of natural teak. Plantation teak can successfully compete against the traditionally lower-priced tropical species and a large share of plantation teak will be supplied to segments that utilize other tropical species. In the case of natural teak, the wood is commonly supplied to segments where teak earns a premium price.

The fact that plantation teak is not a direct substitute for natural teak means that plantation teak will compete with other hardwood species and the competitive pressures are stronger than in the case of natural teak. It is in the best interest of teak plantation operators to benchmark the plantation teak prices as close as possible to the price of natural teak, and to target those end-use segments that are willing to pay a premium for teak in the applications. The ability to secure premiums for plantation teak over competing wood species will be one of the challenges faced by teak plantation companies in the coming decades.

PROBLEMS OF PROCESSING TEAK IN PRODUCER COUNTRIES

General observations

ITTO (International Tropical Timber Organization) has produced several reports analyzing the current state and future potentials of processing value-added wood products in the tropical producer countries. Whilst this work has focused mostly on a broad range of tropical timber without details on species, some of the common findings apply also to teak. A wide array of constraints can be pointed out from previous studies (e.g. ITTO and International Trade Centre ITC, 2002).

Failures in policy support and control

Wood processing consists typically of small and SMEs in producer countries. SMEs tend to be overlooked in public policy making as they are often operating in the informal sector. The relative importance of SMEs is typically high in many segments of the further processing industry, particularly furniture, and they can play a key role in satisfying domestic demand. Being labor-intensive, they tend to make a positive contribution to the broad socioeconomic development objectives of a country. Problems are often encountered with regard to their effective control, particularly when it comes to sourcing roundwood at very tight competition.

Limited access to raw material

Access to raw materials at competitive costs becomes a problem for both natural reasons (diminishing natural stands and growing distances to procurement areas), and also due to the fact that SME processors are at a disadvantage compared to large-scale log exporters. This can become a hindrance in organizing the flow of raw materials from domestic, non-transparent timber markets controlled by various intermediaries.

Quality of natural teak is deteriorating in the last reserve of old-growth teak, namely Myanmar. New veneer log and sawlog grades have been introduced in the recent years, and the volumes contained in the prime grades are diminishing (ISTF, 2004).

Since the best quality logs are reserved for exports, the mills are processing the lower grade logs resulting in poor recovery rates. Several tropical countries have more recently embarked on log export restrictions with the aim of promoting domestic processing industries.

Technological backwardness

The primary processing of timber in most producer countries is characterized by a low recovery in sawmills and plywood production compared to international standards. One of the contributing factors for the low recovery rates is the poor quality of the input logs as explained above. Wood-based industries are often hindered from further development due to waning infrastructure and poor access to appropriate technologies. Investment capital is difficult to find at competitive rates because domestic bank finance is scarce, interest rates are generally high and collateral requirements are strict.

Impeding traditions

Access to knowledge and new designs is a major problem area. SMEs tend to fall behind because of their strong reliance on traditions: e.g. they may be using high-value timber for secondary use, simply through force of habit and thus be gaining revenues far below the timber's real potential. Too often they rely on simply copying or producing according to the buyer's designs.

Lack of integration

There are few integrated installations to utilize processing waste efficiently in the producer countries. Further processing of teak can be a part of core strategy or a sideline to make use of waste on non-marketable grades. Turning shavings into e.g. small solid wood products or processing waste into wood-based panels can increase the profitability of the industry and improve resource utilization efficiency.

Research and development

There are relatively few competent organizations doing research on processing techniques such as drying and preservation in the producer countries, and disseminating results efficiently for processing companies. Some of the big exporters in Asia, notably Malaysia, have created government-led programs to stimulate the industry. The financial incentives provided to the furniture industry have been abundant and have been cited as one of the main reason for the rapid expansion of the furniture industry in the country. Schemes such as the pioneer status, reinvestment allowance, infrastructure and training allowance, etc. have been fully exploited by the furniture manufacturers, especially by the foreign investors. However, the incentives for R&D and design activities are still insignificant, which explains the relatively low level of such activities within the industry.

Red-tapeism

Without a doubt, many producer countries still harbor disabling rather than enabling regulatory frameworks on enterprises. Industrial operators may in worst cases become discouraged to acquire the necessary licenses and permits for starting the wood processing. The system may simply work too slowly, or produce such a cost load that processing of wood never pays off properly. Export taxes and fees may become disproportionately high and customs clearances may delay shipments to cause reclamations.

Attractiveness of teak producer countries for industrial operators: The World bank approach

A wide range of policy instruments has been tried in various countries to promote domestic wood processing (e.g. log export bans, minimum local processing quotas, differentiated export taxation according to the degree of processing, free trade zones, value added tax (VAT) refunds, etc.). Without the creation of an appropriate framework of innovative mechanisms and economic incentives, the agenda for income creation from, and sustainable use of, forests will therefore be difficult to realize. Enabling economic environment, cultivation of latent entrepreneurship and carefully targeted external technical assistance on structural weaknesses could be the centre pillars for enhancing their productive capacities and competitiveness on wood product exports (Tissari, 2002).

The World Bank (WB) Group's Doing Business project provides objective measures of business regulations and their enforcement. The Bank publishes reports concerning the business climate in the global context, and in 2007 a report "Ease of Doing Business 2007" was launched (WB 2007a and 2007b).

S. Djankov, C. McLiesh, and R. Ramalho originally developed the approach used in the report. The core of the reporting is an "Ease of Doing Business Index", based on the WB databases. This index ranks 175 countries worldwide. The main index is a combination of ten separate sub-indexes, of which we adopted the following five for this paper:

- Starting a business
- Dealing with licenses
- Employing workers
- Protecting investors
- Trading across borders

The main index and its sub-indexes with clarifications are presented in the following chapter. The sub-indexes are calculated based on the values of various individual aspects. The WB project team has been cooperating with over 4 400 experts in 175 countries to create them. Given the resources of the project, this data forms a valuable tool for classifying and evaluating different countries in the respect of industrial operational climate.

Whilst this method reveals some common problems faced by wood processing enterprises, it does not take into account the specific conditions in the forestry sectors of individual countries. These vary greatly according to forest policies, resource endowment and ownership status, as well as ecological and climatic conditions and history of forest utilization.

Assessment results for teak producer countries

Teak producer countries are typically countries with generally high risks and a challenging investment environment. As the investment risks are always company specific, i.e. related to the competences and resources of any individual company, this statement is naturally a generalization. Yet, it is clear that in the teak producer countries, the investment risks are significantly higher than those in the teak consumer countries.

Teak is widely used species in the tropical zone hardwood plantation projects. The following evaluation includes only some of the key producer countries, namely Brazil, Costa Rica, India, Indonesia, Thailand, and Malaysia. Of the consumer countries the list includes Germany, France, China, and Belgium (Figure 1).

The "Starting business" and "Employing workers" indexes are fundamentally indicating how challenging it is to start a processing operation in a country. "Dealing with licenses" and "Enforcing contracts" were selected because the "rule of law" concerning the roundwood supply and logistics is a key success factor in the case of wood processing. "Trading across borders" factor indicates the competitiveness of the country as a base for import and export industry. "Protecting investors" index is a link to the country-specific risks, indicating the required risk premium by the investors.

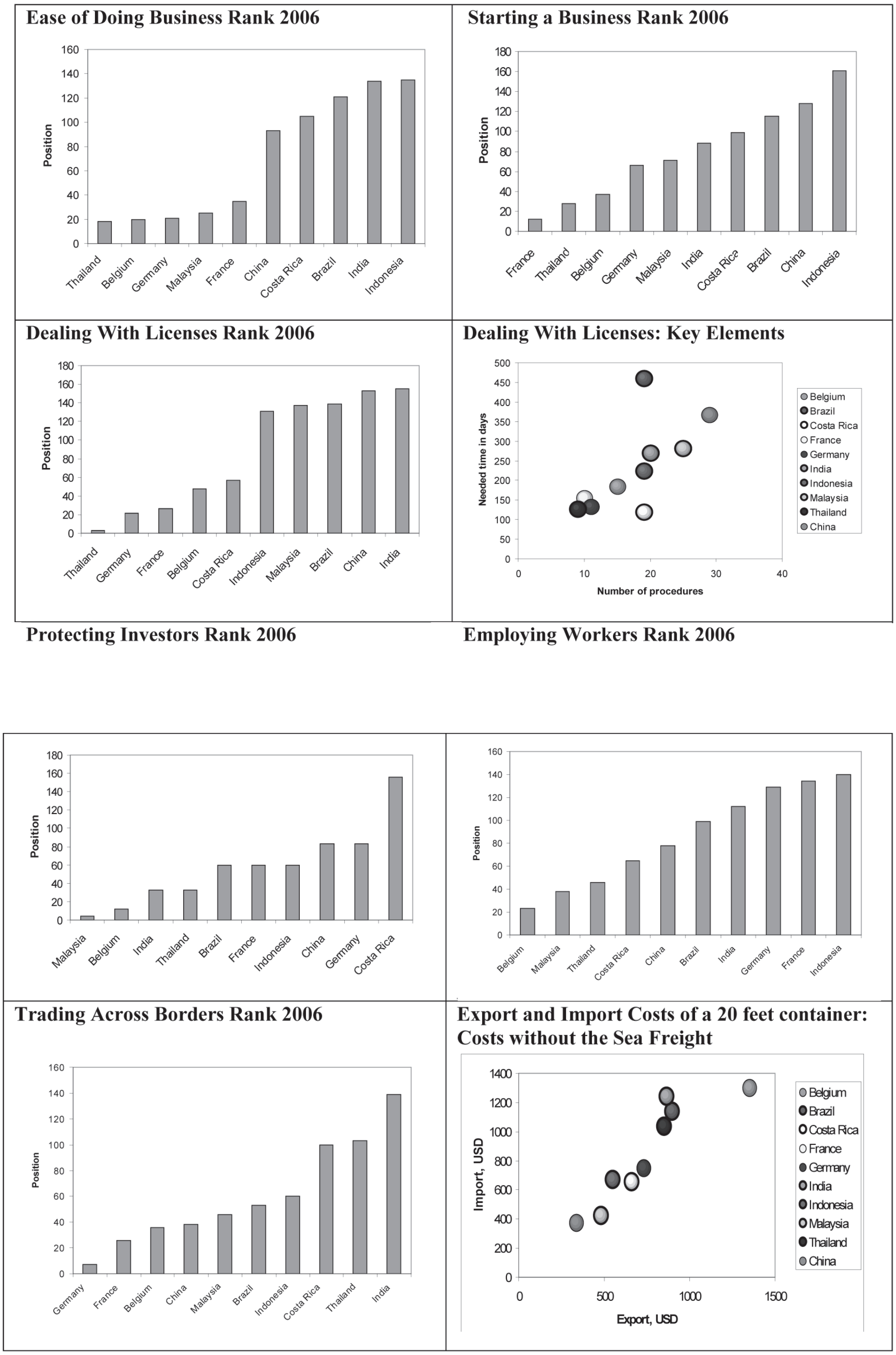

Fig. 1. WB approach summary on ease of doing business in selected teak producer and consumer countries.

The analysis indicates that in the producer countries two significantly different country groups exists. Malaysia and Thailand both have relatively developed wood processing sectors and can thus become plantation teak processors in a major scale, are positioned well. Resource-wise Malaysia will depend on imported teak while Thailand has also domestic resource base. India and Indonesia are located to another end of the scale: about 80% of the analyzed countries are more attractive for the business operations than these two teak growers.

The processing in the consumer countries is always dependent on the reliability of supply of teak logs or rough sawn teak from producer countries. The risks in the producer countries always add a risk premium to the investment calculations for a facility planned in a consumer country. In case of supplying semi-finished goods from a relatively low-risk country (i.e. Malaysia or Thailand) to be processed in a consumer country, the main risks are partner-risks rather than country-specific risks.

Some key observations

- The results indicate highest attractiveness among the producer countries in Thailand and Malaysia, lowest in India and Indonesia.
- With the exception of Thailand, the complexity of starting business in producer countries is higher than on average in all countries.
- Thailand is ranked extremely high, and Costa Rica is also well positioned. Other countries are ranked among the worst 20% of all countries.
- Time needed to arrange needed licenses for a construction project is extremely long in Brazil. Only in Costa Rica the license procedure takes less than five months.
- With the exception of Costa Rica, the level of protecting investors in the producer countries ranks higher than average in all consumer countries. Position of Costa Rica is alarmingly poor, raising the risk premium required by foreign investments to a high level.
- The difference between the best consumer country and the producer country is significant. China is well positioned, where as India is positioned alarmingly poorly.
- When it comes to costs of handling a 20 feet container inside the country, China is very competitive. Malaysia, Indonesia, and Costa Rica are well positioned, whereas India, Brazil, and Thailand are less competitive. Belgium is a surprisingly costly location.
- Malaysia is the best location regarding the workers employment. Indonesia is the poorest, but notable is the poor ranking of France, barely better than of Indonesia.

As some producer countries were ranked among the best 20% of all 175 countries, it is natural that those countries, i.e. Thailand and Malaysia, could be future processing countries of plantation teak coming from other countries in the region. Position of these countries is perhaps even surprisingly good and clearly reflects the official policy supporting the new investments. The fact that two major suppliers, India and Indonesia are totally in the other end of the ranks can be seen to offer improvement potential for large scale processing operations. Logistically all the four countries are well positioned, making the potential even greater. In Latin America there is no such great potential created. Brazil and Costa Rica are equally positioned in the ranking.

The results of the WB model should always be approached with care without bringing the analysis into an individual company level. Its approach is to compare countries with similar approach, and in all countries significantly better and worse locations for processing operations are found. The fact that the "consumer countries", i.e. Germany, Belgium, and France positioned well is not a surprise. As the analysis touched very little, the cost levels of actual processing operations, the analysis is far from a full analysis of the most potential manufacturing platforms. The manufacturing operations in Malaysia and Thailand are generally attractive in cost-wise as well as when it comes to the overall ranking by the WB. When the supply of plantation teak is based on the plantations in Indonesia, India, Costa Rica, and Brazil, the attractiveness of importing logs or rough sawnwood to Europe for the processing is higher and a more likely processing scenario.

China is fairly poorly positioned in the overall ranking. When the analysis goes deeper, some more significant competitive edges of China are reflected. One example is the low costs related to export and import of materials. This can especially materialize in the operations based on the import of materials and re-export to third countries. Due to the overall complexity of making business in China, the value of a local partner is high. A superior model can be a strategic partnership between an Indonesian/Myanmar supplier of rough sawn teak or teak logs and processing in China before re-exporting to Europe or the United States of America (USA).

Based on the evaluation one value-chain model appears most feasible: processing of rough sawn teak and teak round wood in Thailand or Malaysia based on domestic and imported teak. This model utilizes their great operating environment, partially domestic teak roundwood with low logistical costs and plantation teak resources in neighboring countries (i.e. Myanmar, Laos and Indonesia). This does by no means downplay the potentials and endeavors of less developed producer countries to process more teak in the future. Their conditions and enabling environment simply look less attractive at the moment.

COST COMPETITIVENESS AND PRODUCTIVITY IN THE PRODUCER COUNTRIES

The cost competitiveness of the producer countries is typically based on the low labor costs, relatively low roundwood or rough sawnwood costs, and low construction costs. Typically all these elements are 20 80% lower priced in the presented teak producer countries when comparing to the European consumer countries. The most significant difference is in the labor costs. This difference is based on the typically low social costs paid in addition to the salary. In the European countries both the salary levels paid for the workers as well as the social costs paid are extremely high, but this is compensated by the very high labor productivity.

Comparatively lower costs of raw materials and labor are not sufficient factors on their own to guarantee the competitiveness of producer countries' products in export markets. These are just two of the parameters in what is, in practice, a complex equation. The low productivity of local manpower and poor raw material recovery rates all play their part in canceling out the initial advantages. Labor productivity is a key issue in trying to improve the competitiveness of wood processing in the producer countries (ITTO and ITC 2002).

Modern machinery and the related know-how are essential for producing to international commercial and industrial standards. Exporting and further processing means accepting tighter, more complex specifications and quality control requirements set by the clients. This cannot be achieved without modern production lines. With the cost of the equipment and the added expense of shipping, installing and maintaining these production lines in remote places, often the only way to stay in business is to run the equipment at maximum capacity.

BENEFITS OF LOCAL PROCESSING

Wood processing industries have potentially a significant contribution to the national economy, and as the sector moves downstream into value-added production, these benefits may multiply. Secondary processing provides additional employment, which in turn expands the tax base in the country. Dynamic industry creates a trained workforce, and can contribute through consistent demand to the development of physical and institutional infrastructure (e.g. roads, power and water supplies, banking facilities, R&D, etc.). It also contributes to foreign exchange earnings and stimulates investments in a whole range of supporting industries. And very importantly, value-added processing helps the countries to utilize their wood resources more efficiently, which lends support to the sustainable management of the natural and planted forests. Yet, very few producer countries have been able to capture the full potentials of domestic processing (Tissari, 2002).

One growing tendency in the developed European and North American markets is to claim proof of legal origin and sustainability of roundwood and derived products. The burden of proof extends from the purely legal and ecological sustainability matters (i.e. certified and legally verified timber) to wider social responsibility dimensions of goods in trade. Certain customer groups thus prefer products, which are not only ecologically sustainable choices, but also socially sustainable products. For instance, teak garden furniture has received a great deal of attention from environmental groups, which has had its impact on the public, not least in connection with the media attention to the political situation in Myanmar. Quite recently, an international hardwood trader, DLH Group decided to gradually phase out Myanmar from its GSP (Good Supplier Programme) for similar reasons (ITTO, 2007).

The consumer market is complex and involves large corporations, which are actively managing their supply chains (IKEA, Home Depot, B&Q, etc.) and a huge number of medium and small-scale operators. The larger groups, who have direct interface with consumers, have become the key channel for influencing environmental standards of the supply chain and the quality of forest management has emerged as a key concern (Simula, 2001). Teak has been the only high-value tropical tree species in IKEA's products. All teak products are certified according to FSC and thus meet the criteria for originating from well-managed forests.

Teak products based on sustainable plantation sources are potentially very well fitted into the customer preferences in the developed European and North American markets. This image value should be materialized into better market access and hopefully in the mid-term to better average price level of final products. Local processing is offering sustainable, export oriented jobs to local communities and carries high image value in certain market segments. Most potential segments to promote the overall sustainability of plantation based, locally processed teak products would be western European Do-it-Yourself (DIY) chains and companies supplying teak products to publicly financed construction projects in the United Kingdom and similar sensitized markets.

ROUNDWOOD-RELATED RISKS OF PROCESSING PLANTATION TEAK IN PRODUCER COUNTRIES

Plantation teak quality problems and variations

Plantation teak is typically benchmarked against natural, old growth teak among importers and processors. The following quality problems of young plantation teak are often found:

- Easy end splitting of young teak logs
- Significant color difference between the sapwood and the heartwood
- Large sapwood share of the total cross-cut surface area
- Unattractive, pale color of sapwood
- Wide growth rings indicating fast growth
- In some cases lower strength properties

Many of the listed quality problems are partially due to the fact that plantation teak is typically harvested much younger and in smaller diameters when compared to old-growth teak. As the plantations mature, larger diameter plantation teak will be processed and the appearance of plantation teak is likely to improve. In large teak stems, the heartwood proportion of the crosscut surface area exceeds 90%, whereas in the young plantation stems the share is often less than 40% (Perez, 2005).

One additional aspect is the quality variation in plantation-grown teak. Different provenances typically yield different heartwood contents and thus different value-adding potential for mechanical processing. Furthermore, annual rainfall levels affect on the heartwood content, too (Basri *et al*., 2003 and Perez *et al*., 2003).

Extending the rotations of existing teak plantations is a challenge particularly for the private sector teak growers, who are typically loaded with high expectations from the international investor's side. This is more often the case in Latin America, where mostly foreign investors manage teak plantations with relatively high level of technology and competence. Still, the typical 20-25 years' rotation is simply unable to yield the desired quality to compete with old-growth teak. Therefore their outlook to overtake old-growth teak business is limited, unless they adopt more flexible reinvestment regimes to extend rotations beyond current practice (ISTF, 2004).

As plantation logs gain a higher share of the total wood used by the teak processing industries, measures to improve teak quality are to be taken. These measures range from silvicultural treatment and provenance selection to the processing techniques in the mills. The latter ones do not change the actual roundwood properties, but may significantly improve the acceptance of plantation wood products in the international market.

There have been some reports from international markets that teak is losing ground to other species even in its most specialized (wet) applications, and is therefore being turned into other more utility-type of end-uses. This development has been caused partly by the easing of restrictions on the sales and processing of teak logs in Myanmar, and partly because the emerging supply of plantation-grown teak is reportedly less suitable (less oily) than natural teak for high-end of the market uses (Hardwoodmarkets.com, 2000).

Plantation teak needs to be positioned more openly into new applications, i.e. break away from its past locking onto exclusive top-of the market status. It should be accepted that teak from plantations meets in most cases the quality requirements of utility species, but going beyond that is challenging.

Another point to contend is that timber certification is a marketing tool that teak cannot afford to miss. Certification is most prominent in garden furniture and associated labels have become necessary ingredients in displaying these products in showrooms. Partly for this reason, the recent years boom in garden and other outdoor furniture has benefited low-value plantation woods (eucalyptus, acacia) much more than teak (Revista da Abimovel, 1999).
According to ISTF (2004), Latin America is the prime area for certified teak, putting on offer 75% of the world's FSC certified teak.

SELECTED NEW TECHNOLOGIES FOR THE PROCESSING OF PLANTATION TEAK

Heat-treatment

Thermal heat-treatment is considered as being different practice from the kiln-drying of wood. Kiln-drying changes the moisture content of wood, but other wood properties basically remain unchanged. Furthermore the temperature in the kiln-drying process rarely exceeds 100°C, whereas in the heat-treatment the temperatures may exceed 240°C.

There are several heat treatment practices in use on industrial scale. They differ to a certain degree but the basic fundamentals remain the same. Wood properties are changed in a short-term (max. 24 hrs) heat treatment process without chemicals or additives. Typically sawnwood pieces up to thickness 4 inches are treated, although even larger pieces can be processed.

The treatment is executed in drying chambers with load capacity up to 120 m^3 of wood. The treatment consists of consecutive phases, which typically can be described as follows:

- Temperature increase and drying phase: In this phase the temperature of the wood is raised with heat and steam to the level of 100 130°C. Moisture content of wood is 0.5-3%.
- Heat treatment phase: This is the phase when the wood is actually heat treated so that the color changes take place. The temperature of wood is raised to the level of 180-250°C for a period of 1-3 hours.
- Cooling and moisture conditioning phase: In this phase the wood is to be conditioned to the moisture content level of 4-7% and the temperature of wood lowered to the level of 70-85°C.

The fact that there are still several competing technologies in the markets partially indicates the youth of the processing technology and the fact that a lot of R&D works remains ahead. Common technology suppliers are Thermo Wood®, Stellac®, and Plato®.

A fundamental issue in the heat treatment technology is related to the fact that each tree species/moisture content/wood dimension requires an individual "recipe" for reaching the desired color and avoiding quality losses during the process. Thus the company operating the facility commonly develops the actual recipes and the technology suppliers can supply only guideline-type of recipes. Recipe typically indicates the needed temperature levels, schedule of raising the temperature and the overall treatment time. All these aspects are depending on the tree species and dimensions of wood, original moisture content and the desired color and mechanical property changes of wood.

Both hardwood and softwood species can be successfully treated with the technology. Changes in the technical properties of wood are basically similar in all types of wood, although each species has its own unique characteristics.

The majority of the world's heat-treated wood is softwood. This reflects rather the aggressive R&D work among the European and North American softwood companies than difficulties of treating hardwood species. Typically softwood is treated with the aim of substituting chemically treated sawnwood in decking and other outdoor applications.

Changes in wood properties (color, hardness and strength)

Heat treatment significantly changes both visual and technical wood properties. The clearest change is in the color of wood, which can be modified from a light starting point to a very dark brown color. In the technical properties the treatment changes all key parameters (Table 1).

Teak processing case studies: China, India and France

A case study approach was selected for comparing selected operating locations from the perspective of costs. The approach is again simplification of the reality, but is based on an actual heat treatment plant cost structure.

The case is based on a Stellac® heat treatment plant with a capacity level of 10,000-20,000 m^3 of sawnwood per year. This is slightly larger than average heat treatment plant. The facility requires approximately 530 m^2 of floor space for the handling of sawnwood and for the actual treatment unit. Height requirement of the building is 8 9 m. Labor force is needed for sticking of sawnwood and the loading/unloading of the treatment unit.

Table 1. Technical changes of wood in the heat-treatment process

Technical property	Change direction and scale	Impact on the technical value of material	Remarks
Shear strength	Decreasing 15%	Negative	-
Surface hardness	Depending on the treatment: increases up to 15%,decreases up to 10% if the treatment temperature is high	Positive/negative	-
Bending strength	Depending on the treatment: increases up to 15%, decreases up to 15% if the treatment temperature is high	Positive/negative	Typically a negative change as the treatment often decreases the bending strength values
Compression strength	Increasing 5 -25%	Positive	Positive change in manyapplications
Shrinking and swelling	Decreasing 10-80%	Positive	Very positive change in manyapplications
Equilibrium moisture content	Decreasing up to 50%	Positive	Very positive change in manyapplications
Water absorption	Decreasing up to 50%	Positive	Very positive change in many applications

Table 2. Main cost factors in comparable heat treatment plants in three countries (2006)

Location	Capital costs of the machinery line	Water cost	Energy cost	Labor cost	Total key cost factors
	EUR/m³				
France	8 - 14	2.0	29	26	65.0 - 71.0
India	21 - 27	0.8	35	13	69.8 - 75.8
China	21 - 27	0.8	36	13	70.8 - 76.8

Stellac® unit investments costs vary based on the capacity: cost of the smallest unit is starting from USD 780,000 (Table 2).

The differences between the production locations are small. The fact that the building costs are lowest in India makes India fully comparable with France. If the final market region is Europe, competitiveness of China as a location decreases significantly due to the added transport costs both in case of importing teak roundwood as well as exporting final products.

The operation in the producer country allows companies to export only the top-quality heat-treated components, thus avoiding the transportation of second grade products. This makes the processing appear more favorable in a producer country. If the operation is solely focused on teak processing, a recommended operation (in this comparison) is a heat treatment facility in India close to teak plantations.

If the unit is located in Europe, it is reasonable to run the facility to process other species, too. This allows economies-of-scale in the investment and increases the capacity utilization ratio.

Potential market segments of heat-treated teak

Wood color is one of the key characteristics changing in the heat-treatment process. The segments targeted with heat-treated teak must be insensitive for this change, i.e. the fact that the golden teak color changes towards darker brown. Yet, the color change brings another benefit, because the commonly pale and unattractive sapwood color changes so that the difference between the sapwood and heartwood is almost insignificant.

The change allows the use of sapwood in the production of edge-glued boards, such as tabletops and furniture components. The roundwood need decreases significantly as the sapwood is not cut away from the rough sawnwood prior to the gluing.

Because the treatment improves the decay resistance of teak (especially of sapwood), outdoor applications such as decking become an attractive end-use, which values the renewed wood properties. Again, the roundwood quality gaps are overcome by the better use of sapwood. Decking segment is one of the most attractive segments for heat-treated plantation teak, where Brazilian hardwoods like ipe (*Tabebuia* spp.) currently dominate.

Plantation teak carries good strength properties before and also after the heat treatment. As the color changes towards darker tropical species, plantation teak can substitute dark species, such as wenge in the markets. Thus basically all end-use segments, currently accepting dark brown species and not requiring extremely good bending strength properties can be targeted with heat-treated plantation teak.

Computerized camera grading system combined with CAD tools

Camera grading is based on computerized camera vision, allowing sawnwood pieces to be graded and evaluated at superior speed. The latest innovations in this field are based on the combination of camera vision and CAD technology.

The combination of these technologies, innovated by a Swedish Innovative Vision company, allows components to be machined directly from a rough or planed sawnwood. Technology trademark is WoodEye® Cross Cut. The shape of the component is imported from a CAD system to the camera grading system, so that the grading system identifies defect-free parts of the sawnwood, based on the exact shape and size of the desired component. The feeding speed of sawnwood can be as high as 650 m per minute, and typically the system can grade between 40 90 m^3 of 12 cm wide sawn wood per hour. The capacity is usually limited by the feeding speed and capacity rather than the camera system. The actual camera unit is weighing less than 500 kg and requires only about 3 m^2 of space.

This technology is offering significant waste reduction potential, as the component can be machined directly from a sawnwood piece. There is no need to produce edge-glued board as a semi-finished product prior to the production of the component. The speed of the grading exceeds the speed of manual grading, making the technology attractive even in countries with low labor costs.

The technology can be successfully used in the quality control of sawnwood pieces delivered by external suppliers and in the supplier development. Sawnwood pieces can be cost-efficiently graded and the value-adding potential can be determined with accuracy. This allows the teak processing company to determine the feasible price levels for each supplier.

The camera vision technology can be recommended for large-scale furniture component manufacturers and for processing companies who are willing to rank their suppliers and apply supplier-specific pricing of rough teak sawnwood.

CONCLUSIONS

In spite of its longest history among common plantation timbers, teak from plantations has not yet reached its full potential as a raw material for valuable wood products. Because of varied growing and soil conditions, planting and management regimes, and processing capabilities in the producer countries, plantation-grown teak products enter in the markets with mixed quality. This is in stark contrast with old-growth natural teak, which is coveted for its uniformity, color and high content of defect-free heartwood.

Where end-use specifications allow, plantation-grown teak is partly replacing teak supplies from natural forests, which are becoming increasingly scarce in the key Asian producer country, Myanmar. But more often plantation teak is placed in the market as utility species suitable for less demanding applications. International investors may choose to elongate rotations on the well-managed teak plantations and reach for the higher qualities. Flexible reinvestment schemes are needed to implement this fundamental change in the growing philosophy of teak.

It is the task of the governments to create conducive and stable macro-economic conditions, which act as incentives for private sector to harbor industrial development. According to the WB “Ease of Doing Business” indexes, teak producer countries face formidable challenges in creating such an enabling environment.

New technologies can help overcoming some of the main quality handicaps of plantation teak, and most of all lower production costs because of avoided finger-jointing and edge-gluing before further processing. Two such technologies are highlighted in this paper. The first one is the thermal heat-treatment of juvenile plantation teak. It is a kiln-type technique for reducing the amount of pale color of teak wood and for making it extremely stable - without excessive deterioration of strength properties. The second one is a combination of camera vision and CAD technology. In short, the shape of the final component is imported from a CAD system to the camera grading system, so that the grading system identifies defect-free parts of the sawnwood, based on the exact shape and size of the desired component.

Based on the observations discussed in the previous chapters, it appears that chances of success in processing plantation teak are more likely if certain pre-requisites are filled. These can be related to raw material issues, industry structure and experience, market dynamics, and enabling macro-economic policies executed in the country.

1. Domestic processors must have a level playing field for accessing high-quality teak logs, because inferior grade logs will decimate industry's quality competitiveness.
2. Basic wood properties and machineability of plantation teak need to be within the acceptable tolerances of commonly processed other tropical timbers, as the high standards of prime old-growth teak remain an elusive target for most growers.
3. Processing yield can be radically improved by adopting top-notch camera and CAD technologies. Appearance and color of wood may be improved by heat treatment for further processed products.
4. It appears to be easier to adjust an existing value-added solid wood industry into plantation teak use, rather than to establish new industrial structure without experiences of managing roundwood supply chains. This would support future expansion of plantation teak processing in countries like Thailand and Malaysia.
5. Experiences from many tropical countries suggest that successful processors are not created overnight: industries rather develop in phases (on a learning curve) from local market suppliers to import replacement producers, and only a few manage to progress all the way to self-sufficient exporters. Role of dynamic domestic markets is crucial as a training ground for future exporters.
6. Neighboring countries often end up in competing with same products in the same markets, because entry barriers to wood processing are low and experiences can be replicated in similar conditions across the border. Those producers that show innovation in product development, search for direct access to markets and cultivate new marketing ideas will have the best chances of survival.
7. Most of the successful countries in plantation-based forest industry have adopted a set of incentives during the past decades, but they need to be revised as processing industry evolves and becomes the "designated manager" of the plantation resource.

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An International Pricing Mechanism for Teak (*Tectona grandis* Linn.f.) Plantations

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ABSTRACT

The paper examines the importance of teak in the context of the high-grade tropical hardwood sector. Since a wide gap exists between demand and supply of hardwoods, on a sustainable basis, substantially greater areas of industrial plantations, of which teak would be the principal species, are needed to satisfy demand in the long-run. If these plantations are not developed, then the present teak resource is likely to succumb to the destructive forces of excessive demand. A number of alternative scenarios are examined, including the possibility that substitutes will ameliorate or eliminate the need for additional resources. However, the likely increase in the importance of renewable forestry products worldwide, *vis-à-vis* actions to combat global warming, cautions against the assumption that substitutes will be available to offset demand for tropical hardwoods. This affirms the need to create new hardwood plantations and implies substantial increases in investments. However, due to lack of standards, lack of information and misinformation there is widespread uncertainty and confusion around teak investments, particularly in relation to prices. There is, therefore, an urgent need to ensure that informed investment decisions can be made. To begin this process, an international pricing mechanism for teak is presented, which is designed to provide standard, transparent, widely published and up-to-date information on plantation teak prices. The entire sector is positioned to benefit immeasurably from the mechanism. Impact is likely in terms of improved streams of investment, aligned best practices and more equitable returns to stakeholders. The rewards from implementing the mechanism promise to outweigh the costs many times and put the teak sector on a sound footing to face the long-term future with confidence.

Keywords: High-grade hardwoods, pricing mechanism, investment decisions.

INTRODUCTION

What is the price of teak? This is the most-asked question in teak plantation circles. Unfortunately, due to lack of standards, lack of information and misinformation, there is widespread uncertainty and confusion about plantation prices. Accurate pricing information is vital to ensure that informed investment, management and market decisions can be made. This paper examines the topic in an attempt to overcome the weakest link in the decision making process. A standard international pricing mechanism is proposed to solve the problem in the short-term. Although the paper's focus is on plantations, natural forest teak is examined to provide the wider contextual background.

The focus of the article is on the commercial log, which is on offer across most of the species' geographic supply base, is traded internationally and lends itself more easily to the process of standardisation than sawn timber. It would be relatively straightforward, in time, to extend the mechanism to incorporate sawnwood, whose price is derived ultimately from the log.

THE OVERALL CONTEXT

The international price of teak depends on the supply and demand of commercial volumes in the market place and the quality of material on offer. A brief outline of supply and demand is provided below.

Teak Supply

The supply base of teak is the current natural forest and plantation resource. Natural forest commercial teak originates exclusively from Myanmar, which has about 16 million ha under the species (Gyi and Tint, 1998). The annual allowable cut is in the order of 400,000 m^3, down from 600,000 m^3 before 1996 and the extent of these forests is still reducing, the quality declining and the yield dropping (Saw Eh Dah, 2005). Other countries with indigenous teak resources (India, Thailand and Laos) have depleted them beyond the point of sustainable commercialisation, and logging bans apply.

Different surveys of teak plantations over the years are not directly comparable and provide indications of trends only (Del Lungo, 2001). Nonetheless, successive plantation surveys suggest that the total resource has been expanding at an accelerating rate in recent years. According to recent FAO estimates (Del Lungo *et al.*, 2006) teak covers some 5.8 million ha in eight of the principal teak-growing countries. For countries not included in this assessment, the FAO Forest Resource Assessment 2000 estimated that 1.4 million ha of teak existed at that time (FAO 2002). Assuming that, for these countries, the area remains unchanged, it can be concluded that the gross area of teak plantations worldwide is roughly 7 million ha.

However, caution is strongly advised when interpreting gross plantation figures. They depend on official releases by governments but the information is not always supported by field data. Gross figures may include areas designated to teak on which few or no trees exist. Statistics on planting often depend on seedling distributions from nurseries, rather than actual plant survival; losses are not always account for. Many estimates do not differentiate between afforestation and reafforestation and it is difficult to know what part of reported ‘new planting’ is in fact replanting following harvesting (Ball *et al.,* 1999). Many plantings are smallholder owned which are usually not picked up in forest inventory data. Smallholder plantations are frequently unmanaged and, as such, growth is often close to stagnation. Besides, in smallholdings, felling of better trees often occurs early in the rotation, inhibiting stands from reaching their potential yields. Also, the problems of rampant illegal logging and land occupation for farming has led to the dramatic decline in standing stock in all age groups in, for example, Indonesia (Siswamartana, 2005). In addition, a skewed age class distribution exists in plantations and long rotations are the norm. Some 65% of the teak area is under 30% of rotation age and average rotations are high, between 40 and 70 years (Del Lungo *et al.*, 2006). For these reasons, the commercial harvest of the entire teak estate is low. The annual production of industrial plantation teak logs in Asia in the mid-1990s was in the order of one million m3 (Wint, 1995). Although the harvest may have risen since then, any rise is not expected to have been substantial, particularly for large-dimension mature logs. In conclusion, the gross plantation area is of limited value, and is misleading, when predicting the future growth and supply of high-grade commercial teak timber.

Teak Demand

Almost all commercial volumes of teak find a ready market. This has prompted widespread interest in plantation investments in recent years. However, the argument is sometimes made that expectations of optimistic future demand for the species fail to take full account of new plantations being cultivated around the world. Keeping in mind that annual industrial teak consumption is only several million cubic metres at most, it would not take a large area of plantations to swamp the market, particularly with small diameter material and depress prices. Of course, this assumes that the potential demand for teak is limited to its current markets and that the species will not be an appropriate substitute for natural tropical hardwoods, which are likely to become scarce in the foreseeable future.

From henceforth in this paper the term *hardwood* is understood to mean high-grade tropical hardwood[†]. Teak is the most important hardwood plantation species. There are many reasons for its popularity. A large number of tropical hardwoods are in demand by the timber trade but, with a few notable exceptions, like teak, they are difficult to grow in plantations. Teak has a strong reputation for high prices, excellent wood quality and its silviculture is understood making it one of the most valuable multi purpose timbers of the world. Other high-value commercial hardwoods include rosewood (*Dalbergia* spp) and mahogany (*Swietenia macrophylla*) and these species cover an area of 600,000 ha (Del Lungo *et al.*, 2006). However, collectively hardwood plantations (including teak) contribute a small proportion (probably less than 3%) to the overall high-grade hardwood volume on the market.

Future demand for teak, which will influence prices, is likely to be affected by the demand for tropical hardwoods as a whole. The total demand, which amounts to about 90 million m^3 annually, depends mostly on unsustainable deforestation and degradation of natural forests (Keogh, 2005). In future, harvests will be reduced to more sustainable levels or they will drop even more abruptly with the depletion of natural ecosystems (Barbier, 1996). According to several projections of forest depletion this is most likely to happen between now and 2030 (Stern, 2007). Thus, the supply of hardwoods will begin to decrease and the initial manifestation of what has been termed *the tropical hardwood crisis* is likely to occur during this time period, despite the increasing areas of natural forest that are being brought under sustainable management. Besides, a number of issues hamper natural forest management on an economic footing and on a sustained basis, including: high species diversity, lack of a full understanding of the techniques for managing complex ecosystems, low average productivity necessitating extensive areas of supply and greater inaccessibility as natural forests continue to shrink.

In parallel with augmenting pressure on natural forests and tighter wood supplies, the hardwood plantation resource is likely to experience increasing, if not excessive demand. This appears to be happening already. Maldonado and Louppe (2000) suggest that the high levels of international demand for teak have resulted in a harvest level in Côte d'Ivoire that may have exceeded the productivity capacity of the country's teak plantations. As suggested elsewhere the imminent danger is not that teak will lose its (commercial) market, but rather that the market will lose teak (Wint, 1995).

If current per capita levels of demand for hardwoods were to continue, then by 2050 the total demand would be more than 140 million m^3[‡]. Also, if the areas of natural forest under sustainable production were to expand at the same rates as they did since the late 1980s (roughly 1.5 million ha per year according to ITTO (2006b), there would still be a relatively large hardwood deficit to satisfy on a sustainable basis in 2050 and this could only be supplied by new

[†] High-grade tropical hardwoods include such quality woods as teak, mahogany, iroko and other timbers that are used for top-of-the-range end uses like boat building, quality indoor and garden furniture, interior decor, panelling, decking, carving, etc. These woods are sometimes called luxury woods, cabinet woods or speciality timbers.

[‡] Calculation based on current levels of demand (ITTO 2005 a) and mean population data based on U.S. Census Bureau International Data Base (US CBI 2007)

commercial hardwood plantations. Of course, changes in any one of the many basic assumptions in such forecasts (e.g. population growth rates, per capita demand, current levels of output from plantations, future expansion – or contraction - of sustainably managed natural forests and plantations etc) will change the global scenario. Nonetheless, the overriding signal is that sustainable high-grade tropical hardwoods will be in short supply in future. However, some analysts predict that the relative scarcity and rising prices for tropical hardwoods will limit their consumption over the long-term (Barbie, 1996). Besides, scarcity may result in substitutions. Substitutions are predicted to occur in the medium-run partially as a result of an abundance of plantation timbers (mostly low density woods), which is described as a 'blooming global surplus of commodity plantation timbers' estimated at around 900 million m^3 by 2020 (STCP, 2006). Furthermore a wide range of wood treatments is available that can replace hardwoods (e.g. Medium Density Fibreboard with fake finishes, and wood hardening, etc). In other words, it is speculated that the mass market for speciality and decorative tropical timber products can be met partially through developments that eliminate the technical differences between softwoods and hardwoods and reproduce the decorative finishes through overlays. These trends would suggest that the expected tropical hardwood crisis may be ameliorated or eliminated altogether.

On the other hand, current trends are not the best foundation on which to base future forecasts. An alternative view of future demand for wood products is emerging (e.g. Sutton, 1999). The issue that is likely to influence, fundamentally, the future demand scenario for all woods is climate change and actions taken to ameliorate its negative effects. Action on climate change will create significant business opportunities as new markets are developed in low-carbon energy technologies and for low-carbon goods and services (Stern, 2007). An increasingly wood based society would use less fossil fuel and produce less atmospheric CO_2 while permitting its population to still enjoy a high material standard of living (Sutton, 1999).

In this context, preference is likely to be given to materials which, like teak, require low energy inputs in their creation, are renewable, biodegradable, free of toxic material yet have inherent natural resistance to termites and fungi, are long lasting, tend to be used in solid form (the most energy efficient manner of using wood) and are aesthetically pleasing. Life Cycle Analysis (LCA) of products is likely to play an increasingly important role in determining competitive advantage of timber in relation to alternative products.

A *laissez-faire* approach to tropical hardwood development is, in effect, tantamount to a decision that future generations will have to face extreme shortages of these products. The real price to pay will probably be increased pressure on remaining natural forests and existing plantations. One early consequence is likely to be continued deforestation and mounting pressure for an upward redefinition of annual allowable timber-cut ceilings under sustained management of natural forests, which could endanger the output of other goods and services, if not the forest itself. Another likely consequence is the diminution of current tropical hardwood plantations through increased demand in the short-run. Therefore, the danger of producing a surplus of mature teak or other hardwoods is unlikely for some time, though the overriding characteristic of any new commercial plantations must be quality at all stages of the production line.

OVERVIEW OF TEAK PRICES

A wide range of plantation teak prices is available worldwide. However, use of these prices is limited because they are mostly unsubstantiated and lack precise information about log dimensions, time of data collection and to what point along the value chain they belong. Besides, few data exist that provide this information at consecutive intervals through time. This is causing confusion amongst investors, allows unscrupulous parties to take advantage of the situation for their own ends and is hampering the development of a strong commercial teak sector. The foregoing scenario needs to be rectified urgently.

This paper provides, below, an overview of teak prices. Both natural forest and plantations are included for comparison. It then outlines the proposal for developing a standard international pricing mechanism to monitor prices and suggests how it should be implemented. The approach used in assessing prices is twofold:

1. Gather information on international teak prices (natural forest / plantations);
2. Examine interactions of natural forest / plantations teak prices.

INTERNATIONAL TEAK PRICES

Natural Forest

The methods by which natural forest teak logs are sold through tenders in Myanmar is a recognised international pricing mechanism, which is based on evolved grading rules for the Free on Board (FOB) log. The resulting prices of teak at monthly auctions in Yangon reflect the quality of the material on offer and international demand. More information on these grading rules is supplied by U Thein Aung (2003). An overview of natural forest teak prices is presented in Figure 1. The period examined extends from 1997, when ITTO began to record Myanmar data on its Market Information Service, to December 2006. The resulting data are FOB prices in constant 1990 US dollars per m^3 (deflated by the International Monitory Fund's (IMF) Consumer Price Index for industrial countries).

Calculating the real increase in price is difficult and several different approaches may be taken, often producing quite different results. However, to provide a relative comparison between different log grades, data from October 2004 to December 2006 were compared on a month by month base for 2nd, 3rd and 4th Grades of veneer logs and sawlog grades (SG-1, -2, -4, -5 and -6). Sawlog grade SG-3 was not included because data were more incomplete than for any of the other categories. Table 1 shows the average monthly increase over the period for all grades. The prices for all teak categories were positive in real terms. It appears that higher categories tend to increase at a slower rate within the veneer grades

Table 1. Percentage increase in real price for natural forest Myanmar teak (Veneer and Sawlog Grades) between October 2004 and December 2006

Grade of log	Average monthly rise in price (%)
Veneer	
2nd Grade	0.34
3rd Grade	0.39
4th Grade	0.82
Sawlog	
SG-1	1.06
SG-2	0.69
SG-4	1.10
SG-5	0.87
SG-6	2.34

and, although this trend is less clear in sawlog grades, it is also evident. The highest rise exhibited is in the lowest sawlog category (SG-6) and may be due to an upward adjustment from a below-market initial base.

Plantations

As mentioned previously, few reliable pricing data exist for teak plantations. Nonetheless, a total of 28 individual FOB prices, ranging over the period 1993 to December 2006, were gathered from the sources outlined in Table 2. They represent diameters from 15 cm to over 50 cm. The data, from 1997, appear in Figure 1 in real US dollars on a comparable standard to Myanmar teak[‡‡].

Significantly, all the plantation data are lower than the lowest Myanmar grade (SG-6) and would suggest that the upper ceiling for plantation teak prices is, with few exceptions, lower than the lowest category of natural forest teak. Most plantation FOB data (79%) lie between US$ 150 and $ 250 (real prices), equivalent to between US$ 200 and $ 300 (nominal). No meaningful correlation could be found between diameter and price of the collective data although, where available and for any particular set of observations, larger diameters, as would be expected, always fetched higher prices. Unfortunately, with few exceptions, there is not sufficient information to determine changes in real prices. Where consecutive data are available apparent upward international price adjustments from low bases prevented an assessment of real long-term price trends. For example, in Cote d'Ivoire teak accelerated from an artificially low base of US$ 60 in 1993 to $ 300 in 1997 before levelling off (Maldonado and Louppe, 2000). Steep price adjustments like these provide a false perspective of the long-term valuation of teak logs.

Table 2. Gathered information on teak plantation prices for country, year, number of observations and sources

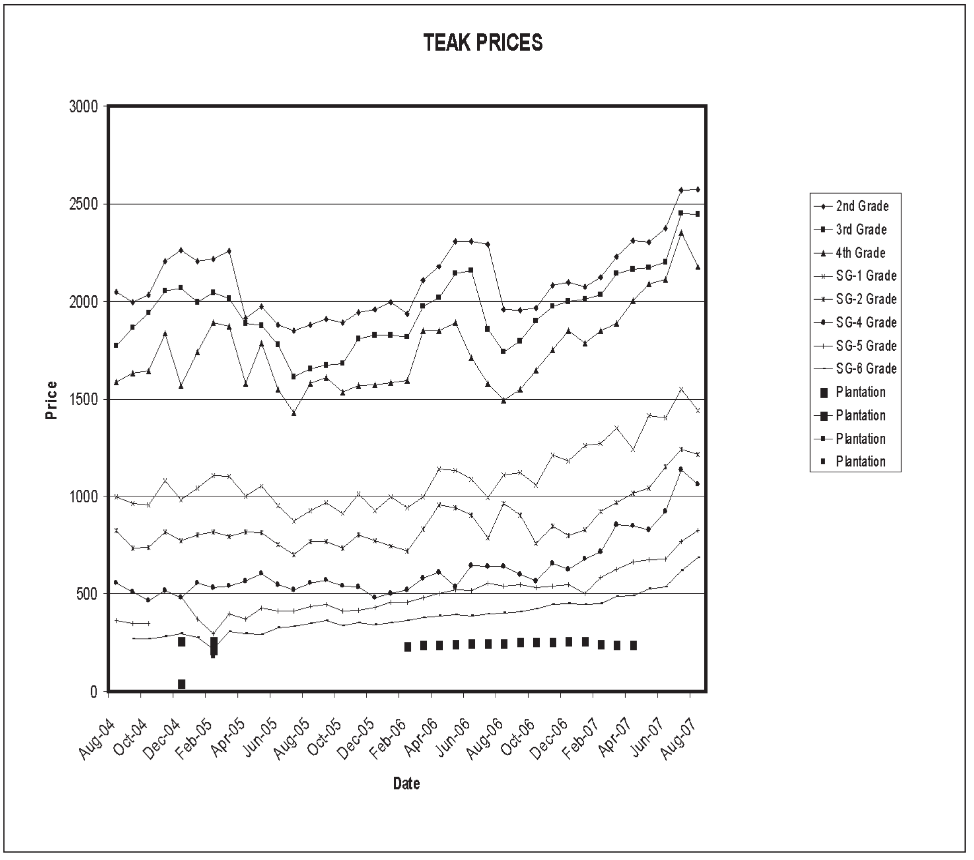
Country	Year(s)	Prices (number)	Reference
Côte d'Ivoire	1993, 1997, 1998	3	Maldonado & Louppe 2000
C. & S. America	1996	2	De Camino *et al.*, 2002
Myanmar	2004	2	Tennigkeit, *et al.*, 2005
Kenya	2005	1	Tennigkeit *et al.*, 2005
Ghana	2000	2	Armstrong *et al.*, (nd)
Guatemala	2006	11	ITTO (2006a)
PNG	1998	3	ITTO (2005b)
Liberia	1998	4	ITTO (1998)
TOTAL		**28**	

It is difficult to validate the pricing range presented (US$ 200 – 300 per m3). However, allowing about US$ 100 or more for freight and other costs would bring the CIF figure to between US$ 300 and $ 400 per m3 and this agrees broadly with the consumption summary report for the urban city of Chennai in India, which imports teak logs from Africa and America. Teak logs from West Africa, Columbia and Brazil range from US$ 300 to $ 500 per m^3 (Muthoo, 2004).

INTERACTION OF NATURAL FOREST AND PLANTATION PRICES

As a result of an increase in price of the then lowest grade of Sawlog (SG-4) in 1994, some of Myanmar's regular customers were compelled to seek substitute sources of supply from outside Asia where it was possible to get cheaper teak logs. These cheaper sources of supply led to the dramatic curtailment of Myanmar teak to some countries such as India and Thailand. According to GAIN (2001), the situation had an adverse influence on the annual revenue of the Myanmar Timber Enterprise (MTE), the state company that is responsible for the extraction and

[‡‡] Real prices were FOB in constant 1990 US $ per cubic metre deflated by the IMF's Consumer Price Index for industrial countries and conformed to the approach as outlined in ITTO (2005a)



Real prices were FOB in constant 1990 US$ per cubic metre deflatedby the IMF's Consumer Price Index for industrial countries as outlined in ITTO (2005a)

Fig. 1. Real prices of natural forest and plantation teak compared (natural teak is illustrated in lines; individual points at the lower end of the graph represent plantation prices)

sale of the logs. To win back the cheaper markets, MTE introduced substitute grades that were within reach of some of its regular buyers. For example, the alternative grade (SG-5 or "Assorted"), which is inferior to the SG-4 logs and is also cheaper, made it possible for the MTE to compete with African plantation teak.

The high demand for lower grades in Asia affected the prices of small-diameter teak in Africa (Maldonado and Louppe 2000) and in the space of a few years, from 1993 onwards, the volume of exported roundwood teak from Côte d'Ivoire grew rapidly, accounting for 99% of the country's exported teak logs. Côte d'Ivoire occupied first place among the 'new' international producers, with exports of nearly 130,000 m^3 of teak timber in 1997. As mentioned above, the FOB price of exported teak logs from the country increased from US$ 60 / m^3 in 1993 to more than $ 300 / m^3 by the end of 1997 (Maldonado and Louppe 2000), which represents a large acceleration in real terms over the period. The increase came about as a combined result of the hike in prices of Asian teak and probably because of a below-market price offered for the Ivorian logs in 1993, which necessitated a relatively rapid upward adjustment towards the true market value.

In contrast to other species, prices for teak logs were less affected during the 1997 Asian financial turmoil (UN/ECE 2000). This is not to say that the crisis had no effect on the prices or volumes of teak sold. According to GAIN (2001), the 1997 crisis seriously undermined the export of Myanmar teak. Furthermore, the volume exported from Côte d'Ivoire followed price movements in the international market, increasing with price increases in 1996 and 1997 (pre-crisis) and suffering a downswing to 97,800 m3 in 1998 compared to 130,000 m^3 in 1997. A corresponding rise and fall in price took place over the same time period; teak dropped to around US$ 250/m^3 in 1998/1999 from US$ 300/m^3 in 1997 (Maldonado and Louppe, 2000). These authors speculate that it is likely the teak market will continue to be governed by trends in Asia.

In conclusion, prices of forest and plantation logs are both influenced by similar market forces and although plantation teak is considered to be inferior to forest teak, each of these products is coming within the competitive influences of the other. These observations clearly demonstrate that the notion of mutual exclusivity of plantation and forest teak is incorrect. Unfortunately, there is no formal mechanism to monitor trends in plantation teak and it is clear that adequate information is severely limited. The simple pricing mechanism, proposed below, would assist greatly in overcoming this problem.

Developing a Standard Pricing Mechanism

The need for a standard pricing mechanism for plantation teak is clear. To be effective it must deal comprehensively with the entire value chain from standing tree to FOB and may include CIF. The approach used in this paper to develop the mechanism is as follows:

1) Focus initially on the teak plantation export log as the international benchmark;
2) Develop standards on which the pricing mechanism is to be established; and
3) Propose how the mechanism would be promoted and implemented.

Developing Standard Grading Rules

The first step in creating standards for the pricing mechanism it to develop standard grading rules for commercial logs. To achieve this, the following actions are needed:

- Devise and agree precise definitions of volumes
- Clarify what is meant by quality

Regarding volume definitions, these are divided into: standing volumes and log volumes. It is important to be able to differentiate between different definitions of standing volumes and cut logs. The standing volume definitions proposed are three:

1. Merchantable volume;
2. Commercial volume; and
3. Residual volume.

Merchantable volume is defined as the total woody tissue in the main stem, under bark, from ground level to 8 cm under bark top diameter;

Commercial volume is defined as the total woody tissue in the main stem, under bark, from ground level to a determined top diameter; for the purposes of the pricing mechanism it is the volume that can be sold on the international market;

Residual volume is defined as the difference between the merchantable and the commercial volumes. The standard dimensions of teak log volumes, which are derived from commercial volume, are discussed below.

In order to determine quality the following must be taken into consideration:

- Dimensions of the log: diameter (cm) at either end (or mid-diameter) and total length (m);
- Cylindrical tendencies (the more the log approaches a true cylinder in terms of roundness - absence of fluting - and low taper, the higher the quality);
- Wood quality (percentage heartwood, colour, homogeneity of colour, number of rings per cm, strength, hardness are normally the primary characteristics of quality teak. Durability is important particularly for certain end uses like garden furniture);
- Defects (the less defects that are present, the higher the log quality; defects include number of knots, splitting, shake, heart rot, etc).

Standard international grading rules for teak must be agreed and these standards should be developed on the basis of the characteristics that are outlined above. International agreement is needed from the beginning. Caution is advised against creating a highly complex system initially. For these reasons, the following grades of logs, based on diameters, log lengths and quality are recommended to initiate the system:

1. Diameter (cm) Class

15 – 19.9
20 – 24.9
25 – 29.9
30 – 34.9
35 – 39.9
40 – 44.9
45 – 49.9
50 +

2. Log lengths are of three types:

Short logs	> 1 m < 2.6 m
Medium logs	2.6 m to 5 m
Long logs	> 5 m

3. Quality Class

A Class	Logs straight, sound and cylindrical throughout the length;
B Class	Straight and sound logs without defects (not entirely cylindrical);
C Class	Logs with minor defects; and
D Class	Logs with defects.

From the initiation of the scheme, particular emphasis must be placed on the proportion of heartwood available in each class. More sophisticated quality parameters can be introduced at a later stage and refined on a continuous-improvement basis during the promotion and implementation phase of the mechanism.

IMPLEMENTATION

Agreement from international stakeholders on the harmonisation of norms and standards is required if a formal pricing mechanism is to be developed. However, this would be a long-term measure. Alternatively, rapid spot-checks of teak along the value chain is recommended as a short-term solution. The objective of these ‘snapshots’ is to estimate the value of teak based on the proposed grading rules and at fixed points along the value chain between standing tree and port, carried out in a number of countries (e.g. two countries in each of three continents: Asia, Latin America and Africa) at a specified time(s). Snapshots of this type would provide a rapid benchmark for plantation teak prices worldwide.

Once the processes are set up it would be relatively simple to update the snapshots annually or periodically, which would also provide data on price trends. Whatever system is used it must:

- Be applied in a standard and transparent manner at the same time across teak growing countries;
- Publish up-to-date and accurate international information from its sources on teak prices; and
- Update information on a regular basis.

The output from the snapshots or a more complex international harmonisation of norms and standards would bring transparency to teak pricing and is likely to speed up the process of price adjustments where the base price is artificially low.

IDENTIFY KEY COMPARATIVE POINTS ON THE VALUE CHAIN

The pricing mechanism must deal comprehensively with the entire value chain but there are three or four key points that must be compared universally when applying the pricing mechanism internationally to plantation teak. The points that are considered here include:

1. The standing crop
2. The roadside log
3. The log as FOB and
4. The log as CIF (Cost Including Freight)

It is assumed that any mark-ups or profits are included in the prices.

The Standing Crop

When evaluating standing trees it is necessary to differentiate between merchantable, commercial and residual volumes. Merchantable volume is the volume that represents the productive capacity of the site. Financial studies and company prospectuses normally use it to predict the future value and financial returns of the crop. To derive a price for merchantable volume it is necessary to consider separately the values of commercial and the residual volumes. Residual volumes have a value if they can be sold; if not the value of the crop is totally dependent on the commercial volume. A common mistake is to apply the value of the commercial volume to the entire merchantable volume thus overvaluing the crop.

All volumes are expressed in m^3. Values are in US dollars (US$). The value of the standing crop may be expressed as:

$$\$V\,sv = \$V\,mv + \$V\,ex \qquad (1)$$

Where,

$V sv = Value of the standing crop;

$V mv = Value of standing (merchantable) volume;

$V ex = Value of any 'extras' (e.g. CO_2, branches etc).

For the purposes of the present exercise, $V ex, which could include carbon values or value of branches, roots, leaves etc, is assumed to be 0. The standing value of the crop may also be expressed as:

$$\$V\,sv = \$V\,cv + \$V\,rv + \$V\,ex \qquad (2)$$

Where,

$V cv = Value of the standing (commercial) volume;

$V rv = Value of the standing (residual) volume;

Other symbols are defined above.

Often the residual volume is not clearly accounted for in the valuation of plantations. For purposes of illustration, it is assumed here that a principal buyer purchases only the commercial volume, leaving the residual volume behind to be disposed of by the owner. In the present exercise, the residual volume is considered to generate no monitory returns. Often the entire commercial volume is not extracted; for example, a stump of up to 0.3 m may be left behind because the felling height is above ground level. In the present exercise it is assumed that the entire commercial volume is extracted. The price of the standing volume also includes any government taxes that must be paid.

The Roadside Log

The roadside log represents the proportion of the commercial volume that is extracted from the plantation. However, the cut volume may differ from the theoretical commercial volume. For example, when felling and extracting, the principal buyer may pay for the volume to a fixed top diameter but only cut and haul logs of a fixed length (e.g. 2.5 m). In this case some commercial volume may be left behind in the plantation (e.g. in trees where the 2.5 m mark, or multiples of this length do not reach the commercial top diameter). In such cases the leftover volume may be added to the residual volume. In the present exercise it is assumed that the primary buyer harvests the entire commercial volume.

Often the roadside log is further cut into baulks (squared off) before being stored in a container. This represents a decrease in volume and an extra charge for cutting which must be taken into consideration. In the present case it is assumed, for simplicity, that the round log is fully utilised. The value of the roadside log includes a cost for felling, cutting into lengths, hauling and stacking or storing (or filling a container) and may be expressed as:

$$\$V\ rov = \$V\ cv + \$C\ xt_1 - \$V\ cv_1 \qquad (3)$$

Where,

$\$V\ rov$ = Value of the roadside logs;

$\$V\ cv_1$ = Value of the commercial volume not extracted by the initial buyer (assumed here to be equal to 0);

$\$C\ xt_1$ = Extraction costs (felling, cutting, hauling, stacking and storage etc);

Other symbols are as defined above.

The logs as FOB

For simplicity it is assumed that the roadside volume of commercial logs is the same as the FOB log volume. The value of the FOB logs includes the cost of loading, transportation, unloading and handling in port, port costs and taxes. The FOB value can be expressed as:

$$\$V\ fob = \$V\ rov + \$C\ th + \$C\ pct \qquad (4)$$

Where,

$\$V\ fob$ = Value of the FOB consignment volume;

$\$C\ th$ = Cost of transport and handling;

$\$C\ pct$ = Port costs and taxes;

Other symbols are defined above.

The FOB value is the principal price indicator of the pricing mechanism because most ports around the world are accessible to international freight carriers and, where information and access are not hampered, the prices for a particular size and quality of product generally tend to reflect international market values. The maximum standing price that the grower can receive represents a residual price after extraction, handling and transport costs and profits are accounted for. Residual price and residual volume should not be confused.

The logs as CIF

It is assumed, for simplicity that, in the current exercise, the CIF log volume is the same as the FOB log volume. The cost of CIF includes freight charges, insurance, taxes and other costs, tariffs and profits to get the consignment from the port of origin to the port of destination.

A worked example of prices through the value chain is provided below:

WORKED EXAMPLE

The following worked example illustrates value of timber along the value chain from FOB to standing timber:

\$V sv	= \$V mv + \$V ex	(1)
\$V sv	= \$V cv + \$V rv + \$Vex	(2)
\$V rov	= \$V cv + \$C xt_1 – \$V cv_1	(3)
\$V fob	= \$V rov + \$C th + \$C pct	(4)

Where,

\$V sv	=	Value of the standing crop;
\$V mv	=	Value of standing (merchantable) volume;
\$V ex	=	Value of 'extras' (e.g. CO_2, branches etc);
\$V cv	=	Value of the standing (commercial) volume;
\$V rv	=	Value of the standing (residual) volume;
\$V rov	=	Value of the roadside logs;
\$V cv_1	=	Value of the commercial volume not extracted by the initial buyer;
\$C xt_1	=	Extraction costs (felling, cutting, hauling, stacking and storage etc);
	=	\$ 15.00 / m^3
\$V fob	=	Value of the FOB consignment volume;
	=	\$ 280.00 / m^3
\$C th	=	Cost of transport and handling;
	=	\$ 24.00 / m^3
\$C pct	=	Port costs and taxes;
	=	\$ 12.00 / m^3.

As the value of the standing timber is a residual value the exercise is carried out in reverse order, starting with equation (4) and working backwards. The first item to calculate is the value of the roadside log (all figures are m3 / ha unless otherwise indicated):

\$V rov (\$ 244.00) = \$V fob (\$280.00) - \$C th (\$ 24.00) - \$C pct (\$ 12.00) (4)

In equation (4), the value of the roadside log (\$V rov) is calculated by subtracting the transport and handling (\$C th) and port costs (\$C pct) from the FOB figure. Having found the value of the roadside log and knowing the cost of extraction (\$C xt_1), the standing value of the commercial component of the standing volume (\$V cv) can be calculated, as follows:

\$V cv (\$ 229.00) = \$V rov (\$ 244.00) – \$V cv_1 (\$ 0.00) – \$C xt_1 (\$ 15.00) (3)

In order to calculate the value of the standing merchantable crop it is necessary to know the volume of the commercial and residual components of the standing crop. Assuming that the stand is composed of 120 m^3 of merchantable volume and 108 m^3 of commercial volume; this means that the residual volume is 12 m^3. The value that the stand receives is, in this particular example, only derived from the commercial volume (108 * 229.00 = \$ 24,732.00). As the merchantable equivalent of the total crop is also equal to the commercial component (as there is no value attached to the residual volume in this example) the value of the merchantable per m^3 is \$ 24,732.00 / 120 = \$ 206.00). This shows that it is misleading and erroneous to use the value of the commercial component of the stand to calculate the value of the merchantable volume, a common error in teak calculations.

CONCLUSION

There is an urgent need to develop an international pricing mechanism for teak plantations and implement it throughout grower countries. The proposed mechanism is likely to have a significant and positive impact on the entire teak sector. Its implementation would bring transparency to teak pricing. It may be implemented informally at first in a number of key countries in the tropics. With a relatively small input in terms of human and financial resources, it would produce immediate results and provide a rapid benchmark for plantation teak prices worldwide. What is required is stakeholder willingness. The rewards promise to outweigh the costs many times and will enable a strong quality plantation teak sector to emerge.

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Investment and Economic Returns from Teak Plantations

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ABSTRACT

Economic benefits from teak plantations are influenced by the financial performance of the venture and the larger social and environmental factors. Among the financial determinants, the productivity, length of rotation, price of different grades of timber output, costs of inputs, taxes and tariffs are important. This paper looks at the productivity and financial performance of teak plantations raised by the Forest Department in Kerala in comparison with other plantations raised by the same agency, to evaluate the potential and reality of teak as a commercial plantation. When plantations were first attempted in India by the British colonists one and a half centuries ago, it had a strategic value in the defence of an empire. Later, it was the preferred plantation species in a planned clear felling and reforestation programme to improve the productivity and value of the mixed tropical forests of India. Concern for the rapidly dwindling natural forests arrested the expansion on teak plantations within forests in India. Now again, it has a latent value as a defence against global warming when used in afforestation programmes outside forests. Carbon credits could be availed by plantation companies operating on a scale sufficient to afford the costs of certification to improve economic results. A private sector teak initiative in India, with aggressive marketing of teak units, floundered during the last decade as performance did not match with promise and eventually all of them got liquidated leaving the credulous investors with worthless paper and no teak. Teak needs a second chance, in a more sober and dispassionate manner. Teak is still a commercial proposition. The strengths of mature teak are its aesthetic quality, durability and its relative resistance to damage by moisture and insects. Not all timbers possess such qualities. There is a premium for mature teak as there is for mature wine. Young teak does not command such premium. Shorn of the hype and myth of teak as a miracle money-spinner, teak is a good investment in many respects.

Keywords: Teak plantations, financial performance, length of rotation, certification, carbon credits, landuse policy.

INTRODUCTION

We are here to discuss teak. People are interested in teak for its uses or the benefits expected from it, including profits. None would be happy about owning teak “units” that fetch neither teak nor profits. Tens of thousands of credulous investors in India lost their entire investments in “Teak” units that appeared lucrative from irresistible advertisements. There was a rich harvest of millions of rupees by the earnest and fake private sector teak ventures, collecting easy money on the reputation of teak as a sturdy, durable and attractive timber.

There was an opportunity in India then for pocketing easy money. There were loopholes in the legal framework, regulatory mechanisms did not exist, people had money to spare, gullible people trusted in the high profile, glamorous media advertisements, and they believed they were riding the teak boom, till they landed with a thud. Teak units are no more acceptable – even as a gift. The fair name of teak has been sullied. This once again proved the elementary economic rule, 'one man's loss is another man's gain'. Teak companies and the media gained while the investors lost.

Ultimately, the Reserve Bank of India and the Securities and Exchange Board of India stepped in and restrained the companies from collecting more money. The private sector teak ventures either vanished or were liquidated. The investors learned a lesson at their cost too. The media profited from the advertisement money and by reporting the scandals in the aftermath. The advertising code and the media regulator, the Press Council, were ineffective.

HISTORICAL TRANSFORMATION OF PLANTED TEAK

The value of teak as a prime construction and boat building timber was well known to the people in peninsular India and the Arab traders who preceded the Europeans, made good use of this timber. The British, while searching for a substitute for their traditional oak began to rely on teak as a strategic timber for their supremacy on the high seas, which was threatened by the French Navy in the early nineteenth century. Teak plantations were established in Kerala by the colonial administration on the direction of the Court of Directors of the British East India Company. Subsequently even after the threat to the empire receded, the commercial success of the teak venture made it a mainstay of the Forest Department of the British rulers. Independent India, which inherited the legacy of the colonial rulers, continued the teak plantations programme with great vigour but less meticulous management oversight. The Five-year Plans set ambitious targets for raising teak plantations in cleared forests and forestry came to be identified with the expansion of teak plantations in almost every forest Division and Range. Creation of monoculture teak plantations was considered as 'development' by converting the low (market) value mixed natural forests to high priced teak plantations. Naturally while the rapid expansion took place, the quality of the plantations declined. By the mid 1980s, forest and environment conservation, neglected in the past, ascended in importance and the clearing of new areas in forests for any purpose, including plantations, was stopped by law (Chundamannil, 1993).

In the 1990s, private sector teak ventures promising high returns from short rotation teak plantations, marketing teak "units" mushroomed. High profile media advertisement was the selling strategy adopted. Miraculous profits were indicated. Each venture competed with the others to project higher and higher levels of expected profits. What attracted the investors was the high-input short rotation angle. This was hyped to produce miraculous results, in contrast to the low input government plantations raised by the conservative Forest Departments. Government foresters, obedient to their service rules which prohibited public discourses and media debates, appeared to silently endorse the fantastic claims of the new high tech, high input short rotation ventures even when many foresters would have realised the un-tenability of the claims of the private ventures. Some retired foresters, lured by lucre, lent their name and official stature to the new companies adding glamour to their claims in a way that seemed to blend dynamism with experience.

The burst of the teak bubble in India

However, contrary to the media hype, the area actually planted did not match the sale of "units" sold to investors. Naturally the bluff was called when cheques stared to bounce and criminal cases were filed. The courts stepped in and the Government of India ordered an official enquiry by a senior silviculturist at the Forest Research

Institute. The Securities and Exchange Board of India, the regulator of Companies, intervened to stop further acceptance of investment funds from the public. In fact most of the companies were using the money from new investors to service previous obligations and to pay for fancy advertisements. When the money inflow stopped, the teak companies along with similar ventures in Acacia mangium and goat farms collapsed. Table 1 shows the yield projections of some of the leading teak companies and the actual average yields obtained in Forest plantations in Kerala, one of the oldest teak growing areas in the world. The figures are surprising. Perhaps the private ventures who adopted a very close spacing did not understand the need for thinning and the relationship between proper spacing and girth increment. But this is unlikely since government plantations are ubiquitous and any forester would have enlightened them. It is more likely that the promoters were simply playing on the dreams of the investors who were promised either a specified number of teak "units" or a specified volume of teak not necessarily from the same tree (even a bundle of poles). The price size gradient of teak is so sharp that an equivalent volume of poles fetch only a small fraction of the price of large diameter logs.

Table 1. Comparison of the projected productivity of teak plantations by private ventures with the actual productivity of government plantations

Company	Yield /tree (m^3)	MAI (m^3 ha^{-1} yr^{-1})	Nature of estimate
STM	1.06	47.13	Claimed
Anubhav	1.13	60.01	Claimed
Govt. Plantations	—	2.52	Actual

Source: Chundamannil, 1997.

A study of the productivity of and profitability of teak and other forest plantations in Kerala was carried out by KFRI (Chundamannil, 2001). This study used yield data from a very large sample as shown in Table 2.

Table 2. Coverage of data from forest plantations for yield assessment

Species (yrs)	Mean rotation	No. of plantations	Area (ha)
Teak	58	717	28,802
Eucalypt	8	571	39,064
Acacia	8	44	1,199
Pine	23	15	603
Wattle	10	22	822
Albizia	15	15	231
Bombax	32	2	117
Silver Oak	28	1	21

Source: Chundamannil, 2001.

The average rotation age of teak plantations in Kerala is 58. Table 3 shows the average productivity of different plantation species in Kerala forests. The average productivity achieved for teak is 2.5 m^3 ha^{-1} yr^{-1}. Conventionally, the output from some plantations are sold by volume of logs while some others, particularly those meant for pulping, are sold by weight. The units of local measurement are shown as such since using an arbitrary volume weight relationship for standardisation may mislead readers.

Table 3. Average productivity of forest plantations in Kerala

Species	Unit	MAI
Teak	m^3 ha^{-1} yr^{-1}	2.516
Albizia	,,	7.466
Bombax	,,	2.636
Silver Oak	,,	3.092
Eucalypt	MT ha^{-1} yr^{-1}	6.432
Acacia	,,	3.610
Pine	,,	3.601
Wattle	,,	3.295

Source: Chundamannil, 2001.

The financial performance of a plantation venture depends on the productivity achieved, the length of rotation, price of different grades of timber output, taxes and tariffs, costs of inputs, transportation and marketing. Financial performance is assessed on the basis of Internal Rate of Return (IRR), Benefit Cost Ratio (BC Ratio), Net Present value (NPV) etc. The internal rate of return shows the rate of profit of the enterprise as a percentage of the money invested. Net present value is the discounted value of the future profits. For discounting, a rate equivalent of the interest cost of borrowing money is taken. However when different plantations with differing length of rotation are to be compared, NPV at infinity is more appropriate. Table 4 shows the IRR of different forest plantations and NPV at infinity. Although the productivity is important, it is the value of the output that is more relevant in a financial analysis. Even though the per hectare output of eucalypt or Albizia is more than that of teak, the differences in price nullify any gains in productivity.

It can be seen that teak has the highest IRR among forest plantations and the only plantation species in Kerala which is profitable with a positive NPV. The other plantations are financially a drain on the exchequer.

Table 4. Profitability of different forest plantations in Kerala

Species	NPV at infinity at 12 % rate of discounting (Rs ha^{-1})	IRR %
Teak	+ 24,031	+ 25.90
Eucalypt	- 27,148	- 4.10
Acacia	- 21,262	- 6.90
Pine	- 21,262	- 0.21
Wattle	- 13,442	+ 4.20
Albizia	- 22,964	+ 2.39
Bombax	- 17,233	+ 4.17
Silver Oak	- 27,542	+ 1.28

Source: Chundamannil, 2001.

A financial analysis shows only a partial picture. An economic analysis takes a broader frame and considering the social, economic and environmental factors. Economic benefits from teak plantations are influenced by the financial performance of the venture and the larger social and environmental aspects. In peninsular India, teak is a native tree and a part of the local ecosystem. Conventional teak plantations in India adopt a long rotation mode which contributes to carbon fixing. Further, due to the durability and the use of teak wood in furniture, cabinet making and construction, it provides a very long lock-in period for the fixed carbon. Therefore raising teak in degraded lands contributes to ameliorating the ill effects of global warming. It is also a good candidate for afforestation programmes due to its hardy nature and tolerance of strong sunshine. All teak growing need not just be an altruistic effort; there are opportunities for gaining carbon credits as proposed under the Kyoto Protocol. However as the carbon exchanges and the certifying agencies are in the rich developed countries, the cost of availing their services is also very high. Currently it is the multinational companies that stand to gain by the carbon trade. Eventually, global pressure from the developing tropical countries will reduce the high costs of access to such carbon credits and authorise regional and national agencies for certification and monitoring.

The strengths of mature teak are its aesthetic quality, durability and its relative resistance to damage by moisture and insects. There are a range of materials now available to choose from, for structural uses and strength properties, such as steel, aluminium, carbon fibre compounds and even concrete. The value of teak lies elsewhere mostly in its aesthetic and environmental qualities. The aesthetic value is mostly due to its grain pattern and cultural preferences of colour etc. There is a premium for mature teak as there is for mature wine. Fast grown young teak does not attract such appreciation or price. Polishing and finishing do add value to any timber. Lacquered rubber wood furniture and panels appear equally attractive to the undiscerning. The advantage of teak is that no preservative treatment with toxic chemicals is required for processing, making it more environment friendly than other timbers that require such treatments. Long rotation, organic teak has an ecological and economic value. Young teak does not command such premium. Let us continue to raise teak in the conventional way, without fertiliser, chemical pesticides and on long rotations as a green enterprise, for environmental, aesthetic and economic reasons. Let us not rush in for short rotation, environmentally polluting ventures seeking quick profits and slaughter the golden egg laying duck irresponsibly.

The right path

Considering the larger economic and policy issues we need to go beyond micro level statistics of productivity and profitability. We need to consider the right land use policy, the right wood production policy, the right economic policy, and the right political policy. Teak plantations require land. Land has many functions and alternate uses. Each of those alternate uses has different impacts for the owners of the land, the local community and the larger society. When public land is being used, the public purpose must be served. Whoever the owner, societal welfare requires that the right land use policy would ensure effective soil and water conservation, avoidance of toxic chemicals and it should help ameliorate global warming and climate change. In this perspective long rotation organic teak farming is the right choice. Society and the State should formulate a land use policy that focuses on maintaining the water flows and the soil fertility for the future generations. Long rotation tree crops are an ideal choice in this respect. From the perspective of the right wood production policy also, organic tree farming and long rotations have a better justification.

The right economic policy should focus on sustainable development. The State should ensure that shady operators do not get away with incredible claims that cheat investors and undermine the credibility and trust of the investors. The advertising code and the media regulator, the Press Council in India, have a major role to play in this regard. Foresters and researchers also need to engage in public debates to provide factual information. The Clean Development Mechanism (CDM) is a new way of correcting the past ways of environmentally destructive modes of production. The long life cycle of teak makes it an ideal candidate for generating carbon credits. Poor tropical countries, particularly India, have a great potential to benefit by the carbon trading mechanism, notwithstanding the current disadvantages.

The right political policy is also important. Politics is about people, human rights, equitable sharing of benefits and people's access to policy making. The more democratic a society is the more inclusive will be its development strategy. The deeper the democracy, then long term issues and the options of future generations will also be considered. An enlightened political policy would focus on making the planet liveable. Greening the earth, reducing environmental pollution, protecting biodiversity and the native species are all important policy issues that need political commitment and will. Ensuring that carbon credits serve social objectives (poverty eradication) and not enrich the already rich Multi National Companies is again a democratic imperative.

In this perspective, the growing of teak plantations should be done in such a way that natural mixed forests should not be sacrificed for monoculture teak plantations in the interests of biodiversity conservation, teak plantation should be raised on a long rotation for environmental reasons, plantations should adopt organic farming practices to prevent chemical pollution of the soil and water, and avoid weedicides and chemical pesticides altogether for human health reasons. Regulatory mechanisms to control fraudulent claims on teak growth and returns that defraud investors must be implemented. Factual information regarding the performance and potential of teak must be made available by the academic community and foresters so that an informed and enlightened policy on teak can be developed at the national and international level. The TEAKNET, an initiative of FAO, has the potential to guide the production and utilisation teak in the right direction.

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Wood Production in Planted Forests

Wood Production in Planted Forests

Teak Farming in India: Challenges and Opportunities

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ABSTRACT

The phenomenal growth in market economy as a consequence of globalization and adjustment processes also has a bearing in the tree growing sector. Agroforestry is an important remedial strategy to meet the demand of wood-based and other allied industries. About two-third of the country's timber requirement is met from agroforestry and sources outside forests. The lack of planting stock and the crippling timber trade rules are the major constraints in teak farming. With vast areas of farmlands at the disposal of farmers there is ample scope for planting teak which is highly remunerative. Besides, agroforestry and tree farming are potential and promising mechanisms of carbon sequestration.

Keywords: Agroforestry, management practices, short rotation, plantation technology, public/private corporations.

INTRODUCTION

Exploitive policies of the past have seriously impaired the productive capacity of designated forest. Huge gap exists between demand and supply with a billion population exerting pressure.

Area under privately owned tree crops in India fell from 2.7% (1951-52) of total reported area to 1.15% by 1980-81. Agroforestry is the only remedial strategy to meet the demand of wood based and other allied industries like timber, plywood, etc. About 2/3 of country's timber requirement (81.8 million m^3 in 2000) was met from agroforestry and sources outside forests. As per the State Forest Report (2003), the area under tree cover outside forests is 4.56% and there is a need to increase this. The teak caught up the fancy of farmers and attained importance because of the entry of corporate sector projecting attractive revenues with unattainable outturn. Studies of performance of teak in farmlands in 5 agroclimatic zones of Tamil Nadu give varying results according to edapho – climatic conditions and site selection. Studies confirm that with proper selection and management practices, teak could rank as the best tree for agroforestry system under short rotation. There is need for transfer of technology.

SOCIO-ECONOMIC PROFILE OF TEAK GROWING

Hitherto teak was believed to be slow growing but with improved planting stock, advanced nursery and plantation technology, followed by intensive care and management, it was found suitable for short rotation farm forestry. Many public and private corporations have raised excellent teak plantations availing credit from National Bank for Agriculture and Rural Development (NABARD) and other banks. Many private entrepreneurs floated companies seeking investment in teak equity with promise of high returns.

NABARD promoted teak under farm forestry with a regime of thinning on 7 and 13 years, which was technically feasible and financially viable. Major problems faced by teak farmers are lack of quality planting stock and the crippling timber trade rules which kill all enthusiasm of farmers.

Tree growing practices are successfully practiced in many states to meet out the demands of timber, plywood etc. There are vast extents of marginal lands, farm and fallow lands at the disposal of farmers and ample scope exists for tree planting in wood lots of teak, which will be remunerative. The various projections of corporate bodies give credence and support to such initiatives.

The economics of teak growing in farmlands have been worked out both by bank and others making case studies like ANTHIYUR irrigated plantations model with three case studies in Tamil Nadu. The Cost benefit studies of various tree crops have been carried out in Thanjavur canal bank plantation project.

Agroforestry practices and tree farming have the potential to store carbon and demonstrate as a promising mechanism of carbon sequestration in India. It has strong implications for sustainable development because of interconnection with food production, rural poverty etc. Policy to promote agro forestry system will help to sequester carbon thereby providing climate change mitigation benefits (Watson *et al.*, 2000).

CHALLENGES AND OPPORTUNITIES

The challenges and opportunities in teak farming including nursery, regeneration, plantation and production economics, finance and marketing are to be considered in proper perspective and addressed.

CONCLUSION

Any produce which has a good marketing potential is accepted by farmers. As such there is immense opportunity for farmers to step up production. India has a booming economy with annual growth having reached 9%. The developments reflected in allied sectors are attributable to globalization and adjustment processes. Thus phenomenal growth in market economy has also bearing and implication in tree growing sector.

Improvement of Planted Teak in India by *Vrikshayurved* Methods

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ABSTRACT

Having been in teak trade as an importer, processor and exporter for 60 years, the author has been a witness to the facts that, India which was one of the largest producers of teak is today dependent on imports to meet its requirements. The supplies being received from countries other than Myanmar are all of plantation origin and of medium to poor quality. This has weaned away many consumers from teak to other hardwoods from Africa and South-East Asia. If the quality aspect of teak is not taken care of, it will lose its importance. The planters and investors will also be affected as their economic returns will not be anywhere near their projections. To improve quality of planted teak, the author has invited attention to the vast fund of traditional knowledge available on this subject from ancient manuscripts which have been compiled as *Vrikshayurved*. It is hoped that all concerned will shed reservations in application of these time-tested recommendations, wisdom and techniques to produce natural forest quality teak and also help bring back homogenous environment to the man-made forests.

Keywords: Teak monoculture, *Vrikshayurved*, homogeneous environment.

INTRODUCTION

The erstwhile first Inspector General of Forests for India, Mr. D. Brandis had remarked that "among timbers, teak holds a place which diamond maintains among precious stones and gold among metals". This is very true. India used to be the largest producer of fine teak in the world, and we had that gold as also logs like diamonds for veneer production, but today India itself is starving for good teak and imported teak is nowhere in quality comparison.

Since the 1982 ban on felling of trees to augment the dwindling forests, India improved the forest cover from 9% to 23% and the policy still continues. We are still depending on imported timber for our needs. We used to get natural forest teak of good quality from Myanmar, Indonesia and Thailand (Figure 1). These have now been reduced to a trickle as Indonesia and Thailand no more permit export of teak logs and sawn timber. Myanmar supplies have dwindled and prices are getting beyond reach of average consumer, hence the shift is to buying more and more of plantation teak. Because of this situation manufacturing of teak veneers, teak plywood and the traditional boat building industries have suffered immensely because suitable logs for these products are hardly found from plantation material. People are shifting to other species such as meranti, merbau, balau, iroko, wenge, padauk, bubinga, ovangol, hopea, etc. from West African, Malaysian and Indonesian forests for plywood, boat building and builders' joinery for residential and commercial complexes.

Exports of teakwood door frames from India have also suffered as middle-eastern builders are placing teak with iroko, meranti and merbau.

Therefore, producing good quality teak from planted forests has become an urgent necessity.

Target of Plantations

plantation teak of various origins. These imports plus whatever we are able to get from Myanmar have helped feed requirements of teakwood for multifarious uses ranging from doors, windows and other builders' Joinery for residential and commercial buildings, for furniture and other wooden items required in Indian households as also for its uses in industries. Since India used to be the largest producer of teak prior to 1982, Indians have weakness for using teak for any conceivable purpose in the areas which were having natural stands of forest teak.

Unfortunately the major portion of whatever teak that is being imported are fast grown varieties and very young with very little heartwood formation and very wide sapwood with thick bark. If you see the consignments arriving in Mumbai you will react as to how can anyone use this *Rupee teak* (nickname given to this quality) because the heartwood is so small in size of rupee coin.

Processing

To see how first thinnings are processed by our industry is also an experience worth having. The freshly sawn water dripping teak wood sizes are individually coated with a mixture of teak sawdust, *geru* and cowdung in water and stacked. While stacking dry sawdust of teak is sprayed on each layer and within few days the sap gets the colour of heartwood and it is marketed in that condition by saw millers to processors. The processed colour is superfluous and with first touch of planer blade the sap will be exposed in its original colour. The

Fig. 1. Myanmar teak logs rated with one star.

required items will be manufactured and will be given a coat of coloured primer if the final finish is going to be with paint and stained with clear colour if it is going to be polished. This is how we use the material unwanted in the producing countries and satisfy a part of our requirements. It is a win-win situation for both at present but it needs to be improved otherwise replacements will displace teak for processing and marketing in India.

To speak the truth, when the idea of replacing mixed stands of natural teak forests with monoculture plants for plantations was mooted in India in almost all teak growing states, nobody had visualized that the resulting teak from plantations will be of inferior quality. Not only the quality suffered, but we lost a lot of wildlife and plant habitat by clearfelling of natural forests for plantations. Having been very actively involved in teak trading for last 60 years, I remember the enthusiasm of State Forest Departments to establish all teak plantations and creating Forest Development Corporations to raise the plantations on commercially viable basis.

Plantation teak as we are getting today is deficient in strength, colour, figure, luster, the waxy feeling and the peculiar lovely smell of natural teak. Many countries which did not have teak as domestic species and introduced it as a commercial commodity have also experienced the same problem. They had expected harvesting Myanmar quality teak and projected their financial forecasts based on Myanmar teak prices. They are now finding that size-to-size and quality, the realizations are almost half that of Myanmar prices. Presently for plantation teak logs, the rates range from US$ 145 to US$ 550 per m^3 F.O.B port of loading as against US$ 300 to US$ 1050 realized by Myanmar also on F.O.B basis. For sawn timber also the price realization for plantation teak FEQ (First European Quality) is US$ 1000 as against US$ 2000 for natural teak. From the F.O.B prices when you deduct log preparation expenses and freight from plantation to the port of loading, the balance net realization is meager and nowhere near targeted income. This is a serious situation for investors and plantation managers and it is high time that experts find a solution to improving the quality of plantation teak so as to improve the prices realizable and the consequent rise in profits.

The purpose of my paper is to draw attention of experts at home and abroad to the outstanding contribution in the field of agroforestry made by botanists of the yore in ancient India. The science they developed was known as "*Vrikshayurved*" - a Sanskrit term meaning "tree life science" or "plant life science". Indians have been conscious about importance of flora and fauna since centuries. This is born out by stamping of trees, well protected by railings. The fauna is represented by elephants, bulls/cows, rabbits, frogs, fishes in pond, etc. on coins (Figure 2).

Fig. 2. Coins stamped with flora and fauna: From left 1st coin - 2nd Century A.D coin showing tree in railing; 2nd coin - 2nd Century B.C coin showing tree, mountain and river; 3rd Coin - 4th Century B.C coin showing tree, elephant and bull

I am reproducing some for all of you to see that not only the tree planting was encouraged but their protection was equally emphasized. Necessity of fauna was also stressed by representing them on imperial as also tribal coins. So much as a background scenario for *Vrikshayurved* wisdom.

Research scholars have made efforts to retrieve ancient manuscripts and recover the works done in this field as much as possible and have published original Sanskrit texts with translations in Hindi and/or English and local vernacular languages like Tamil, Telugu, Gujarathi, etc since last 25 years. The efforts to find out more ancient scripts to revitalize present day organic practices are continued. The works done by Sushrut, Varahmihir, Sarangdhar, Surpal, Parashar and others are well known. They have highlighted that trees are not only just living plants but they have their individuality with temperaments, liking for certain habitats. The diseases have been identified with prescriptions for cure as they have done for humans in "*Ayurved*". Plants started getting attention like humans as they are also built up with "*Panch Tatva*" the five elements namely Earth, Water, Air, Fire and Ether with which human body is also created and that is why they termed it as "*Vrikshayurved*" as against "*Ayurved*" for humans. This is a unique traditional knowledge kept alive by folk practices related to agro and agro-forestry sectors.

Different species have different likings. *Shorea robusta* is gregarious which likes to be in company of its own species. If you plant others among them they will kill them. That is why you find pure stands of *Shorea robusta* but it is not so with teak. Ancient wisdom dictates that teak wants friends around and not just its own family. Teak loves to be with bamboo, *Adina cordifolia, Ougenia dalbergiodes, Pterocarpus marsupiam, Dalbergia latifolia, Terminalia tomentosa, Chloroxylon swietenia, Diospyros melanoxylon, Gmelina arborea, Gargua pinnata, Lagerstroemia lanceolata,* etc. These are the members of teak club and if we want same quality of teak as forest quality then we have to shake off indifference to traditional practices and provide the friendly atmosphere for teak to grow well. This diversity of plants flourishes together and protects each other by providing necessary bio-culture developed over centuries of adjustments. I have given the names of species that I have come across whilst buying teak in India and Myanmar. Now-a-days teak is being grown all around the world. Other countries will have to provide suitable and acceptable friends from amongst the local species growing well in their climates.

Besides the above, to improve the quality and quantity of teak in planted forests *Vrikshayurved* advises giving additional nutritional support by way of mixing the mulch from the site itself in the ground, cattle farm manure, abattoir waste, fish meal, and poultry farm droppings, etc. as additional growth enhancers. The ancients have also favoured introducing vermiculture for good aeration to the roots. It will also help them get deeper and draw more nutrition from the soil. They favour providing bird houses at the site to attract diverse community of birds who will keep the plants free of wood destroying insects. They also encourage establishing honey-bee colonies, not only for the additional income but the help that bees render in pollination process. On top of it, the honey available will be useful in preparing various organic mixtures to which I will refer later. Ancients have been favoring establishment of healthy environment for the best growth of the targeted crop as also help the society in which it is situated.

Looking to the present price realizations for plantation teak it would still be commercially viable project if some of the friends of teak are selected for planting along with it which will give good prices and for which regular market exists.

The mixed plantation will arrest soil erosion which is found where monoculture is practiced, mainly owing to lack of soil holding under growth. A suitable mix of species will also help deter pests and various diseases to which teak is prone. This principle is also well demonstrated in "*Vrikshayurved*" not exactly for teak but for various other agro products and on similar principles, line of defence for teak can be planned. With mixed stands problem of stem boring bees and leaf borers will also get reduced and these can be further eliminated with organic products like "*Panch Gavya*" and/or other formulas given by ancients. This can be a subject matter for another special paper.

CONCLUSION

Experiments are being made in some of the South-East Asian countries to grow CITES listed endangered species like *Santalum album, Aquilaria agallocha* and *Pterocarpus santalinus* along with teak and the prognosis looks to be bright. This will not only support teak but will also boost profitability of the venture. In short, the policy of monoculture needs to be reviewed, negative attitudes dropped and suitable changes made on the basis of ancient precepts and modern experimental results. Let us not be rigid. Flexibility will more than compensate the efforts required to be put in, to alter the single species composition. Efficient planning will enhance rewards and provide cash profits at short intervals.

Various manuscripts of *Vrikshayurved* have given guidance on all aspects of plant science relevant to raising planted forests of teak. The guidance given includes:

- Optimum altitude and desirable landscape. For example, teak to have good heartwood development, we must have land with gradients to drain excess water. As we all know teak roots abhor waterlogging and if we insist on having teak plantations on flat grounds then the logs have large sap, small heartwood and thick bark. Hills and valleys have reported best quality growths from natural teak growing areas, viz., India, Myanmar, Thailand and Laos.

- Having described seven different types of soils, for teak, red and black soil with gravel for porosity is recommended. With right soil the roots will have proper aeration and water drainage will also be satisfactory. If teak is planted on clay-soil then results will be stunted growth. Soil selection is very essential so that the trees get proper nutrients from the soil including minerals, carbon, hydrogen, oxygen, etc. Ancient manuscripts have also given taste of different soils and their suitability for different products.

- Seeds require maturity for best reproduction. Seeds from mature, well grown, seed bearers are recommended, because genes control plant growth, quality of wood and resistance to pests. Tissue culture is not mentioned in old literature. So I have no comparative comments. The traditional planters prefer planting of stumps as far as teak is concerned and they report very good results.

- Necessary treatments of seeds/saplings before planting to build up resistance to various pests and diseases have been advised in the manuscripts. They have specified various formulations like *Panchgavya, Jeevamrutham, Saptangor,* and *Dashaparna* extract and prescribed with directions for preparing them and using. The research done in their times are already been tried by so many farmers and reported wonderful results. As far as teak is concerned, dipping the saplings in diluted solution of *panchgavya*, speeds up the growth and imparts resistance to the roots against root destroying fungus.

- Providing suitable habitat is also crucial as described earlier. That is to say, selection of companion plants for healthy growth and atmosphere. I will only reiterate that *Vrikshayurved* is good understanding of relationship between diversity of trees and their effects for healthy growth of the entire colony of teak forests as such. The wood produced would be as good as natural forests.

- Watering schedules are suggested for different crops including describing of dry periods without which heartwood formation will be delayed. This time schedule for watering will depend on the soil, the gradient, the monsoon period, whether single or double monsoon and also the temperature variations for different seasons.

- At present in folk tradition, there are water diviners in mofussil areas. They are experts in locating flow of water underground with the help of a copper wire. The manuscripts have given guidance about how to locate water with the probable deft of the water with the quantity expected from superficial observation of the site based on existing plants on the site. This information can be very helpful while selecting sites for planted teak forests.

- Plant growth enhancers and various formulations have been prescribed and some of them are already being used by organic farmers in our country. Some have even been improved upon for better results and I have seen them work wonders.

Here, I can only mention that wealth of research has been left for us by the ancient *Rishis* of vedic times. *Vrikshayurved* is referred in as early period as '*Rigved*'. We all should draw the best we can use and improve the quality of teak and improve economic benefits for planters, consumers and most of all environments. Let more birds, bees, worms, cattle, butterflies return to the plantation sites and add to our economic benefits.

Model farms can be set up to test the validity of discovered knowledge. Good wood will allow qualitative processing for which there will be no dearth of market. All will be happy, the producer, the manufacturer and the ultimate buyer.

Wood Property Survey of Indian Teak Provenances

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ABSTRACT

Wood property survey was conducted to assess the differences in growth rate (ring width and dbh), heartwood content and basic wood density among 23 Indian teak provenances. Study material originated from 81 trees, representing five age groups of natural growth and plantations, which covered 23 geographic locations including the moist and dry deciduous forests in different Indian states, viz., Madhya Pradesh, Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh, Kerala, Gujarat, Orissa, Chattisgarh and Rajasthan. Wood samples were extracted from breast height level in the form of 5-10 cm cross sectional discs and increment cores for wood property analysis. The distinct age groups of teak trees sampled were: Age Group I (20-29 years); II (30-39 years); III (40-49 years); IV (50-59 years); V (60 -69 years). The dbh increased with age and the mean ring width (growth rate) decreased after the initial increase up to 40-49 years in contrast to the significant increase in heartwood percentage up to 30-39 years. However, for a given age group, dbh and heartwood percentage varied considerably among the geographic locations implying the role of provenance in determining growth rate and heartwood content. The higher growth rate with mean ring width >4.7 mm and greater heartwood content (>90%) were noted in trees grown in southern states like Kerala, Tamil Nadu and Karnataka (including Teli variety). Wood colour varied among the provenances from yellowish brown to light yellowish brown or dark yellowish brown and occasionally brown to dark brown. Wood density did not vary with age consistently while the densest and lightest wood recorded was from Banaswara (Rajasthan) and Khariar (Orissa), respectively.

Keywords: Wood properties, teak provenance, heartwood content, colour, growth rate, ring width.

INTRODUCTION

Teak (*Tectona grandis* Linn.f.) belongs to the family Verbenaceae which is predominantly tropical or subtropical in distribution (Tewari, 1992). Teak is known to occur naturally in four Asian countries, viz., India, Laos, Myanmar and Thailand. As teak is a good tree to be raised in plantations, it has recently been recommended for production of quality timber from sustainable plantation management in the tropics (Bhat *et al.*, 2005).

Indian region is considered to be the only known centre of genetic diversity and variability of teak with distribution over 8.9 million hectares. In India teak is distributed naturally in the peninsular region below 24^{o} latitude (Tewari, 1992) and the most important teak forests are found in the states of Madhya Pradesh, Maharashtra, Tamil Nadu, Karnataka, Kerala, Uttaranchal, Gujarat, Orissa and Rajasthan. Teak is known to display wide variations in the wood characteristics among different growing conditions and regions in India

(Bhat and Indira, 1997). Enough evidences are available from different parts of the world to show that plantation grown teak is not inferior to naturally grown timber in strength properties. However, in some localities natural teak shows superiority or vice versa (Nair and Mukherji, 1957; Sekhar *et al.*, 1960; Sono and Rativanich, 1965; Weimann, 1979; Durand, 1983; Sanyal *et al.*, 1987; Shukla and Mohan Lal, 1994; Tint, 1995).

Teak is known to exhibit wide geographic/ provenance variations in India with regard to wood figure and strength properties (Tewari, 1992). The Malabar teak (Nilambur, Kerala) from the Western Ghats region in India, generally displaying good growth and log dimension with desired wood figure (golden yellowish brown colour), has a wide reputation in the world trade for ship building. The central Indian teak from the drier region is reputed for better tree form, deeper colour and twisted or wavy grain, although it is stated to be often 7-8% lighter than South Indian and Myanmar teak. The slow growing trees in drier localities, which resist forest fire and tend to develop twisted/ wavy grain are known to yield heavier, stronger and close grained wood with beautiful figure. From a preliminary study, it was found that percentage of logs with flutes and knots was greater in generally quicker growing location (Nilambur) than in slow-growing area (Konni, Kerala) in India (Balasundaran and Gnanaharan, 1997). However, recent study reported greater genetic diversity in the teak populations of the Western Ghats region than in Central India (Nicodemus *et al.*, 2003). Without considering the provenance as a source of variation, earlier studies reported contradictory findings with regard to the relationship between growth rate and wood properties in teak (Bourdillon, 1895; Choudhury, 1953; Mukherji and Bhattacharya, 1963; Bryce, 1966; Rao *et al.*, 1966; Bhat, 1998; Bhat and Priya, 2004).

Teak of different origins is considered to vary in height, growth rate and stem form. There are also differences in the physical properties of the timber. Thus Central Indian teak is reputed to possess a better form and deeper colour than the teak from the West Coast, which closely resembles Myanmar teak in its properties. Limaye (1942) found Central Indian teak to have slow growth and 7-8 percent lighter wood than Myanmar or South Indian teak. Several studies reported variations in percentage of heartwood, colour, durability and mechanical properties depending on ecological conditions (Kokutse *et al.*, 2004; Moya *et al.*, 2003; Bhat *et al.*, 2005). Fast grown teak is not always inferior in timber properties as there is scope to maintain optimum timber strength (Bhat and Indira, 1997; Bhat, 2000).

Some of the earlier studies showed negative correlation between growth rate and wood density and the general notion among the teak wood users is that fast grown tree produces only light, weak and spongy wood (Choudhury, 1953; Bryce 1966). In contrast, Bhat *et al.* (1987) indicated 14% higher wood density for faster growing dominant trees than suppressed trees of the same stand. Many authors reported that wood density and strength properties were superior in fast grown ring porous species (Nair and Mukherji, 1957; Harris, 1981). The controversy over the effect of growth rate on wood quality persists even among other ring porous timbers of temperate zone. For instance, Wheeler (1987) reports a positive correlation between growth rate and wood density arguing that wider rings contain more latewood with fewer vessels. Earlier studies based on teak samples obtained from different countries such as Bangladesh, India and Myanmar indicate that the strongest wood is produced from a modest annual radial growth of 4-5 mm (Limaye, 1942).

The colour and markings of the heartwood also vary considerably with locality (Tewari, 1992). The colour of wood differs widely among species and also within a tree. It is an important factor for end-user to consider and the price of wood is often dependant on its colour parameters. The wood colour along with other quality parameters such as poor log form, visual defects such as bends and sound knots and low sawn timber output from dry site might influence the price of the teak timber from home-garden forestry (Thulasidas *et al.*, 2006). Altitude also plays a decisive role in growth and establishment of natural regeneration of teak. Teak does not normally grow above 900 m of altitude and infact the vigour of the tree decreases above 750 m (Takle and Mujumdar, 1956).

The objective of the present study was to assess the wood property variations among Indian teak provenances with reference to growth rate, heartwood proportion, colour and basic density.

MATERIAL AND METHODS

Study material originates from 82 trees of various ages, sampled from plantations and natural teak growing areas in twenty three localities of India (Table 1, Figure 1), including the moist and dry deciduous forests of Madhya Pradesh, Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh, Kerala, Gujarat, Orissa, Chattisgarh and Rajasthan. The girth was measured at breast height and wood core samples were collected from the outermost growth increment to the inner core near pith. As soon as the samples were collected, they were wrapped in polythene bags and taken to the laboratory for wood density determination by gravimetric method. The density of wood was measured on oven-dry (OD) weight to green volume basis. The green volume was measured by water displacement method.

Core length from cambium to pith was measured in millimeters and used as the stem radius inside bark (R). The number of growth rings from cambium to pith (NR), which is also used to determine age of trees at breast height, was counted. The sapwood–heartwood boundary was sharply defined by heartwood colour. Heartwood width (HW) was measured in millimeters. Other variables related to heartwood and radial growth were computed from the measured variables: sapwood width ($SW = R - HW$), heartwood percentage ($HW\% = 100 \times HW^2/R^2$), and average ring width or radial growth rate ($GR = R / NR$).

Wood colour variation was studied using the Munsell notation (1976), the visual matching method. Accurate comparison was obtained by holding the wood sample directly behind the apertures separating the closest matching colour chips. The colour was then identified by its hue, value and chroma. The symbol for hue is the letter abbreviation of the colour of the rainbow (R for red, YR for yellow-red, Y for yellow) preceded by numbers from 0 to 10; indicates its relation to red, yellow, green, blue and purple. The notation for value consists of numbers from 0, for absolute black, to 10, for absolute white; indicates its lightness. The notation for chroma consists of numbers beginning at 0 for neutral grays and increasing at equal intervals to a maximum of about 20; indicates its strength (or departure from a neutral of the same lightness).

The collected wood samples were grouped into five age classes (I –V) for studying the selected properties such as diameter at breast height, percentage of heartwood, average ring width, density and colour as shown in Table 2.

Table 1. Field sampling locations representing different regions/states in India

Location	Geographic position		Elevation (m)
	North latitude	East longitude	
Kerala			
Thamaravellachal	10^0 35’ 51.19"	76^0 25’ 29.89"	80
Vazhani	10^0 46’ 31.255"	76^0 13’ 11.355"	58
Nilambur	11^0 12'-11^0 32'	75^0 82'-76^0 32'	35
Parambikulam	10^0 26' 52.3"	76^0 48' 22.5"	560
Arienkavu	8^0 59' 18.4"	77^0 07' 28.6"	381
Konni	9^0 3'-9^0 85'	76^0 41'-77^0 6'	31
Karnataka			
Doddaharve	12^0 24’ 10.301"	75^0 57’ 35.877"	877
Dandeli	15^0 15’ 9"	74^0 37’ 53"	480
Tamil Nadu			
Ashambu	8^0 22’ 55.009"	77^0 18’ 50.21"	200
Andhra Pradesh			
Adilabad	19^0 18' 25.2"	78^0 33' 51.5"	356
Bhadrachalam	18^0 31' 30.8"	80^0 57' 50.1"	181
Rajasthan			
Banaswara	23^0 44' 54.3"	74^0 30' 04.3"	225
Baran	24^0 51' 28.5"	76^0 46' 39.8"	308
Maharashtra			
Pench	21^0 34' 23.3"	79^0 17' 33.7"	460
Allapalli	19^0 24' 51.5"	80^0 04' 55.5"	157
Gujarat			
Rajpipla	21^0 35' 48.5"	73^0 44' 0.5"	403
Valsad	20^0 45' 19.4"	73^0 27' 44.3"	164
Madhya Pradesh			
Dewas	22^0 25' 26.9"	76^0 21' 35.5"	227
Burgi	22^0 56' 44.6"	79^0 47' 11.1"	376
Chhattisgarh			
Chouki	20^0 41' 34.7"	80^0 43' 41.2"	382
Basthar	18^0 50' 57.3"	82^0 07' 41.3"	489
Orissa			
Berbera	19^0 51' 51.6"	85^0 01' 44.5"	213
Khariar	20^0 06' 18.7"	82^0 24' 25.5"	300

RESULTS AND DISCUSSION

The dbh increased with age and the mean ring width (growth rate) decreased after the initial increase up to Age Class II (30-39 years) (Figure 2). The variations in both dbh and ring width in relation age were however significant (Table 2). Heartwood percentage stabilized after the significant initial increase up to the Age Class II while basic density did not show consistent pattern of variation although 60-69-year-old trees (Age Class V) had slightly less denser wood. However, for a given age group, dbh and heartwood percentage varied considerably among the geographic locations implying the role of provenance in determining growth rate and

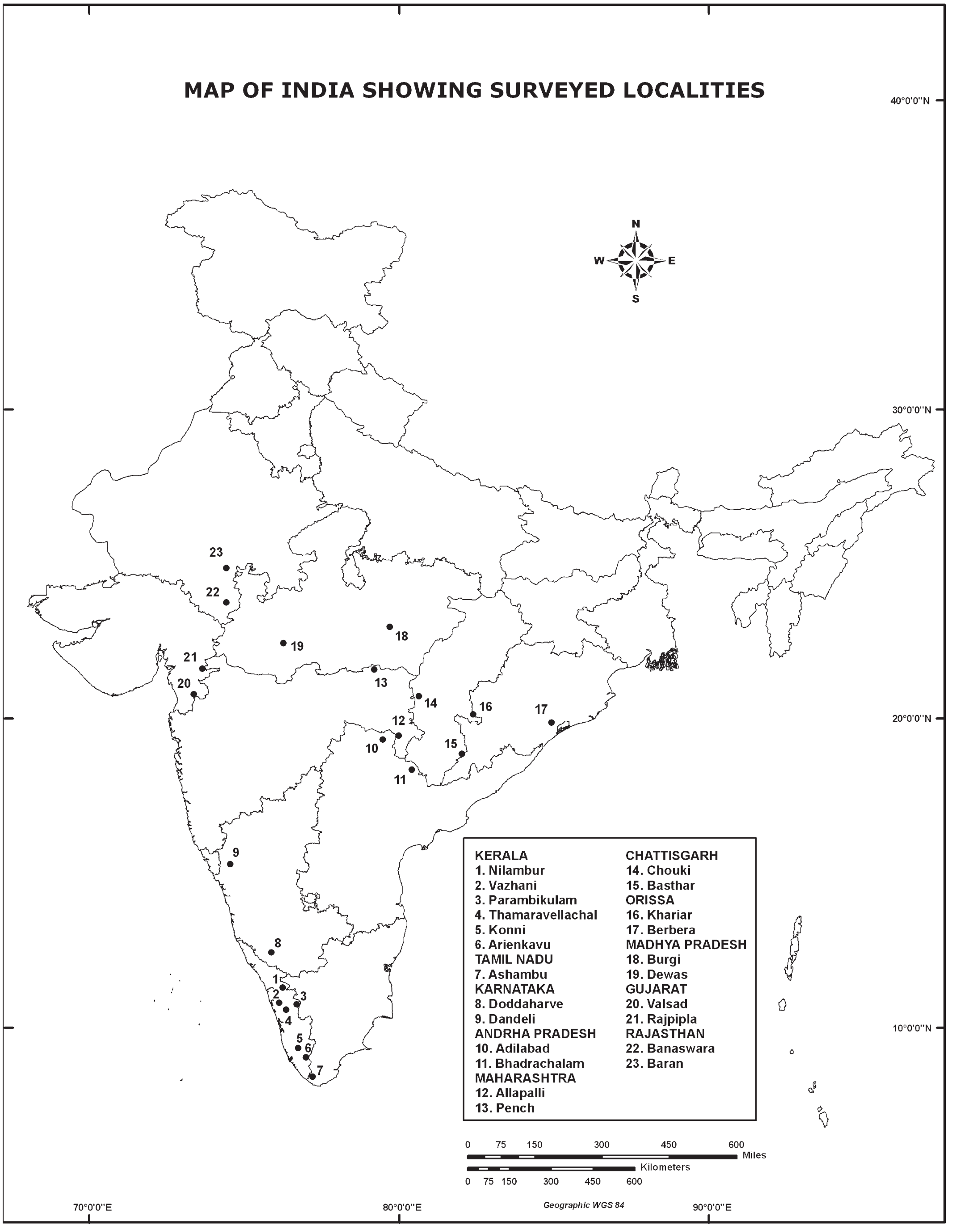

Fig. 1. Geographic locations of the trees sampled from among the 23 Indian provenances

Table 2. Comparison of selected properties of teak from different Age classes and Geographic locations

Age class	Location	Property			
		Dbh (cm)	Heartwood %	Average ring width (mm)	Density (kg/m³)
	Baran	17.0	51.5	3.5	668
Age I (20-29-yr)	Nilambur	20.9	61.3	5.0	628
	Basthar	22.0	72.8	5.0	659
	Mean	**20.0**	**61.9**	**4.5**	**652**
	Basthar	20.0	70.2	2.9	540
	Berbera	23.0	83.4	3.6	668
	Dewas	36.2	84.3	5.1	608
Age II (30-39-yr)	Dandeli	34.0	91.6	4.7	539
	Khariar	35.0	80.5	4.9	524
	Adilabad	41.4	92.6	5.9	653
	Rajpipla	50.3	87.5	7.0	556
	Valsad	43.8	88.8	6.6	564
	Mean	**35.5**	**84.9**	**5.1**	**582**
	Valsad	44.2	88.4	5.1	650
	Rajpipla	47.0	89.1	5.4	596
	Banaswara	38.6	83.9	4.5	692
	Chouki	31.0	71.1	3.5	569
Age III (40-49-yr)	Nilambur	62.1	94.9	7.6	554
	Bhadrachalam	30.3	90.8	3.2	618
	Pench	36.6	87.1	3.9	663
	Allapalli	35.0	88.6	3.6	626
	Dewas	44.6	85.7	5.2	636
	Basthar	30.5	68.8	3.2	669
	Mean	**40.0**	**84.8**	**4.5**	**627**
	Allapalli	51.7	87.9	4.8	644
	Burgi	38.0	80.6	3.7	627
	Thamaravellachal	67.9	91.4	5.9	657
	Vazhani	51.3	88.1	4.9	577
	Nilambur	70.1	92.8	6.6	632
Age IV (50-59-yr)	Ashambu	53.2	90.6	5.0	660
	Adilabad	38.2	86.1	3.3	583
	Bhadrachalam	39.3	87.4	3.5	615
	Pench	27.4	82.6	2.4	627
	Rajpipla	43.0	86.5	4.2	633
	Mean	**48.0**	**87.4**	**4.4**	**626**
	Adilabad	42.3	80.5	3.2	624
	Thamaravellachal	68.8	89.9	5.3	638
	Pench	34.7	80.9	2.7	608
	Nilambur	62.5	90.8	4.5	592
	Ashambu	53.0	89.9	4.0	626
	Doddaharve	56.6	86.7	4.4	608
Age V (60-69-yr)	Arienkavu	43.3	82.8	3.3	557
	Konni	34.4	86.1	2.6	584
	Parambikulam	60.1	90.5	4.5	673
	Allapalli	54.1	89.7	4.3	538
	Vazhani	69.1	90.0	4.6	614
	Bhadrachalam	46.9	87.0	3.0	585
	Mean	**52.2**	**87.1**	**3.9**	**604**

Table 3. Colour variation in teak samples from different geographic locations

Location	Munsell system			Colour
	Hue	Value	Chroma	
Thamaravellachal	10	4	4	Dark yellowish brown
Vazhani	10	5	4	Yellowish brown
Nilambur	10	4	4	Dark yellowish brown
Parambikulam	10	4	3	Dark brown
Arienkavu	10	5	6	Yellowish brown
Konni	10	5	6	Yellowish brown
Doddaharve	10	5	3	Brown
Dandeli	10	4	4	Dark yellowish brown
Ashambu	10	5	3	Brown
Adilabad	10	6	4	Light yellowish brown
Bhadrachalam	10	5	4	Yellowish brown
Banaswara	10	4	4	Dark yellowish brown
Baran10	4	4		Dark yellowish brown
Pench	10	4	4	Dark yellowish brown
Allapalli	10	4	4	Dark yellowish brown
Rajpipla	10	4	4	Dark yellowish brown
Valsad	10	4	4	Dark yellowish brown
Dewas	10	4	3	Dark brown
Burgi 10	4	4		Dark yellowish brown
Chouki	10	4	4	Dark yellowish brown
Basthar	10	4	4	Dark yellowish brown
Berbera	10	5	4	Yellowish brown
Khariar	10	4	4	Dark yellowish brown

heartwood content (Table 2). The higher growth rate with mean ring width >4.7 mm and greater heartwood content (>90%) were noted in trees grown in southern states like Kerala, Tamil Nadu and Karnataka (including Teli variety). Wood colour varied among the provenances from yellowish brown to light yellowish brown or dark yellowish brown and occasionally brown to dark brown. (Table 3). The teak samples collected from drier localities of central parts of India were darker in colour than South Indian provenances and Adilabad (Andhra Pradesh) teak which was lighter. Wood density did not vary with age consistently while the densest and lightest wood recorded was from Banaswara (Rajasthan) and Khariar (Orissa), respectively.

The results also show positive correlation between age and dbh and between age and heartwood percentage (Figure 3). However, wood density did not correlate with age. Growth rate increases with age in the trees upto 39 years age and then decreases. However, the results show variation in dbh and heartwood percentage of teak samples in the same age class collected from different ecological zones and it means ecological zone has an important role for determining the wood quality. The results also show the highest heartwood percentage in teak samples of Nilambur (Kerala) and highest density in teak samples of Banaswara (Rajasthan). The lightest wood was noted from Khariar (Orissa).

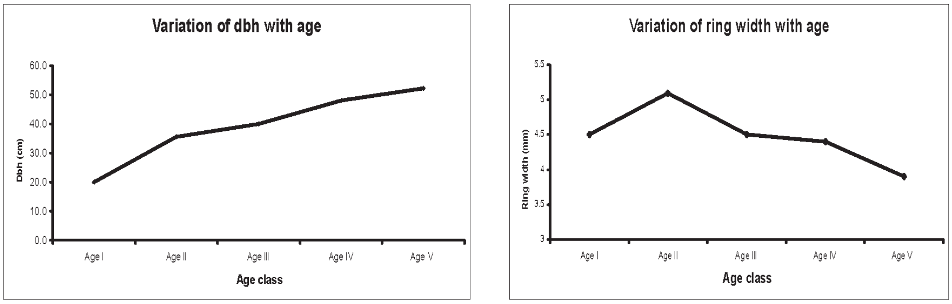

Fig. 2. Diameter at breast height (dbh) and mean ring width in relation to age groups

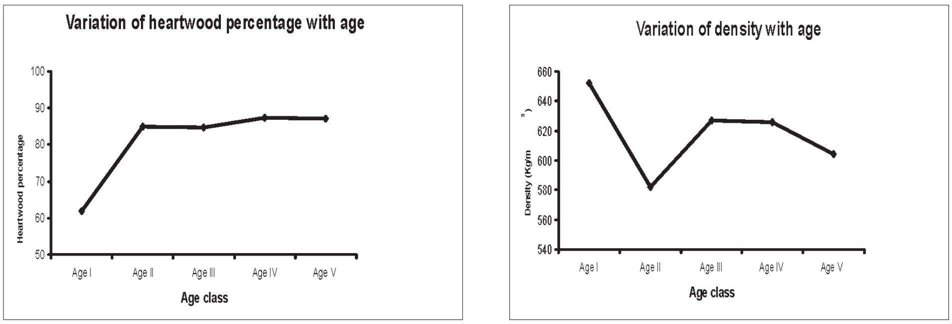

Fig. 3. Heartwood percentage and basic density in relation to age groups

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Processing and Marketing of Teak Wood Products of Planted Forests pp 126 - 128

Teak Farming: Grower's Experiences from Karnataka State, India

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ABSTRACT

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. Observations on growth of teak planted in farmlands with tree age varying from 3 to 14 years and initial spacement of 2 x 1-5 m and 2 x 2m are presented in this paper. Seed sources of these trees are Nilambur (Kerala), and local provenances including Shimoga (Karnataka). The results indicate that irrespective of seed sources, wider espacement favours girth increase. Although irrigated trees grew faster with greater heights, they showed a tendency of bending more with wind often resulting in weaker stems and stunted growth at later stage. With the close espacement of 1 x 1 m, trees produced straight and narrow stems. In less fertile land with no irrigation facilities, growing of cover crops was beneficial for tree growth. Sandy red or black soil seems to be ideal although fast growth is recorded in river beds. Lateritic or fine textured soil is not so favourable for teak growth. Green manuring in the beginning of the monsoon enhances the tree growth to the extent of doubling the wood volume. Teak grows better in well drained soil of the land with slight sloping. Therefore, digging 0.5 x 0.5 m trenches with a depth 1 m in waterlogged areas would be beneficial. As the root system of teak spreads mostly along the subsurface layer of soil, soil working will have added advantage for better aeration and tree growth. In wet and shaded sites, pest and diseases were more frequent in the early stage after planting. In younger trees, oozing of sticky fluid from nodal regions is often a major problem although with aging, it gets reduced. As the live crown facilitates greater girth, good proportion of live crown needs to be maintained if pruning treatment is given. The role of teak farming in rural development and poverty alleviation is also discussed. For the benefit of farmers, training programmes on intervention of more appropriate and modern technology in teak farming are suggested.

Keywords: Farm practices, growth rate, income generation, teak farming, poverty alleviation, rural development.

INTRODUCTION

Conventionally in Dakshina Kannada District of Karnataka, India the main agricultural practice is growing annual crops like rice, vegetables and often commercial crops of arecanut, 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.

There are five distinct varieties of teak used for planting. The differences may be due to their seed origins/ provenances:

- Local provenance: Seems to be a good variety which grows fast and straight
- Another source was the supply by the Karnataka Forest Department: Tender leaves are reddish; leaves relatively small in size; relatively slow growth of the trees
- Another variety where ventral surface of the leaf is greyish, Growth is average; tender leaves are reddish yellow.
- Large –leaved tree. Leaves are relatively smooth. Average growth rate is recorded
- 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.

Non-governmental Oraganisations like *Bharathiya Kisan Sangh* encourage Nilambur provenance for high quality timber. The efforts of the Kerala Forest Research Institute in supplying quality stumps on a large scale to farmers of Dakshina Kannada District of Karnataka is appreciated.

Mangala Farm has two 8-year-old plantations with 2000 and 4000 trees in two locations. Average height of the trees is about 10 m with a diameter of 45 cm. Espacement is 2.5 m x 2 m. In each plantation, organic manuring is practiced by composting in trenches. The trees grow well only if there is open canopy to receive good sun light and wind.

When pure plantation is established, it needs adequate manuring like any other agricultural crop such as arecanut, coconut, etc. In the first year after planting, treatment with cowdung mixture with leaf litter or with NPK of about 100 g per plant favours establishment and the quantity needs to be increased year after 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.

In this paper we present the results of measurements taken in two different farm lands.

RESULTS AND DISCUSSION

Growth observations were made in teak trees planted in our farmlands with tree age varying from 3 to 14 years and initial espacement of 2 x 1-5 m and 2 x 2m. Seed source of these trees represented Nilambur (Kerala), and local provenances including Shimoga (Karnataka). The results are presented in Table 1.

The results indicate that irrespective of seed sources, wider espacement favours greater girth of the trees.

Some of our important observations are given below:

- Although irrigated trees grew faster with greater heights, they showed the tendency of bending more with wind often resulting in stunted growth at later stage and weaker stems.
- With the initial close espacement of 1 x 1 m, trees produce straight and narrow stems. For higher girth and effective pruning, wider espacement by mechanical thinning is recommended after the initial period of 3-4 years after planting.
- In less fertile land with no irrigation facilities, growing of cover crops would be beneficial for tree growth.
- 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 soiled is not so favourable for teak growth

Table 1. Growth performance of different teak provenances in farmlands of D K District, Karnataka

Seed Source	Age (yrs)	Tree No.	Height (m)	Girth at breast height (cm)	Planting espacement (m)
Nilambur, Kerala	3	1	12	35	Boundary trees
	13	1	10	41	2 x 1.5
	13	2	10	41	2 x 1.5
	13	3	11	44	2 x 1.5
	13	4	12	52	2 x 1.5
	13	5	12	53	2 x 1.5
	13	6	12	55	2 x 1.5
Shimoga, Karnataka	14	1	12	55	2 x 2
	14	2	12	69	2 x 2
	14	3	12	66	2x 2
	14	4	12	68	2 x 2
		Mean	**13**	**60**	

- Green manuring in the beginning of the monsoon period will enhance the tree growth to the extent of doubling the wood volume.
- Teak grows better in well drained soil of the land with slight sloping. Therefore, digging 0.5 x 0.5 m square trenches with a depth 1 m in waterlogged areas would be beneficial.
- As the root system of teak spreads mostly on the upper layer of soil, soil working will have added advantage for better aeration and tree growth.
- In wet and shaded sites, pest and diseases were more frequent in the early stage after planting.
- In younger trees, oozing of sticky fluid in nodal regions is often a major problem although with aging it gets reduced.
- As the live crown facilitates greater girth, good proportion of live crown need to be maintained if we give pruning treatment

Training Needs for Farmers

For the benefit of farmers, training programmes on more appropriate and modern interventions in teak farming are needed in the following lines to improve the wood quality:

a) Enhancement of wood density of fast grown teak

b) Wood quality prediction of standing trees by non-destructive methods.

c) Technology for reducing the bole taper for more uniform girth of logs.

d) Simple and easy techniques for determination of soil properties and other critical environmental factors as significant differences are noticed in tree growth and wood quality from site-to-site.

e) Role of "*Vrikshayurveda*" in wood quality improvement. For instance, the influence of solar and lunar rhythms and planets on teak seed germination and tree harvesting.

f) Intensive knowledge of medicinal values of teak trees.

Role of teak farming by NGOs and Self Help Groups (SHG) in rural development

In DK District of Karnataka, each village has about 40 Self Help Groups (SHG), with an average of 6 members, in about 400 villages accounting for a total of 16000. Even if each member can grow 5 trees in the house compound with a casuality rate of one tree, 4 trees can fetch at least Rs. 134,831 (US$ 3288) after 25 years. This will generate an average district income Rs. 13 billions (US$ 323 millions) after 25 years implying that teak farming contributes significantly to poverty reduction and rural development.

Vanilla Cultivation in Teak Plantation: Varanashi Experience

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ABSTRACT

At Varanashi Farms in Dakshina Kannada District of Karnataka State, India, teak is grown under irrigated conditions as an intercrop with coconut. Both coconut and teak were planted in the year 1989 in a field measuring 57 x 57 m. The teak grew too fast and suppressed the coconut. After seven years, vanilla was introduced at a spacing of 2.3 x 2.3 m with *Glyricidia* as support plant. Vanilla adapted well and started yielding after three years. The deciduous nature of teak supports and matches with stress requirements of vanilla during winter. Vanilla is giving 0.2 kg average dry yield per plant. The teak plants have been periodically removed and the present density is 227 plants per hectare. The 17 -year -old teak trees have attained an average girth of 0.89 m. The plantation receives weekly sprinkler irrigation during summer. Black pepper, planted a few years ago, is slowly establishing in the plot. The entire field has been under organic farming from the beginning.

Keywords: Vanilla, organic farming, irrigation, coconut, black pepper.

INTRODUCTION

Teak, when cultivated with manure and irrigation, can grow and put up the girth much faster than in the natural condition. Even then a period of 25 - 30 years of time is required for harvesting. Vanilla, a tropical orchid, grows on a support plant under shade. Pods of vanilla are much valued for aromatic spice. It starts yielding within 3 years of planting. This paper describes a farmer's experience of growing vanilla under teak.

MATERIALS AND METHODS

Varanashi Farms (VF), Adyanadka is situated in the South west side of Karnataka state, India and is about 25 km away from the Arabian Sea. The farm is certified organic by SKAL International and is growing various combinations of mixed crops both perennial and annual.

Climate, topography and soil

Adyanadka is at 120 m above MSL. The land is undulating with small hillocks. The weather data of the region is given below:

Annual rainfall: 2800 mm (mostly from June to November)

Temperature: Maximum; 28-35°C

Minimum; 18-24°C

Humidity: 60-90%

Soil: Sandy loam

pH range: 5.6 – 6.5.

Organic matter: high

Available phosphorus: low

Available potash: medium

Vanilla cultivation in teak plantation – a rare combination tried at VF

An old rice field measuring 57 m x 57 m (0.33 ha) was converted into a coconut cum teak plot in the year 1989. Coconut was planted at 9 m x 9 m spacing. Teak was grown in rows running both ways at the centre of coconut with a spacing of 3.3 m. Teak was planted in a pit of 0.75 m x 0.75 m x 0.75 m size, filled with farmyard manure. Coconut and teak, both received equal importance. Initial 2 years, teak has received some chemical manure and only organic since 1991. Teak started growing rapidly and suppressed coconut because of faster attainment of height. After 7 years vanilla was introduced, initially in 4 corners of teak at about 0.4 m distance with gliricidia as support. In subsequent years the remaining gap was also filled by glyricidia as standard with a spacing of 2.3 m x 2.3 m and vanilla was planted. The vanilla plants received regular care as per organic farming principles (Ashwini Krishna Moorthy and Varanashi Krishna Moorthy, 2004).

RESULTS

The establishment of vanilla was quite good when grown under the teak plants. It took 3 years for the commencement of yield. As the teak started crowding, the population was reduced by removing weak plants. The height of tree was also restricted by pruning the top at about 9 m height. As on August 2007, 74 teak plants and 398 vanilla vines on glyricidia are present in this plot. Coconuts are also kept without removing. Pepper has been planted in between teak and coconut trees to make the plot more mixed.

In case of vanilla mixed planting, no plant wise data was maintained. The over all picture is presented in Table 1.

Table 1. Performance of teak and vanilla

Crop	Growth/ yield
Teak (Girth)	0.89 m
Vanilla (yield in kg)	0.20 kg

As on June 2007 the average girth of teak at 1.10 m height was 89 cm with a range of 62 to 126 cm. The average yield of dry beans of vanilla during the past 5 years was 0.2 kg per plant.

DISCUSSION

The first author has been growing various forest plants since 1981. He found irrigated teak giving faster growth at Gandhi Krishi Vigyan Kendra (GKVK), University of Agricultural Science, Bangalore. But when mixed and planted with coconut, coconut got suppressed. However, these coconuts have been maintained without giving any additional manure. At present, they are used as support plants for pepper. After about 13 years of growth, coconuts also attained height and started giving 8 – 15 nuts per tree. Possibly, when teak is removed they are expected to give more profitable yield. Vanilla introduction was another trial and it has given desired result. The yield of 0.2 kg dry or 1.0 kg green vanilla pods per plant is quite attractive. Vanilla has adopted well under teak (Figure 1).

Fig. 1. Vanilla, pepper and teak

CONCLUSION

The deciduous nature of teak supports and matches with stress requirement of vanilla during winter. Thus the experiment has established the vanilla as a mixed crop to take return under teak – which otherwise would have prolonged gestation period.

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Forest Certification of Planted Forests Based on the Experience of Bhopal - India Process

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ABSTRACT

Managing planted forests by following sustainable forest management practices provides sound basis for balancing the interests of business organizations with that of society and the environment. Various initiatives on developing standards for Sustainable Forest Management (SFM) have emerged subsequent to Rio-earth summit on sustainable development. Among these initiatives, one of the pioneer work has been that of ITTO's Criteria and Indicators (C&I) for SFM of which Bhopal-India (B-I) Process is an offshoot. The Indian national set of C&I, after adaptations to local requirements, are being operationalised at the Forest Management Unit (FMU) level in 12 forest divisions in four states covering teak, sal and miscellaneous forests. Indian Institute of Forest Management (IIFM) has standardized the application of C&I of B-I process at FMU level which can be adopted for planted teak forests and would form sound basis for certification. Forest certification has emerged as a marketing toll for linking the good forest management (SFM) practices with the environmentally conscious consumers. Two globally recognized systems of Forest Certification namely – FSC (Forest Stewardship Council) and PEFC (Programme for Endorsement of Forest Certification Schemes) have been well accepted in the developed markets. The National C&I for SFM developed under Bhopal-India Process provides an opportunity to develop a national forest certification scheme for India. The forests (both natural and planted) can be assessed against these standards for seeking forest certification to facilitate better market access for timber harvested from these certified areas. Teak plantations in India, thus, have potential opportunity to benefit from such a national forest certification initiative emerging from Bhopal-India process.

Keywords: Criteria, indicators, sustainable forest management, forest certification, Bhopal-India process.

INTRODUCTION

Plantation forests play an increasingly important role in meeting the world's growing requirements for wood and non-wood forest products. They represent less than 3% of the world's forest resources, yet are estimated to supply around a third of industrial roundwood and 10% of fuelwood (ABARE, 1999).

Given the high GDP growth of plus 9% during 2002-2007 and corresponding increase in purchasing power, demand for timber is increasing at a much higher pace than the supply in India. Supply of timber, mainly from forest plantations and wood production, are showing a decreasing trend. Also the productivity of timber in India is only 0.7 m^3/ha/year whereas the world average is 2.1 m^3/ha/year. Thus India is likely to face severe shortage of supply of timber to meet its requirement from both domestic and international front. The total demand of timber has been estimated at 64 million m^3 in 1996, that increased to 73 and 82 million m^3 in 2001 and 2006 respectively. Out of 64 million m^3 demand of timber, nearly 31 million m^3 came from farm forestry and other woodlands and 12 million m^3 from forests. The balance 21 million m^3 was removed from plantations and natural forests, largely (70%) as small timber to meet the domestic need (FSI, 2006). The recorded timber removal from forests has declined to as low as 1.9 million m^3 (FAO, 2005).

The production of timber from forest areas is very small percentage of the total consumption and is further declining over the years (Figure 1). In the absence of adequate supply from domestic sources, the nation has to depend heavily upon

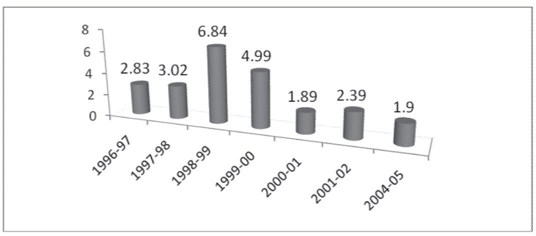

Fig. 1. Timber production from forests in India (million m^3)
Source: FAO Stat, FRA 2005

imports to meet its demand. This will result into the nation's forest footprint, particularly in Southeast Asia from where it is sourcing its timber supplies. In order to minimize the forest footprint, it needs to encourage consumption of certified timber by promoting sustainable forest management (Manoharan, 2007).

Forest plantation area (187 million ha) constitutes just 5% of the total world's forest area and 1.6% of the world's land area (13,064 million ha). Of the total plantation forest area at least 48% is used for industrial purpose and contributes to 35% of the global round wood supply in 2000 and would rise to 44% by 2020 and 46% by 2040 (ABARE, 1999). Industrial wood supply from plantations is projected to increase by 67% from 624 million m^3 in 2000 to 1043 million m^3 by 2040. Plantations also supply a range of non-wood products and services including fodder, cork, nuts and fruit, latex, tannin and oils and are used for recreation and environmental protection, such as soil and water protection **(**ABARE, 1999**).** The expansion of plantation area in India has been encouraging during all plan periods, particularly in the 9th Plan period (Figure 2).

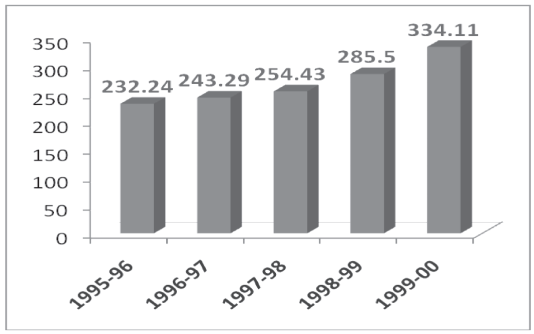

Fig. 2. Cumulative planted forest area in India over the years ('000 km^2)
Source: MOEF 1999, ICFRE, 2001

Natural forests have traditionally maintained a competitive advantage over plantation forests, given the high cost of intensively managing plantations. However, this gap is narrowing as a result of improvements in the productivity and efficiency of plantations, decreasing availability of wood from natural forests, and also the increasing cost of gaining access to these forests. Markets are recognizing the increasing competitiveness of plantations, mainly on account of risk-free assured supplies and uniform fibre quality (Hyde *et al.*, 1991). Japan (the world's leading importers of hardwood chips), for example, has increased its use of wood from plantations.

The increasing proportion of teak coming from plantation forests may avoid some environmental controversies related to over-exploitation of natural forests for teak production. But sometimes plantations also attract criticism, mainly from environmental and social groups. Although not specifically targeted, teak plantations have been included in general anti-plantation campaigns which are based on the premise that plantations - especially monoculture plantations - tend to have lower levels of biodiversity than natural forests and may also be more susceptible to catastrophic damage, especially from pests and diseases, wind, storms and fires **(**Pandey and Brown, 2000*)***.** However, most of the environmental criticisms directed at teak plantations are the result of inappropriate management techniques rather than irrevocable plantation characteristics. Also, in a number of countries, mixed plantations are being established to provide better soil cover and stability, to increase biodiversity and to reduce commercial risks.

As the demand for forest products is likely to increase significantly and the area of natural forests available for harvesting is not expected to increase (now almost exclusively from Myanmar and India), and may even decrease, there will be more timber sourced from plantations. Although plantations require a high initial investment cost, increasing harvesting and transport costs in natural forests are making plantations more cost-competitive in the supply of timber. As against many other land uses, plantation development is considered a long term investment (with rotation lengths ranging from five to over fifty years) and can result in economic, environmental and social costs and benefits. Plantation managers can improve the economic benefits by careful selection of species and provenances and by using silvicultural regimes that increase wood production and improve returns to the investors.

The social benefits of plantations include employment, infrastructure development (such as roads, communications, and housing) and generation of byproducts (such as fuelwood and other non-wood products to remote areas). Thus governments have encouraged the establishment of plantations to achieve a range of economic and social objectives, including the development of rural economies. Negative social impacts of plantations usually reflect reduced access to forests for local people and limited rights to use land for traditional activities.

However, plantations are also associated with potential environmental costs such as simplification of ecosystems, sedimentation, pollution from fertilisers and weedicides, and the rise of disease and pest incidence (with a potential impact on surrounding land uses). Problems can also arise if plantations reduce the availability of water for other uses (Pandey and Brown, 2000). A balanced consideration of economic, social and environmental factors in the planning and management of plantations can ensure maximization of benefits to the investors and the local communities and minimization of social and environmental costs. Sustainable forest management practices coupled with third party verification can address the same.

Forest certification has emerged as a marketing tool for linking the good forest management (SFM) practices with the environmentally conscious consumers. One of the first certification initiatives has been that of Forest Stewardship Council (FSC) initiated by plantation companies, timber traders, NGOs etc. In 1993 Forest Stewardship Council (FSC) also proposed a conceptual model that

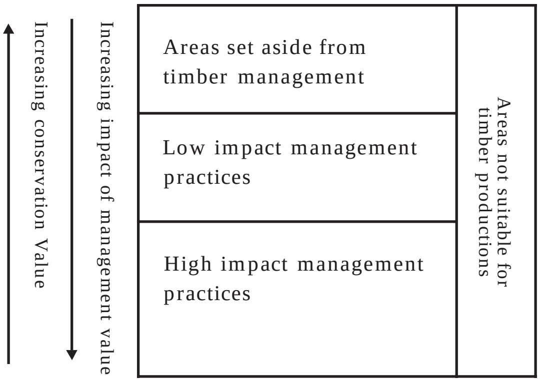

Fig. 3. FCS model guideline for plantations

addresses the environmental concerns into plantation management practices as depicted in Figure 3. The model is intended to describe the potential and actual impacts of the applied management practices on the ecosystem and how these effects are prevented, mitigated or remedied. It also describes how the choice of management practice is linked and tailored to existing conservation values. In describing the strategy to maintain ecosystem integrity within a management unit, the management practices should be listed and slotted into the model according to their level of impact on the ecosystem, with the corresponding relative area in which the practice occurs (FSC, 2003; 2006).

Forest Certification of teak plantations by companies and countries supplying markets in Europe and North America, where the interest in certified forest products is highest, may find a cost-effective option for increasing their market shares. Since teak is generally targeted at high-value niche markets, forest certification adds to the attractiveness and viability of teak plantations. The area of teak forests with internationally recognized certification appears relatively small, as suggested by the fact that plantation forests in general have been certified, according to standards set by the Forest Stewardship Council, in only four of the 35 countries currently known to be growing teak: Costa Rica, Indonesia, Panama and Sri Lanka.

SUSTAINABLE FOREST MANAGEMENT AND BHOPAL – INDIA PROCESS OF C& I

Forests provide tangible and intangible benefits to human beings since time immemorial. The direct benefits attract the attention of human beings and often lead to overexploitation of forests that adversely affects the sustainability of forest resources. At the first Earth Summit at Rio in 1992, the world leaders realized that there should be a management regime for forests that would ensure their sustainability and thus evolved the concept of sustainable forest management. Since then the Sustainable Forest Management (SFM) is globally recognized as an integral part of sustainable development. SFM deals with multiple objectives of forest management, encompassing environmental, economic and socio-cultural dimensions. International Tropical Timber Organisation (ITTO) was the first organization to develop the Criteria and Indicators (C&I) approach for the purpose of assessing sustainability of tropical forests. Currently more than 160 countries are actively participating in one or more of 9 internationally recognized processes for SFM in the development of C&I for SFM (Castenada, 2000).

The concept of sustainable forest management is not new to India because in India scientific management of forests is in practice since 19th century. In India the National Forest Policy, 1988 and the National Forestry Action Plan, 1999 envisaged sustainable management of forest resources involving communities. However, despite good policy framework and scientific management, the forest resources in the country have degraded over the period on various accounts, i.e., low forest cover, poor productivity, biodiversity loss, etc. Many factors, beyond control of forest managers, such as high incidence of fire, grazing and over-exploitation for fuelwood, timber and non-wood forest produce are some of the causes of forest degradation in the Country.

Following the global initiatives, India (through Indian Institute of Forest Management) took the initiative of developing C&I for sustainable forest management in the Country. It was through the Bhopal-India Process in 1998 at IIFM, that the first-ever-national set of C&I for SFM was developed. This process was supplemented by recommendations of the National Task Force (1999), Government of India. It has roots from one of the internationally recognized process for SFM, the Dry Forest Asia initiative involving nine Asian countries in 1999. This process developed a national set of 8 Criteria and 43 Indicators at national level after extensive consultation involving various stakeholders. The B-I Process has much strength:

- Developed by involvement of a large number and all types of stakeholders across the country and thus has wide acceptability.
- Is in consonance with the Indian Forest Policy.
- Recognized by Govt. of India (National Working Plan Code, 2004)
- Has semblance with the recognized international initiatives of SFM
- Is suitable to Indian forestry situations.
- Encompasses all the three aspects of sustainability- ecological, economic and socio-cultural.
- Has developed operational strategy and field application model.
- Is flexible for development of site-specific set of indicators according to specific forestry situation at FMU level.
- Is based on ‘bottom-up’ approach involving the communities.
- Indicators are simple, scientifically robust and the relevant data / information can be collected by involving communities at FMU level.
- Does not require high technology and huge expenditure.
- Is incorporated in the National Working Plan Code 2004 and that most of the indicators are already covered in it for which the data / information is already collected during preparation of the working plans.

The national level set of C&I developed under Bhopal-India Process, revised in 2005 (IIFM, 2005), is given in Table 1.

APPLICATION OF B-I PROCESS IN NATURAL TEAK FOREST

IIFM-ITTO Project at IIFM Bhopal has been attempting to field test the indicators developed under B-I process. The 8 criteria of B-I process are taken as common with the national set of C&I while indicators are flexible and have been modified over the time because it is an evolving process. These set of indicators are being implemented in 12 Forest Management Units (FMUs) in four states (6 FMU in Madhya Pradesh State, 2 FMU each in Chhattisgarh, Gujarat, and Orissa states) with community participation. The main forest types covered in the project are teak, sal and miscellaneous forests. Indian Institute of Forest Management, Bhopal has standardized the methodology for development of site-specific sets

Table 1. National Level C&I of Bhopal-India Process (2005)

Criteria	Indicators		Data availability	FMU	National
	1.1	Area and type of forest cover under (a) Natural forest	A	+	+
		(b) Man-made forest (tree plantations)	A	+	+
Criterion 1: Increase in the extent of forest and tree cover	1.2	Forest area officially diverted for non-forestry purposes	A	+	+
	1.3	Forest area under encroachment	A	+	+
	1.4	Area of dense, open and scrub forests	A	+	+
	1.5	Trees outside forest	C	+	+
	2.1	Area of protected eco-systems (Protected Areas)	A	+	+
	2.2	Number of			
		(a) Animal and	B	+	+
		(b) Plant species	B	+	+
Criterion 2: Maintenance, conservation and enhancement of biodiversity	2.3	Number and status of threatened species			
		(a) Animal	C	+	+
		(b) Plant species	C	+	+
	2.4	Status of locally significant species			
		(a) Animal and	C	+	-
		(b) Plant species	C	+	-
	2.5	Status of species prone to over-exploitation	C	+	+
	2.6	Status of non-destructive harvest of wood and non-wood forest produce	B	+	+
	3.1	Status of natural regeneration	A	+	+
Criterion 3: Maintenance and enhancement of ecosystem function and vitality	3.2	Incidences of forest fires	A	+	+
	3.3	Extent of livestock grazing			
		(a) Forest area open for grazing	A	+	+
		(b) Number of livestock grazing in forest	B	+	+
	3.4	Occurrence of weeds in forest			
		(a) Area	B	+	+
		(b) Weed type	B	+	+
	3.5	Incidences of pest and diseases	B	+	-
	4.1	Area under watershed treatment	A	+	+
Criterion 4: Conservation and maintenance of soil and water resources	4.2	Area prone to soil erosion	B	+	+
	4.3	Area under ravine, saline, alkaline soils and deserts (hot and cold)	B	+	+
	4.4	Soil fertility / Site quality	C	+	+
	4.5	(a) Duration of water flow in the selected streams	B	+	-
		(b) Ground water in the vicinity of the forest areas	B	+	-
Criterion 5: Maintenance and enhancement of forest resource productivity	5.1	Growing stock of wood	A	+	+
	5.2	Increment in volume of identified species of wood	C	+	+
	5.3	Efforts towards enhancement of forest productivity:			

(contd..)

		(a) Technological inputs	A	+	+
		(b) Area under Hi-tech plantations	A	+	+
		(c) Area under seed production, areas under clonal seed orchards etc.	A	+	+
Criterion 6: Optimization of forest resource utilization	6.1	Recorded removal of wood	A	+	+
	6.2	Recorded collection of non-wood forest produce	A	+	+
	6.3	Efforts towards reduction of wastage	C	+	+
	6.4	Aggregate and per capita consumption of wood and non-wood forest produce	B	+	+
	6.5	Direct employment in forestry and forest-based industries	B	+	+
	6.6	Contribution of forests to the income of forest-dependent people	B	+	+
	6.7	Demand and supply of wood and non-wood forest produce	C	+	+
	6.8	Import and export of wood and non-wood forest produce	A	-	+
Criterion 7: Maintenance and enhancement of social, cultural and spiritual benefits	7.1	(a) Number of JFM committees and area(s) protected by them	A	+	+
		(b) Degree of people's participation in management and benefit-sharing	A	+	+
		(c) Level of participation of women	A	+	+
	7.2	Use of indigenous technical knowledge: Identification, documentation and application	A	+	-
	7.3	Quality and extent to which concessions and privileges are provided	A	+	+
	7.4	Extent of cultural/sacred protected landscapes: forests, trees, ponds, streams, etc.	A	+	+
		(a) Type and area of landscape		+	+
Criterion 8: Adequacy of Policy, Legal and Institutional framework	8.1	Existence of policy and legal framework	A	+	+
	8.2	Number of forest-related offences	A	+	+
	8.3	Level of investment in Research and Development	A	+	+
	8.4	Human resource capacity building efforts	A	+	+
	8.5	Forest resource accounting			
		(a) Contribution of forestry sector to the GDP	B	+	+
		(b) Budgetary allocations to the forestry sector	B	+	+
	8.6	Monitoring and Evaluation mechanisms	B	+	+
	8.7	Status of information dissemination and utilization	B	+	+

A: Indicators whose data are readily available in the official records

B: Indicators whose data can be generated with some efforts and within the available resources

C: Indicators whose data require detailed research inputs.

(+): Indicator applicable

(-): Indicator not applicable

of criteria and indicators (Forest Management Unit level) that suit the concerned forest types/ conditions. This is termed as Local Unit Criteria and Indicators Development (LUCID) (Kotwal and Chandurkar, 2002). Thus, development of a procedure for developing site-specific indicators is important. The application of this concept needs to be institutionalized by incorporating in the Forest Working Plan at the time of revision.

The importance of FMU level indicators is that it is specific to a smaller geographical area, evolved involving the communities and of direct management significance to the forest. This provides a tool for monitoring the direction of change and forms building blocks for adaptive management of the FMU. These indicators are representative of the specific ecological, economic and socio-cultural environment.

To arrive at the FMU level C&I, the national level C&I are filtered using the filters- Relevance, Applicability, Measurability, Assessment ease and Aggregation. While developing the FMU level indicators the criteria remain the same and only the indicators are adapted (modified, deleted or added) as per the FMU-specific forestry scenario. The traditional knowledge and experience of the communities provides the basis for identifying these indicators at local level. Indicators so identified are simple, based on sound scientific premises and involve minimum assessment costs (Figure 4).

Once the local level indicators are finalized, the relevant information is collected form various sources in the predetermined formats on a periodic basis. A working group of the local community is assigned with this responsibility. For each of the identified indicators a minimum acceptable

Standardised methodology for development of site-specific indicators involving communities: LUCID

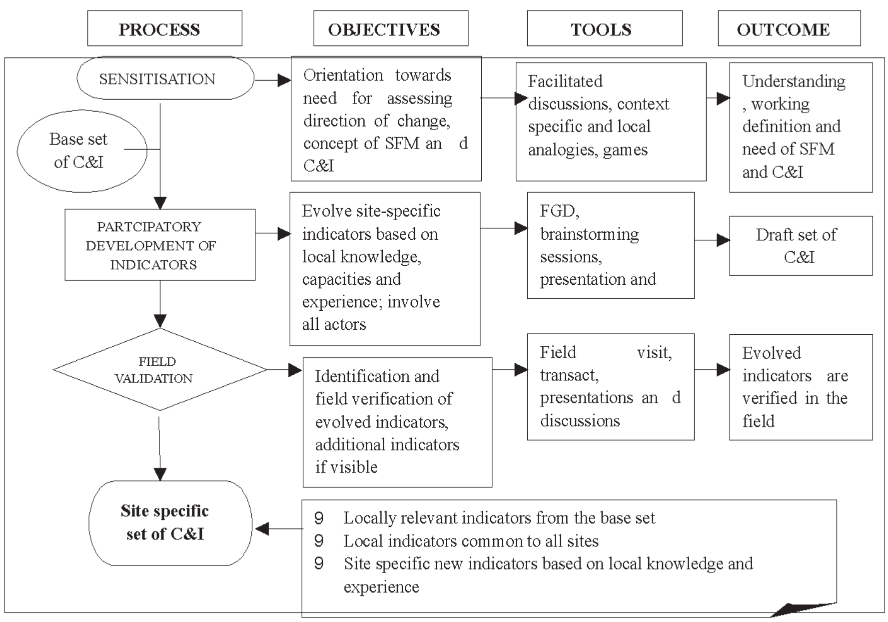

Fig. 4. Methodology for local unit criteria and indicators development (LUCID)

standard / norm / reference value / standard value / threshold value / bench mark / baseline value is decided based on published data, average of last 3-5 years, periodic field observations. The observed values of identified indicators are compared with the standard values of the indicators. Following this approach, FMU level indicators are identified, relevant data is collected and analyzed and even sustainability index (SI) can be computed.

A more detailed analysis of 8 criteria under B-I for natural teak forest divisions in Madhya Pradesh is given in the Table 2. These criteria are applicable for natural tropical forests (including teak forests), it can be seen from the justification in the last column of this Table that these criteria also match with teak plantations. The criticism of environmental groups against plantations on aspects such as biodiversity, soil and water conservation is thus well addressed through these indicators. On the other hand, teak plantations help in achieving national goal of increasing tree cover, meet increasing demand for timber, involve and benefit communities and reduce pressures on natural forest.

Thus it can be conclusively said that plantations are desirable economically, environmentally and socially and meet requirements of sustainable forest management principles and hence standards of forest certification. This is also the essence of FSC guidelines for certification of plantation forests that encourages integration of plantation management with natural forest management (formally linking plantations with natural forest management).

- In India, considering the Forest Policy imperatives and the current forestry situation, the criteria have been prefixed with specific adjectives that indicate the direction of intended changes.
- Indicators have been evolved for the natural tropical forests and methodology for their application at FMU level involving the communities has been standardized.
- The criteria of B-I process are also equally suitable for tree plantations and appropriate indicators can be evolved by involving the stakeholders.

Based on the data collected for Harda Forest Division of Madhya Pradesh sustainability index is computed for the study years as presented in Figure 5. These observed values when fed into specifically developed software-Forest Management and Control System" (Sudeshna *et al.*, 2007) for this purpose under the project at IIFM, generates sustainability index over the period of data fed.

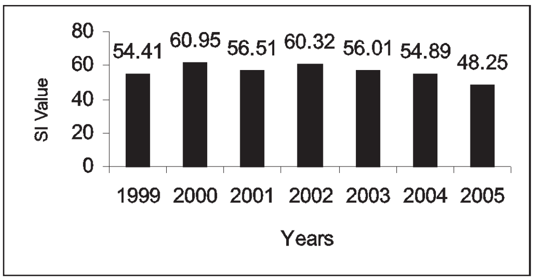

Fig. 5. Sustainability Index computed for Harda Forest Division

CERTIFICATION OF PLANTED FORESTS AND CRITERIA AND INDICATORS OF B-I PROCESS

Many international initiatives are examining the certification of environmental characteristics of forest products. Forest Certification is a procedure by which a third party provides written assurance / market labeling that a product, process or service conforms to specified standards, on the basis of an audit conducted to agreed procedures (Bass *et al.*, 2001). Forest certification is the process of inspecting particular forests or woodlands to see

Table 2. Annotations of the Criteria of B-I Process for natural tropical forests and planted forests.

Criteria of B-I Process (2005)	Natural tropical forests	Planted forests (teak)
1. Increase in the extent of forest and tree cover	One third of the total geographical area should be under forest and tree cover (National Forest Policy, 1988).	The forest and tree cover in India is 23.68% (FSI, 2003) which is less than the Forest Policy target. The tree plantations contribute towards achieving the forest policy target.
2. Maintenance, conservation and enhancement of biodiversity	As per the Govt. of India Policy five percent of total geographic area should be under protected area for *in situ* conservation of biodiversity	The tree plantations primarily do not target for biodiversity conservation but in order to maintain the ecosystem balance, other associated species (herbs, shrubs, birds, etc.) *in situ* with the tree plantations would serve the purpose.
3. Maintenance and enhancement of forest ecosystem function and vitality	There exists dynamism between biotic and abiotic factors (natural, man-made, qualifiers) in the natural forest ecosystem. These affect the health and resilience of forests and need to be intricately managed.	The health and vitality of tree plantations need to be maintained to achieve the anticipated growth and productivity.
4. Conservation and maintenance of soil and water resources	The soil and water influence the composition, growth, productivity etc. of natural forests and also the underground recharge.	The tree plantations also require amicable soil and water conditions for normal growth and in turn also play similar role in maintaining the soil and water regime.
5. Maintenance and enhancement of forest resource productivity	Maintaining and increasing forest productivity is an important aspect of forest management to provide a wide range of goods and services. In India the forest productivity is low as compared to Asian or world average.	The tree plantations add to the productivity of desired forest goods particularly the timber and some NWFPs.
6. Optimisation of forest resource utilization	Annual collection should not exceed average annual increment put by the growing stock.	The tree plantations reduce the exploitation pressure of the natural forests.
7. Maintenance and enhancement of social, cultural and spiritual benefits	The most of the forest areas are coming under participatory management regime involving the local communities.	Raising and management of tree plantations also require involvement of communities.
8. Adequacy of policy, legal and institutional framework	India has the best forest policy documents to maintain and enhance the forest resources and their optimal utilization.	The forest policy support raising tree plantations

if they are being managed according to an agreed set of standards (FSC, 1998; Bass *et al*., 2001; Meidinger *et al*., 2003; FERN, 2004). Certification of public and private forests is a major topic of discussion in forestry worldwide, and every one has his or her own perspective on it. Environmental groups see it as a way to verify a landowner's or firm's commitment to sustainable forestry. Industrial forest companies and some government agencies hope to use their certification to get credit with the public for conservation efforts. Wood product companies hope to capture new markets and gain market advantage as they communicate their good environmental performance by using eco-labels to identify wood products from their certified forests. Whatever the reason is, the main issue behind forest certification is a need to provide objective evidence that forest products are being produced without harm to forests or to the natural and human systems that they support (Fletcher *et al.*, 2002). Given that worldwide forest products trade was valued at more than USD 185 billion in 2004 (FAO FRA, 2005), the potential impacts of certification on markets cannot be ignored.

A group of timber users, traders and representatives of environmental and human-rights organisations met in California in 1990 to discuss how they could combine their interests in improving forest conservation and reducing deforestation. Their meeting confirmed the need for an honest and credible system for identifying well-managed forests as acceptable sources of forest products. It was from these beginnings that the Forest Stewardship Council (FSC) was established. In September 1993, 130 representatives from around the world came together to hold the Founding Assembly of the FSC in Toronto, Canada. In October 1993, an agreement was reached to launch FSC, and by August 1994 a definitive set of *Principles and Criteria*, together with the Statutes for the Council, were agreed and approved by the votes of the Founding Members (www.fsc.org). Thus FSC became the first certification scheme in the world. The FSC P&C consist of 10 Principles, 52 Criteria and runs to 11 pages. The FSC principles focus more on social issues in the first few components, and then address ecological issues. The individual principles cover (Forest Stewardship Council 2003): (1) compliance with laws and FSC principles, (2) tenure and use rights and responsibilities, (3) indigenous people's rights, (4) community relations and worker's rights, (5) multiple benefits from the forest, (6) environmental impact (biodiversity), (7) management plans, (8) monitoring and assessment, (9) maintenance of high conservation value forests, and (10) plantations.

Programme for Endorsement of Forest Certification Schemes (PEFC) was launched in 1999 as a Pan European Forest Certification Scheme primarily for the European countries. There are 31 countries from 6 continents which are part of the PEFC Council in 2006. National forest certification systems in 22 of these countries have gone through the rigorous PEFC assessment and endorsement process and have successfully implemented equally high standards for forest certification systems, in their countries. Only PEFC endorsed certification systems can participate in the global trade of PEFC certified products and use the PEFC logo on their products. The area of PEFC certified forests reached nearly 200 million ha (480 million acres) globally in 2006 making it the world's largest resource of certified wood with 70% market share. United Nations statistics show that some 25% of the world's industrial roundwood production is currently certified and about two thirds of all certified forests are certified to PEFC endorsed certification, an estimated 370 million m^3 (PEFC, 2006)

Apart from two global certification schemes – Forest Stewardship Council (FSC) and Programme for Endorsement of Forest Certification Schemes (PEFC), several other national schemes such as Sustainable Forest Initiative (SFI), Canadian Standards Association (CSA), Malaysian Timber

Certification Council (MTCC), etc. have also emerged in the last one decade or so. A comparative analysis of all these schemes is presented in Table 3.

Similarly a comparison of principles, criteria and indicators of the two global certification schemes and B-I process (potential certification standard) verifiers); and B-I process has 43 indicators (at National level) while in case of PEFC the 6 criteria are first divided into concept area – which is further divided into number quantitative indicators and descriptive indicators.

The Bhopal India process, FSC and PEFC criteria are depicted in Figure 6 to indicate their

Table 3. Comparison of the five major forest certification schemes (and potential B-I process)

Scheme*	**FSC**	**PEFC**	**SFI**	**CSA**	**MTCC**	**B-I Process (Potential)**
Sponsor	Forest Stewardship Council	Programme for the Endorsement of Forest Certification	American Forest &Paper Association	Canadian Standard Association	Malaysian Timber Certification Council	Indian Timber Certification Council
Geography	Worldwide	Europe (now Global)	USA & Canada	Canada	Malaysia	
Establishment	1993	1998	1995	1996	1998	To start
Performance Standard-Setter	Stakeholder Committees	Stakeholder Forums	Sustainable Forestry Board	Committee+ Some Public Inputs	National Committee	Stakeholder Committees
Eco-Label	Yes	Yes	Yes	Yes	Yes	-
Chain-of-Custody	Yes	Yes	Yes	Yes	Yes	-
Certified (millha in 2007)	90.8	204.7	54.1	73.4*	4.7	0
Principles, Criteria & Indicators	10 P, 52 I	6 C & large no. I	9 P, 13 O	7C, 20 I	9 P, 47 C, 88 I	8 C & 43 I

Source: the scheme's respective websites
* FSC = Forest Stewardship Council (Sept., 2007); PEFC = Program for the Endorsement of Forest Certification (31/08/2007), Schemes (formerly Pan European Forest Certification); SFI = Sustainable Forestry Initiative; CSA = Canadian Standards Association; and MTCC = Malaysian Timber Certification Council.
December 2006, about 60%, or 73.4 million ha out of 123 .7* million ha of certified Canadian forests had been certified under the CAN/CSA-Z809 SFM Standard.

it is observed that these match at least on 70-80 % of criteria (Table 4). However at the indicators level there is much difference owing to the differences in regional/local situations under which these standards have been developed. FSC has 52 indicators (which are further divided into sustainability with respect to ecological, economical and social-cultural aspects. A forest certification scheme based on B-I process has potential to become the basis for a national certification standard comparable with two global certification schemes – FSC and PEFC.

Table 4. Comparison of FSC, PEFC and B-I Process Principle, Criteria & Indicators (P, C & I)

Certification system	Ecological	Economic	Socio -cultural
FSC	– Maintenance of high conservation value forests – Environmental impact – Management plan (FSC P 6, 8, 9)	– Benefits from the forest – Monitoring and assessment – Plantations (FSC P 5, 7, 10)	– Compliance with laws and FSC principles – Tenure and use rights and responsibilities – Indigenous peoples' rights – Community relations and worker's rights (FSC P 1, 2, 3, 4)
PEFC	– Maintenance of forest ecosystem health and vitality – Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems – Maintenance and appropriate enhancement of protective functions in forest management (notably soil and water) (PEFC C 1, 2,3)	– Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles – Maintenance and encouragement of productive functions of forests (wood and non-wood) (PEFC C 4, 5)	– Maintenance of other socio-economic functions and conditions (PEFC C 6)
BI process (potential)	– Increase in the extent of forest and tree cover – Maintenance, conservation and enhancement of biodiversity – Maintenance and enhancement of ecosystem function and vitality – Conservation and maintenance of soil and water resources (B-I C 1,2,3,4)	– Maintenance and enhancement of forest resource productivity – Optimization of forest resource utilization (B-I C 5,6)	– Maintenance and enhancement of social, cultural and spiritual benefits – Adequacy of policy, legal and institutional framework (B-I C 7, 8)

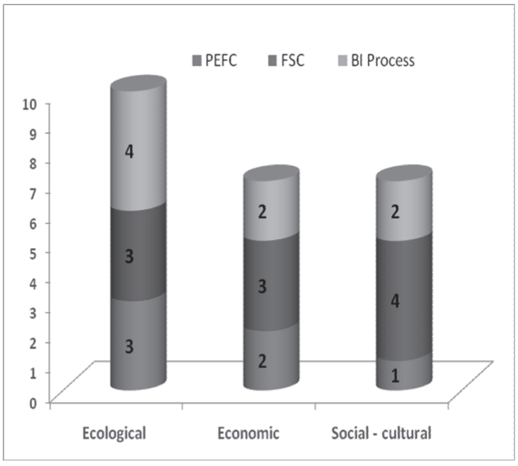

Fig. 6. Comparison of FSC, PEFC and B-I process P&C

STATUS OF FOREST CERTIFICATION IN INDIA

As of now, India does not have a certification scheme of its own as is the case for many countries like USA, UK (and almost all other European countries), Malaysia, Brazil, Chile. Government of India has set up a working group on forest certification and three committees for developing certification system for the Country. It is hoped that the Indian Forest Certification Scheme could be developed based on the B-I process C&I. Currently there is only one forest certification in India for rubber plantation in Kerala by IMO, a FSC certification agency. Also there are 4 chain-of-custody certifications two in Jalandhar, one each in Delhi (FSC) and Mysore (PEFC). There are other certification audits underway in in central and northern India.

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Quality Control and Mass Production of Teak Clones for Tropical Plantations

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ABSTRACT

The dramatic reduction of high grade teak timber supplies from natural stands and the concomitant increasing worldwide demand have accounted for a greater interest in teak plantation establishment, especially from wisely selected clones for ensuring the best yield and quality returns in the shortest time. Results from fifteen years of collaborative research work between the Sabah Foundation Group and CIRAD in Sabah on genetic improvement, early selection on wood traits combined with the development of efficient nursery and *in vitro* propagation protocols have led to the availability of superior quality planting stock. The development of this 'package' of technologies for upgrading the clonal selection is now paying off, as evidenced by the widespread interest and demands for our clonal material from buyers in Malaysia and around the world. Quality control of the planting material is essential to guarantee the reliability and the future of teak clonal forestry. The initial selection of candidate trees, traditionally based on phenotype criteria only, can be refined by taking into account at an early stage, economically important wood characteristics (sapwood percentage, specific gravity, shrinkage, figure and natural durability). The purpose is to enhance the ultimate value of the clones planted either in the form of monoculture or agroforestry systems. Reliable DNA markers have been developed jointly for identifying the genetic background and possible relatedness of the candidate genotypes for wiser and safer clonal deployment. These molecular analyses are also useful for checking the genotypic conformity of the propagated clones, as well as to ensure that trading practices comply with laws on intellectual property rights.

***Keywords*:** Teak clones, plantation establishment, genetic improvement, quality control, Malaysia.

INTRODUCTION

As foreseen (Monteuuis and Goh, 1999; Monteuuis *et al.*, 2004; Goh and Monteuuis, 2005) teak clonal plantations are rapidly expanding under the strong demand of private investors eager to maximize their return on investments with the shortest delays. Using the best clones with optimal silvicultural management should be a priority in plantation establishment, as it can be assumed that yield and, predominantly, the quality of the timber produced, will be the two overriding commercial factors for the near future, especially when considering the reduction of the natural sources due to depletion or international bans. This is particularly true for the highly prized Myanmar or Burma teak.

The rationale of teak clonal forestry has been largely advocated in previous papers (Monteuuis and Goh, 1999, Goh and Monteuuis, 2005) highlighting the importance of a wise clonal selection and deployment. Yield and wood quality especially, are the two main components to improve for enhancing the value of future teak plantations. In addition to classical growth rate, the following traits must be taken into consideration while field selecting candidate plus trees -the so-called CPT -for cloning:

- Clear bole diameter and length.
- Bole shape (straightness, circularity, taper) with minimal knots, buttresses or flutes at the bottom of the tree.
- Frequency and size of lateral branches responsible for nodes affecting wood quality especially for veneer end-use.

However, these selection criteria relate only to external features of the trees. In order to improve CPT selection by including internal wood quality traits, then to ensure a good control of CPT mass clonal propagation, new methods have been developed recently, as detailed in this paper.

REFINING CPT SELECTION USING WOOD QUALITY CRITERIA

Wood quality is classically defined by the combination of five main groups of factors detailed in Table 1. However, in practice, teak buyers and end-users give more emphasis to the characteristics listed in Figure 1 according to the final utilization of the timber (Baillères and Durand, 2000). For greater value, teak wood must be as homogeneous as possible with minimal within-tree variations, such as differences between juvenile and mature wood, notwithstanding site effects liable to induce differences between individuals from the same clone (Figure 2).

Two sampling methods, destructive or otherwise, depending on plant material availability, can be considered for determining wood characteristics of individual trees.

Destructive sampling

Destructive sampling involves securing a diametrical plank 1m in length and 3 to 5 cm in width from the lower portion of felled trees. The good correlation between results from such a sample and the 'whole tree' have already been demonstrated (Zobel and Jett, 1995). In order to maintain the genotype alive, this destructive approach can be used for clones represented by several trees in clonal tests or clonal plantations.

The information that can be obtained from such sampling includes:

- Modulus of elasticity assessed by the non-destructive "Bing" method (Baillères *et al.*, 1998).
- Strength.
- Basic density.

These three related physical properties are usually not markedly different for teak than what can be observed for other planted species, and are therefore of less importance for determining teak wood value (Baillères and Durand, 2000).
The following properties, conversely, are linked to aesthetic features and durability responsible for

Table 1. List of the main factors classically used for determining general wood quality (drawn from Bailleres and Durand 2000)

Wood quality factors	Wood properties	Remarks
1 -Mechanical factors	- Modulus of elasticity - Modulus of rupture - Maximum crushing strength - Hardness (for flooring uses) - Growth stresses	First four are correlated to specific gravity. For young trees
2 -Physical factors	- Shrinkage - Tangential / Radial shrinkage - Sorption properties such as fiber saturation point.	Assessed for tangential and radial directions of wood structure. Transverse anisotropic ratio indicating dimensional stability. Key impact on dimensional stability.
3 -Biological factors	- Decay resistance - Termite resistance - Weather resistance	Reflect the natural durability
4 -Aesthetic factors	- Colour and veining - Grain - Texture	Can be referred to under the same generic term of "figure".
5 -Structural factors	- Heartwood / sapwood ratio - Bole shape (straightness, taper, buttressing, fluting) - Knots size and frequency - Grain angle	Important for sawing as directly related to timber yield (i.e.: sawn timber grade and recovery).

Relevant properties: Sapwood percentage, Dimensional stability (shrinkages), Figure (colour, grain, structure) & Natural durability

End-uses	Wood technological characteristics
Joinery	- Natural durability - Dimensional stability - sapwood percentage
Flooring and parquets	- Figure - Dimensional stability - Natural durability - Specific gravity - Sapwood percentage - Figure
Furniture	- Dimensional stability - Sapwood percentage
Sliced veneer	- Figure

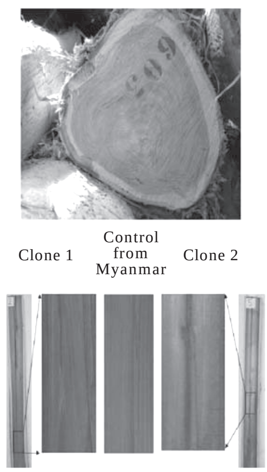

Fig. 1. Wood property assessment using destructive (board) samples

Heartwood / sapwood ratio variability

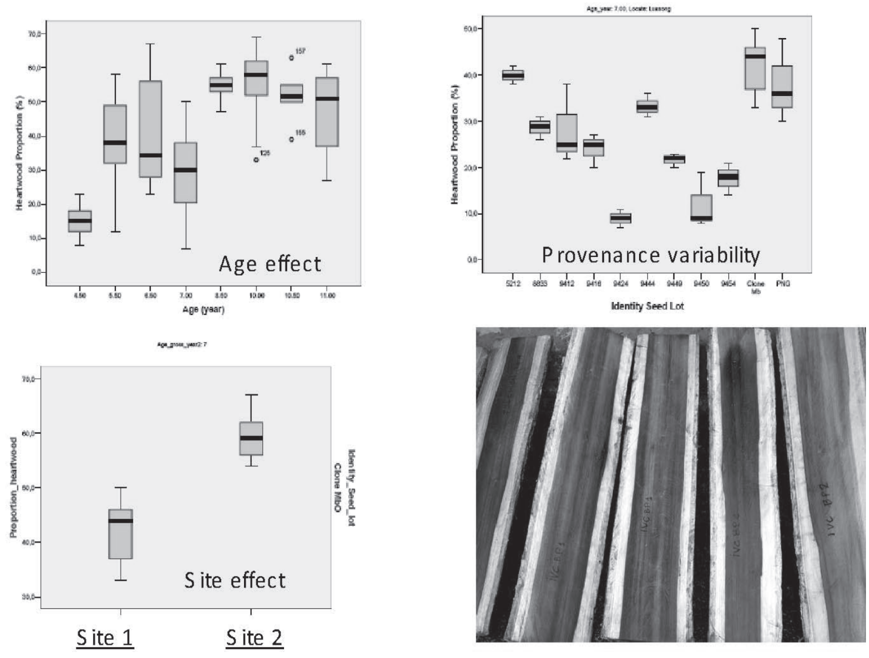

Fig. 2. Variations of heartwood / sapwood ratio according to the age, the origin and to the planting site (for a given clone) using board samples.

teak wood incomparable quality, and which should be therefore considered as essential for genetically improving teak wood value:

- Ring analysis in order to assess the texture (when the limit between rings is clear enough).
- Figure, including grain and color (Figure 1).
- Heartwood / sapwood ratio, liable to vary according to: the age, the genetic identity assessed at the provenance and clone level, the site within a clone (Figure 2).
- Dimensional stability by radial and tangential shrinkages measured in the green state at 6% and 0% moisture content. Teak clones can display obvious differences in longitudinal, radial and tangential shrinkages as illustrated in Figure 3.
- Natural durability along with extractives content (standard measurement and NIRS prediction: standard measurements usually take 5 to 6 months due to the time needed, at least 16 weeks, for assessing fungal attacks).
- Wood uniformity (minimal within-tree variation between juvenile and mature wood).

Such a comprehensive set of wood characteristics is more than what is usually needed for upgrading the initial phenotypic selection to superior wood quality plant material with higher market value, either in the form of raw materials or different levels of processed end products (Bath, 2000).

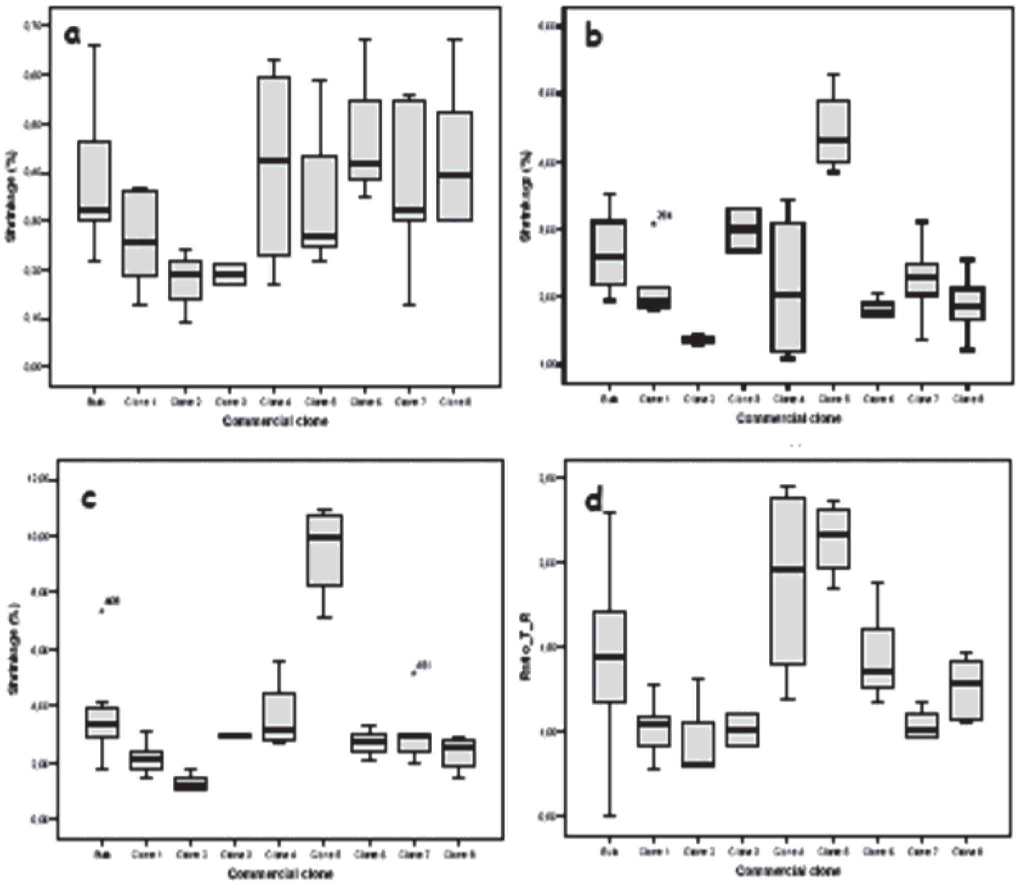

Fig. 3. Shrinkage variability of 8 yr-old teak clones: a: longitudinal shrinkage (L), b: radial shrinkage (R), c: tangential shrinkage (T), d: T/R ratio.

Non-destructive sampling

Similar information or knowledge can be obtained using non-destructive methods, e.g., core sampling (Figures 4 and 5). These approaches are very useful for genotypes represented by only one tree that must be kept alive, for instance to be potentially used as a mother tree for seed or clone production. By attaching the wood corer specially developed for teak to a hand-held motor driven drill (Figure 4), a suitable core of 15mm in diameter and 40 to 60 cm in length can be easily extracted from any teak tree within 2 to 5 minutes, depending on the size of the tree.

Use of near infra red spectroscopy (NIRS) technology will help assess from such core samples the basic density, the modulus of elasticity and strength, the radial and tangential shrinkages, the natural durability as well as the extractive content. Once properly calibrated, NIRS is a fast, low-cost, easy-to-use, non-destructive, reliable and versatile analytical method which can accommodate heterogeneous wood samples and point out slight

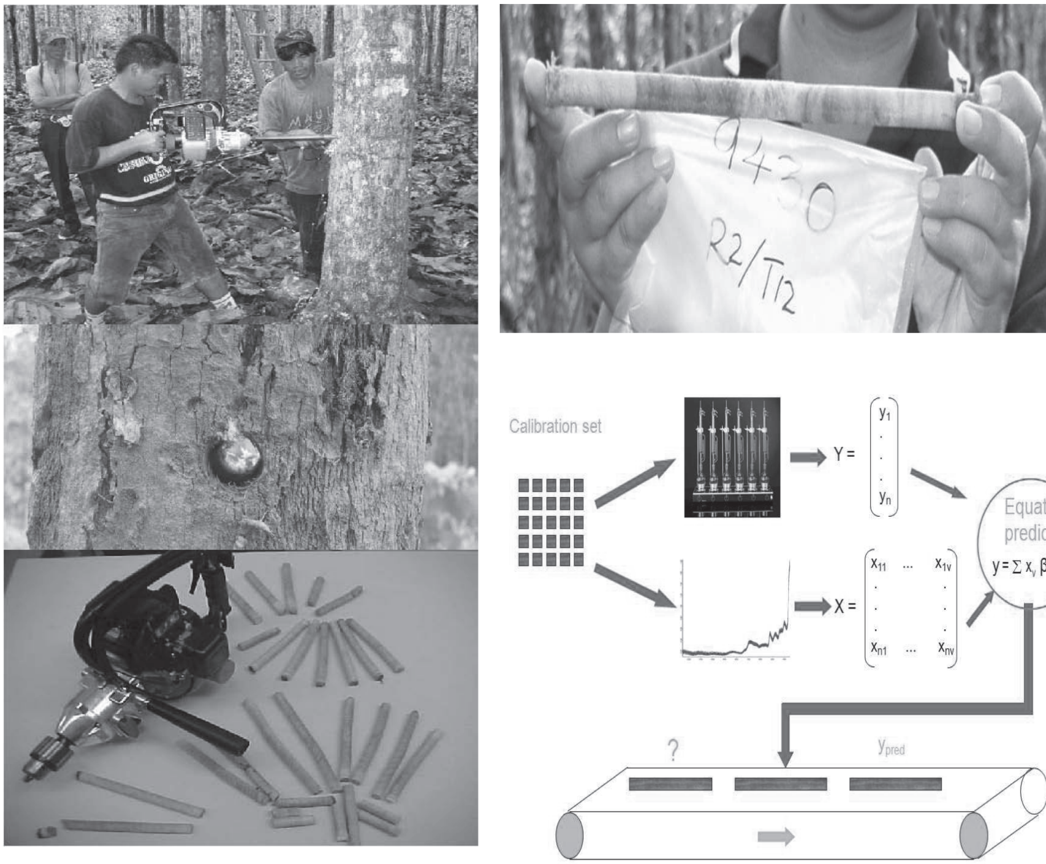

Fig. 4. Non-destructive core sampling method using a hand-held motor driven drill and the resulting core samples that can be analyzed by NIRS.

chemically-induced wood variations (Figures 4 and 5).

USEFULNESS OF ADAPTED MOLECULAR MARKERS

The development of clonal plantations for teak can be supported by DNA molecular markers in four different ways.

1) Through determining the primary origin of the various populations of teak available locally, i.e. whether they were initially imported from India, Myanmar, Thailand or Laos, which are the four native countries for teak. The usefulness of such information is obvious for basic research e.g., for indicating the range of adaptability of the native teak provenances to other environments in various countries, as well as for operational and commercial activities.
2) Through assessing the genetic diversity and levels of co-ancestry in the teak germplasm that exists locally, the understanding of which is needed for optimal management and utilization within sound tree improvement programs (Figure 6). Knowledge of the genetic background of the seed producers will enable

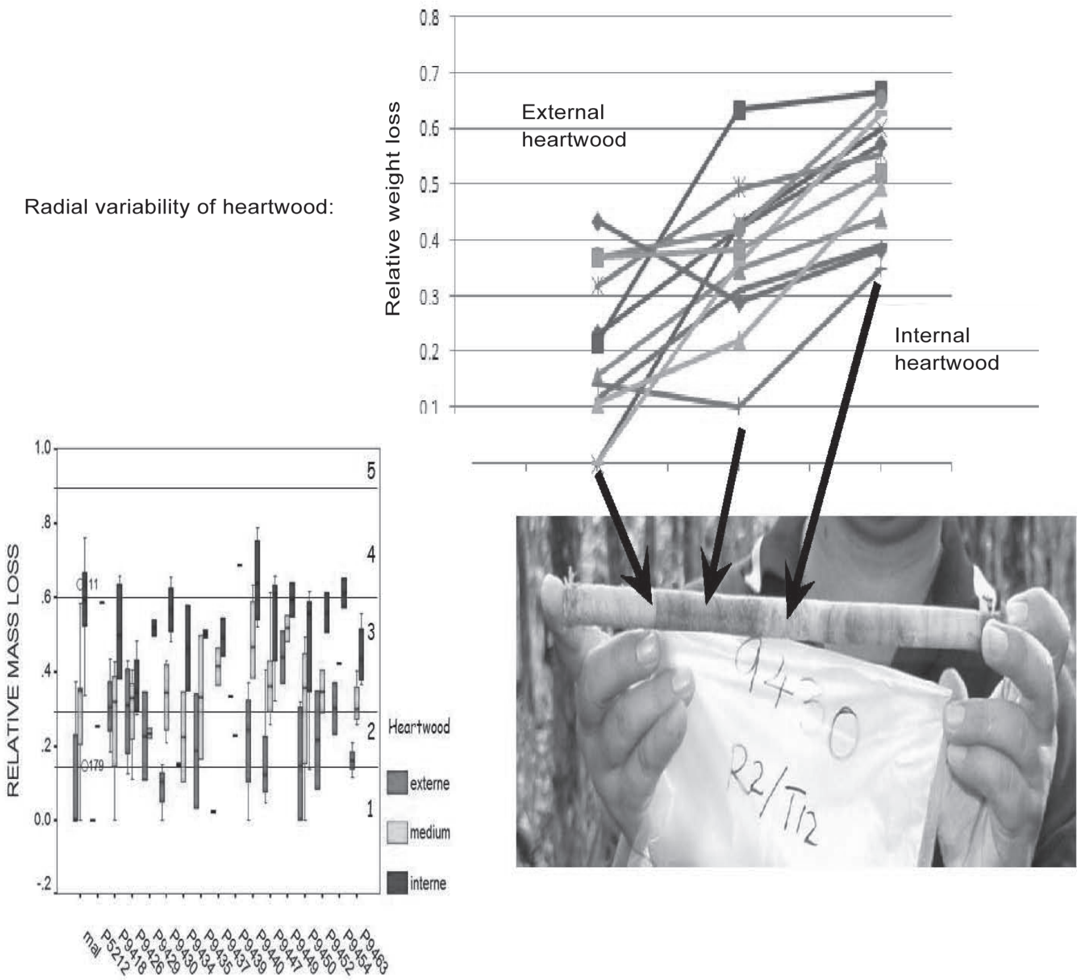

Fig. 5. NIRS prediction results of teak wood properties from core samples.

strategies to be employed to reduce risks of inbreeding, for instance by limiting the numbers of genetically close relatives within seed orchards.

3) Through phenology and gene flow studies with a view to understanding these phenomena then taking relevant actions for maximizing gene exchanges and perhaps achieve panmixia within seed stands and seed orchards, thus limiting inbreeding while enhancing genetic recombination.

4) Through clonal identification by DNA fingerprinting with application to establish property rights or test genetic fidelity of the mass-propagated clones, as illustrated in Figure 6. Choice of the most appropriate DNA marker technologies among all those available (Mueller and Wolfenbarger, 1999) is a crucial issue. Respective efficiencies of technologies such as the Amplified Fragment Length Polymorphism or AFLP, and the Simple Sequence Repeat or SSR, also known as microsatellites, were therefore assessed in our laboratory using several teak populations of

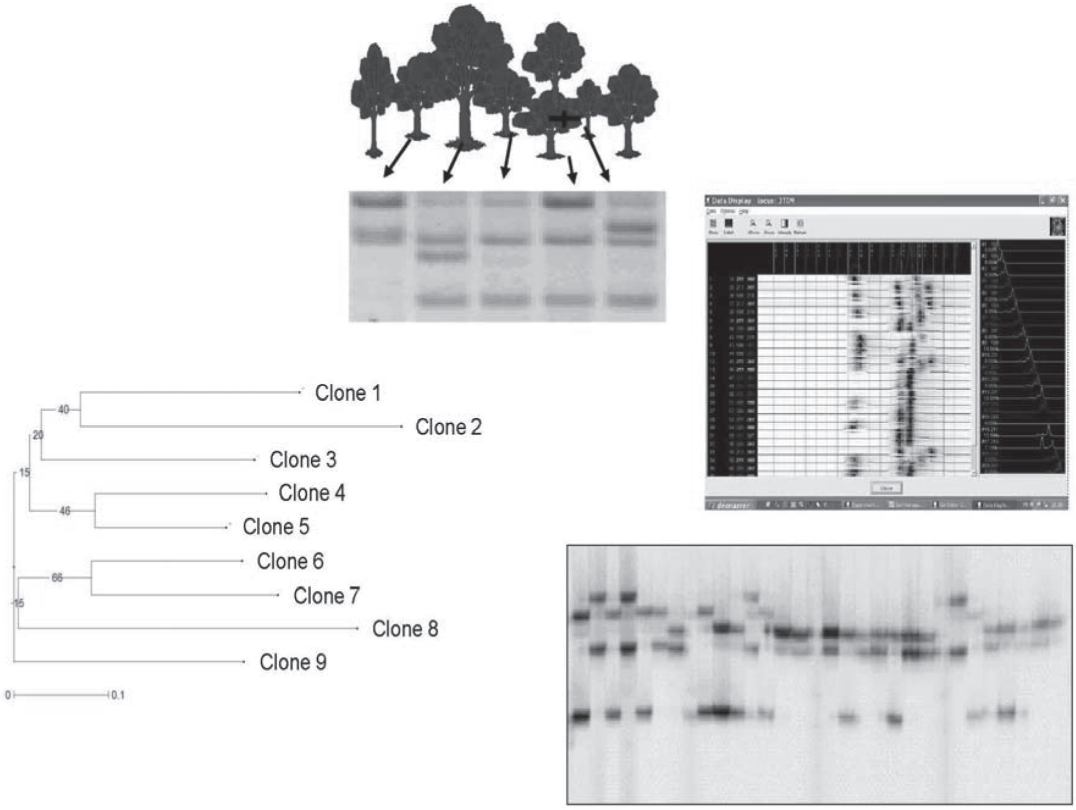

Fig. 6. DNA molecular marker applications: genetic relatedness and fingerprinting of commercial clones

known origins. The SSR technology was found to be more reliable and better adapted to our current objectives as mentioned above, which is in accordance with findings from other species (Rahman and Rajora, 2002; Kirst *et al.*, 2005). Further, the availability of a teak microsatellite bank developed previously by our team under another teak project (Verhaegen *et al.*, 2005), had a determining influence on this choice.

Mass clonal propagation process

Most of the teak planting materials developed by ICSB/CIRAD are clones that are mass produced either by rooted cuttings in nursery facilities or by tissue culture from mature selected plus trees. The methodologies used as well as their respective pros and cons have already been extensively described (Monteuuis *et al.*, 1998; Monteuuis, 2000; Goh and Monteuuis, 2001).

Although requiring more skill and expertise than the routinely-used nodal explant tissue culture technique, teak meristem culture – 0.1 mm as overall explant size – (Figure 7) is more efficient for rejuvenating mature genotypes while overcoming the contamination problems that commonly affect the primary cultures (Figure 7). This latter technique is therefore becoming more frequently used for our new introductions of

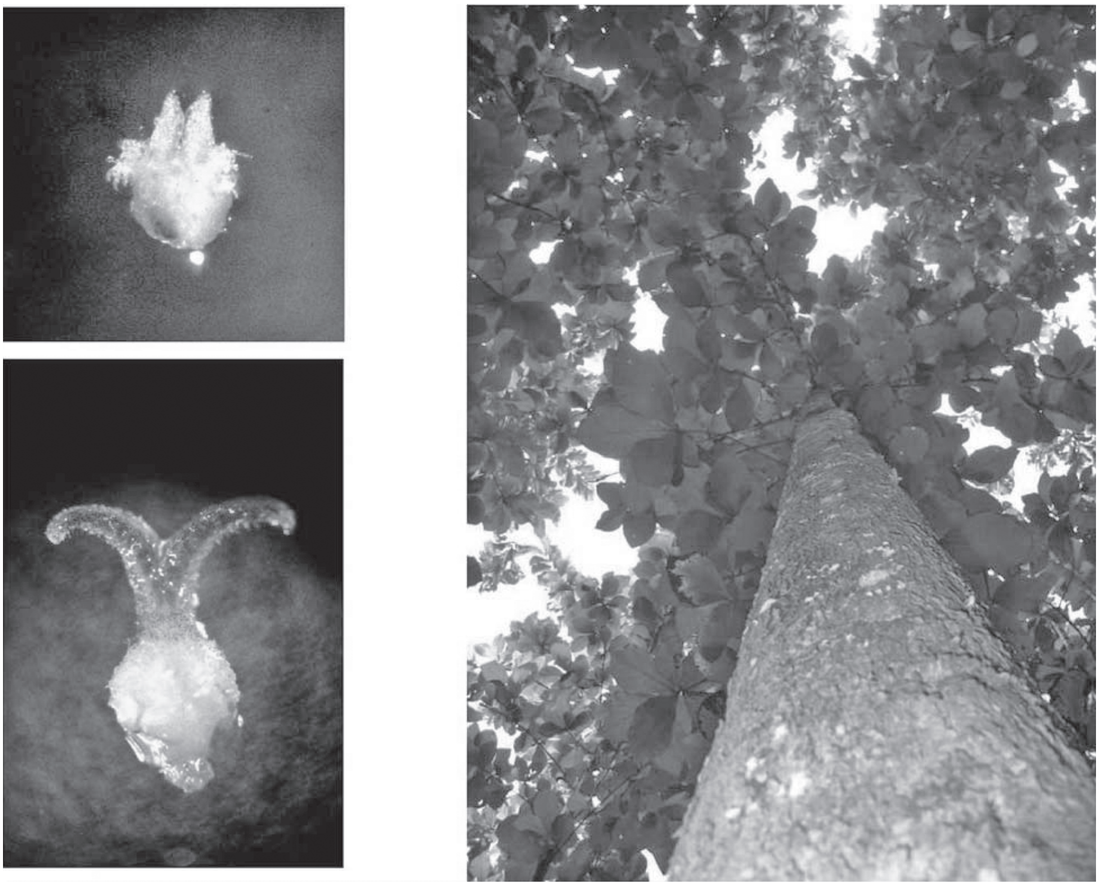

Fig. 7. Clonal propagation of mature selected teaks using shoot apical meristems (0.1mm as overall size): *in vitro* culture three (left top) and eight weeks (left below) after introduction, then 5 years later in outdoor conditions (right) in absence of any pruning.

mature genotypes resulting from field selection. Regardless of the technique used, the objective is to rapidly mass produce actively growing 4 – 6 cm long micropropagated shoots with high adventitious rooting capacity from any teak genotype irrespective of its age.

These shoots can be easily transferred to *ex-vitro* conditions for rooting under appropriate mist-system conditions, then raised to a suitable developmental stage for field planting. The behaviour of the tissue-cultured microshoots is assessed regularly during the *ex-vitro* rooting and acclimatization phases, as well as under different field conditions.

Technical assistance can be provided upon request to help ensure the best acclimatization success of the tissue cultured shoots dispatched to various overseas destinations. DNA fingerprinting can be used at any step of the process for certifying the genetic identity of the micropropagated plant material.

Fig. 8. The clone identification form: clone TG2 as an example. (*Source:* ICSB-CIRAD, 2006)

Clone identification form

Under the present commercial production system, in order to ensure efficient and reliable mass micropropagation, only the best 12 to 15 clones are kept in intensive production for sale. However, the current list of clones can be extended at any time by physiologically "reactivating" the organogenic capacities of the clones stored in our *in vitro* clonal bank, or by introducing additional clones resulting from new selection work. Information on each clone is readily available upon request. Each of the main characteristics of individual clones is described in a comprehensive two-page leaflet as illustrated in Figure 8. The first page of this leaflet illustrates the two methods of propagating and supplying the clones, distinguishing between rooted cuttings for the local market and tissue-cultured microshoots ready for export in well insulated styrofoam boxes. This latter method must satisfy the phytosanitary conditions specified by the destination country where the plantlets will be set for rooting, then acclimatized before planting out in the field. The clones can be deployed either in the form of monoclonal blocks, as clone mixtures or in association with annual or perennial crops within agroforestry systems. The second page of the leaflet (Figure 8) shows the growth potential, DNA profile for genetic background identification and wood characteristics as detailed previously. It also includes photos of the wood produced by the given clone when grown under Sabah conditions.

CONCLUSION

The alarming reduction of teak natural stands and simultaneously the remarkable worldwide increase in demand for teak wood have accounted for the greater interest in teak plantation establishment. High yield of top quality teak wood in the shortest time is now becoming a priority for a lot of land owners and investors. This presents a challenge requiring early delivery and ongoing improvement of planting stock capable of providing high yields of logs with the most prized wood properties. Outcome from fifteen years of a research and development-oriented collaborative program between the Sabah Foundation Group and CIRAD on teak clonal forestry focusing on wise genotype selection, tree breeding and mass clonal propagation have led to the availability of such quality planting stock. The sustained focus on the development of this package of technologies and genetic material is now paying off, as evidenced by the widespread interest and demands for our clonal materials from buyers in Malaysia and around the world.

Recently, the applications of DNA fingerprinting and wood analyses lend emphasis not only to our seriousness in developing the best quality planting materials, but also on the usefulness of having such information.

With such strong interest, the need to continuously upgrade the performance and quality of new generations of clones remains our priority target. As the interest in establishing quality teak plantations continues, so shall the research within our collaborative program attempt to keep pace, to lead us into the production of planting material that will enhance profitability with the shortest possible delay.

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Growth and Volume Equations through Stem Analysis of *Tectona grandis* in Costa Rica

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ABSTRACT

Management prescriptions and growth projections for *T. grandis* in Costa Rica very often lack high-quality supporting data. The present research focuses on the use of stem analysis techniques for constructing DBH, total height, and volume equations, and their comparison with existing models developed from temporal and permanent sample plots. A total of 25 trees with ages between 8 and 46 years, DBH between 9.4 and 55.4 cm, and total height between 12.4 and 33.3 m were felled for stem analysis. Previous developed models for teak in Costa Rica using sample plot databases were satisfactorily “duplicated” by models developed with stem analysis data. Stem analysis has proven to be a useful tool for creating a growth database in the absence of consecutive measurements or for supporting existing chronological databases.

Keywords: Tree-ring, management, projections, Silviculture, wood quality.

INTRODUCTION

Forest plantations have a worldwide reputation as providers of high return on investment and high quality timber. In Costa Rica and many other countries in Central America, reforestation projects represent a considerable portion of the overall forested areas and a primary source of national and local income. *Tectona grandis* has been one of the most preferred species for investment opportunities, due to its high wood quality, excellent growth performance, and worldwide reputation.

Management prescriptions and growth projections for *T. grandis* in Costa Rica very often lack high-quality supporting data. Within the next 10 years, most of the teak plantations in Costa Rica will be thinned for a third or forth time, or even harvested at rotation ages between 20 and 30 years. Wood prices, management options and related costs, final yield (total and merchantable volume according to market requirements), management options, and growth / yield projections are urgently needed to inform owners, investors, and consumers about the real stock and estimated value of *T. grandis* commercial timber available in the country.

Temporary sample plots provide one-time measurements, their use requiring strong assumptions that are usually violated in practice (Clutter *et al.*, 1983; Walters *et al.*, 1989). When available, sequences of consecutive measurements on permanent sample plots are widely considered the best basis for prediction of individual and stand development. Dendrochronology is the science of dating the annual rings of trees and the application of dated rings to a variety of scientific questions (Fritts, 1990). Tree-ring or stem analysis in the tropics exists since more than one hundred years (Worbes, 2002).

Stem analysis reconstructs past diameter and height growth from growth ring observations on dissected sample trees (Dahms, 1963, Curtis, 1964). From this diameter and height growth information, changes in form, and hence, volume growth, can be determined for a given tree. Less intensive stem analysis procedures are employed to determine tree taper and current volume. A major use of stem analysis is in reconstructing a tree height development for fitting height-age equations (Dyer and Bailey, 1987).

Several studies on stem analysis have been carried out for modeling different growth parameters for a variety of forest species. Garcia (2005) compared site index models developed with stem analysis data and permanent sample plot data for *Pinus pinaster* in northern Spain; Drake *et al.* (2003) carried out a retrospective evaluation (by means of stem analysis) for determining a thinning opportunity in a 24-year-old Douglas fir (*Pseudotsuga menziesii)* stand in Chile, while Dyer and Bailey (1987) tested six methods for estimating true heights from stem analysis data using 28 loblolly pine trees in Georgia. In other similar studies, yield tables and volume equations have been developed using stem analysis data (Rosot *et al.*, 1993; Reed and Green, 1984). Stem analysis has also been implemented for evaluating pruning regimes and environmental relationships (Friedl *et al.*, 1997; Fritts, 1990).

In Costa Rica, very few studies on stem analysis have been reported in the literature. Perez *et al.* (1999) carried out a stem analysis of *T. grandis* trees of 8 to 46 years of age in Costa Rica as an aid for supporting the sample plot data collected and used for the construction of empirical growth models and management scenarios. Mora and Gomez (2003) developed volume tables and equations by means of stem analysis of *T. grandis* trees in the Pacific region of Costa Rica The present research focuses on the use of stem analysis techniques for constructing DBH, total height, and volume equations, and their comparison with existing models developed from temporal and permanent sample plots. The study aims at identifying possible scopes for implementing the technique of stem analysis when data from sample plot measurements are scarce or absent, or simply not enough for developing proper growth projections and management guidelines.

METHODOLOGY

The material was collected from plantations on private farms in different zones of Costa Rica (Figure 1), including the following sites and provinces: Carrillo, Hojancha, and Tempisque (Guanacaste); Jicaral, Buenos Aires, Palmar Norte, Quepos, and Parrita (Puntarenas).

For this study 15 plantations were selected on 8 sites representing different climatic conditions (Table 1a and 1b) and plantation densities (156 to 893 trees ha^{-1}). From these plantations, a total of 25 trees (average individuals according to the diametric distribution of each plantation) with ages between 8 and 46 years (average = 14.7, std = 10.1), DBH between 9.4 and 55.4 cm (average = 23.3, std = 10.3), and total height between 12.4 and 33.3 m

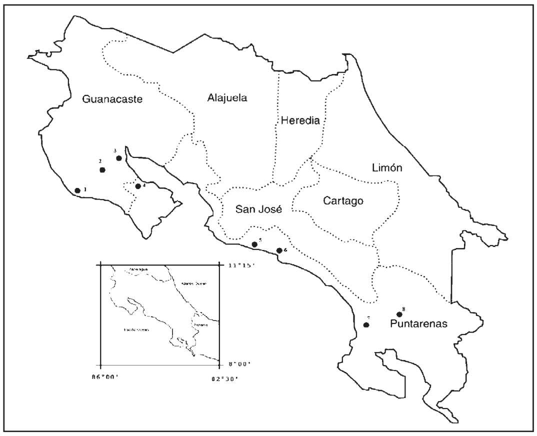

Fig. 1. Location of the *T. grandis* plantations evaluated in Costa Rica.

Table 1a. Bioclimatic variables of sites where *T. grandis* trees were harvested.

Site code	Location	Precipitation (mm year $^{-1}$)	Dry Months$^{(*)}$	Elevation (m)	Mean annual Temperature (°C)	Age (years)	N
1	Carrillo	1659	6	100	26.1	8-10	8
2	Hojancha	1850	6	145	26.6	9-16	7
3	Tempisque	1901	6	30	27.1	13-19	3
4	Jicaral	1659	6	85	26.8	10-11	2
5	Parrita	3117	3	25	26.0	45	2
6	Quepos	3900	3	70	25.9	12	1
7	Palmar Norte	3644	3	80	27.0	22	1
8	Buenos Aires	3627	4	300	27.0	26	1

(*) months with rainfall less than 100 mm month^{-1}

Table 1b. General data from the research sites in Costa Rica where teak plantations were evaluated and trees were harvested for stem analysis.

Site code	Location	Precipitation (mm year $^{-1}$)	Dry months a)	Elevation (m)	Mean annual Temperature (°C)	Stand density (trees ha^{-1})	Age b) (years)
1	Carrillo	1659	6	100	26.1	667-736	8-10
2	Jicaral	1659	6	85	26.8	333-750	11-18
3	Tempisque	1901	6	30	27.1	389	14-20
4	Garza	2205	6	90	25.9	816	6
5	San Carlos	3393	1	90	26.1	640-1600	8
6	Parrita	3117	3	25	26.0	156-541	13-47
7	Quepos	3900	3	70	25.9	775	19
8	Palmar Norte	3644	3	80	27.0	893	23
9	Buenos Aires	3627	4	300	27.0	357	27

a) Months with less than 100 mm annual rainfall.
b) Single age entry means that sampled trees were of same age (does not mean average age)
c) Trees planted in lines at a distance of 3.0 m from one another.

(average = 20.6, std = 5.7) were felled for stem analysis.

Trees were used for different studies; therefore the sampling procedure was standard only regarding the selection of the three strata position. The number of individuals varied from one plantation to another, for instance half of the samples corresponded to young trees 10 years of age or less. Advance-aged plantations (>15 years of age) are scarce in Costa Rica and private owners are not willing to allow their harvesting.

Stem cross-sectional samples were taken from each felled tree at the base of the stem and at DBH. From 2.0 m of height on, sections were taken along the stem every 2.0 m. Diameter (with and without bark) was measured on each stem section. Total volume (m^3) with and without bark was calculated using the Smalian formulae for each stem section (i.e. 0.0 – 1.3 m, 1.3-2.0 m, 2.0-4.0 m, 4.0-6.0 m, etc). The last stem section (from the last-taken disk to the tip of the tree) was calculated as a geometric cone.

On each stem section the growth rings were counted and measured from pith to bark, following the direction North-South (previously marked in the field). Measurements were carried out using a caliper to a precision of ± 1.0 mm. Any sector of the cross-sectional sample with any irregularity was discarded and the radial measurements were taken in the next clear portion of the sample. The bark thickness at different ages was estimated as a percentage of the stem diameter without bark based on the relationship at the moment of harvesting. Out of the 25 sample trees, a total of 368 trees were obtained from the stem analysis.

A potential bias in the estimate of tree height corresponding to a given age in a cross-cut section can arise from sectioning of the stem, and a number of studies have investigated the extent of such bias for temperate and coniferous species (Carmean, 1972; Dyer and Bailey, 1987). For estimating the length of the "hidden tip", different methods listed by Rayner (1991) were tested, selecting that of Carmean (1972) as best procedure. The result of this calculation is similar to estimating the hidden tip as half of the height between the sections if the number of rings differs in one, and one third of the distance if the difference between sections is two rings. No more than two rings difference occurred between sections of the sampled trees.

Following similar procedures, growth models (age-DBH and age-total height) and volume equations developed by Perez and Kanninen (2005), respectively, were developed using the stem analysis database and compared.

RESULTS

Figure 2 shows the stem analysis profile of a 45-year-old teak tree harvested in the Central Pacific region (Site #5) of Costa Rica.

Figure 3 shows the current and mean annual increment in DBH of the same tree. The tree (and the plantation) presents a very heterogeneous annual growth (CAI) and a decreasing mean

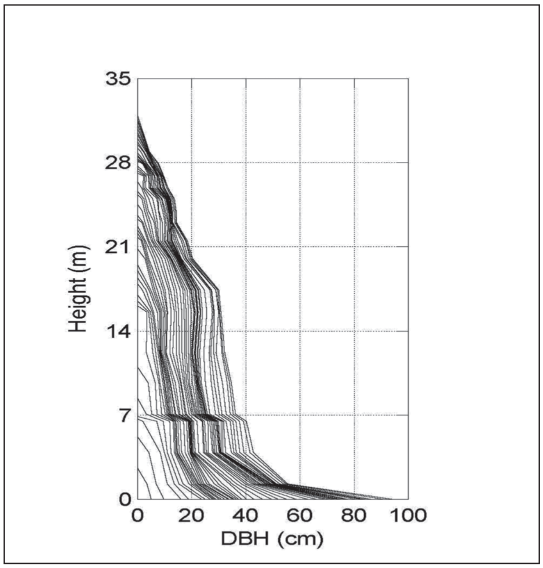

Fig. 2. Stem analysis profile of a 45-year-old *T. grandis* tree harvested in Costa Rica

growth (MAI) in DBH. Nevertheless, the tree shows several increments along its 45 years of growth, influenced probably by the occasional but irregular

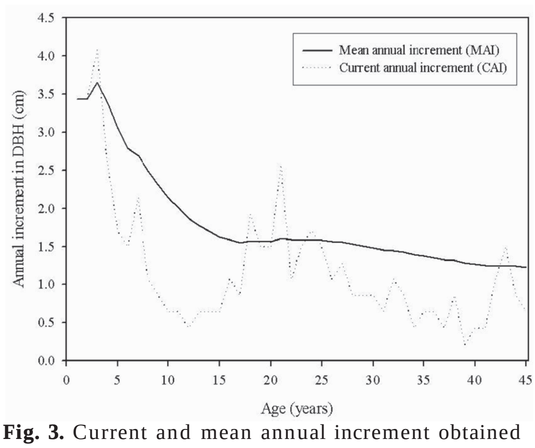

Fig. 3. Current and mean annual increment obtained from a stem analysis of a 45-year-old *T. grandis* tree harvested in Costa Rica.

thinning interventions carried out by the owner. The tree presents a very cylindrical stem up to a height of approximately 18.0 m, probably due to the reduced formation of branches probably due to a high stand density.

The development of growth functions for diameter at breast height (DBH) and total height with age was based on a fitted curve (Chapman-Richards model), following the same methodology of Perez and Kanninen (2005) for their growth equations. The idea was to test the same models but using the stem analysis database. Following their methodology, an average curve (corresponding to a Site Class II, 80% of the species potential) was obtained through non-linear regression, followed by an upper curve (Site Class I – 100% of the potential) and a lower curve (low class – 60% of the potential) derived from the average curve accordingly (Figure 4a). The corresponding residual distribution is presented in Figure 4b. As evidenced in Figure 4a and Table 2, the model presents a good fit to the stem analysis data (r^2=97.7). Similarly, an average curve (corresponding to a Site Class II, 80% of the species potential) was obtained through non-linear regression for the variable total height, followed by an upper curve (Site Class I – 100% of the potential) and a lower curve (low class – 60% of the potential) derived from the average curve accordingly (Figure 5a). The corresponding residual distribution is presented in Figure 5b. As evidenced in Figure 5a and Table 2, the model presents a good fit to the stem analysis data (r^2=98.4).

For predicting total volume over bark, the equation of Perez and Kanninen (2003) for modeling the relationship between DBH and total volume over bark was used in the present study, aiming at comparing the same model but obtained from two different data sources, i.e. sample plot vs. stem analysis data (Figure 6a).The corresponding residual distribution is presented in Figure 6b.As evidenced in Figure 6a and Table 2, the model presents a good fit to the stem analysis data (r^2=97.5).

The comparison of the DBH equation (for the relationship between age and DBH) from Perez and

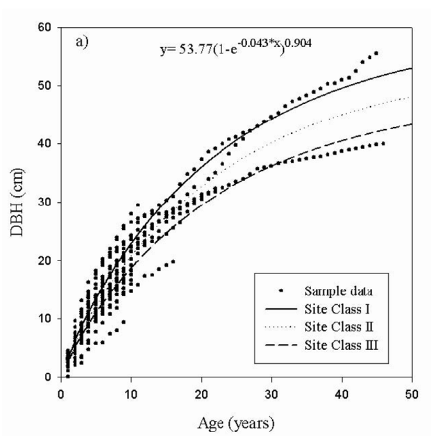

Fig. 4a. Fitted curve for the relationship between age and DBH for *T. grandis* in Costa Rica.
Curve for Site Class I corresponds to 80% of the potential (mother curve), and Site Class III to 60% of the potential. *For model description see Table 2.*

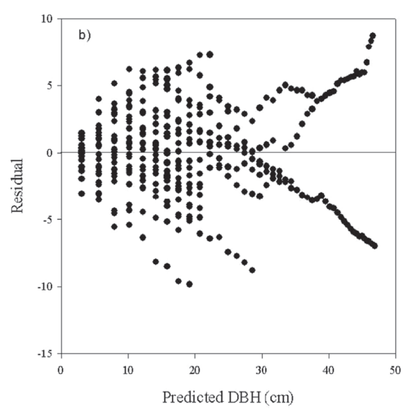

Fig. 4b. Residual distribution for the relationship between age and DBH.

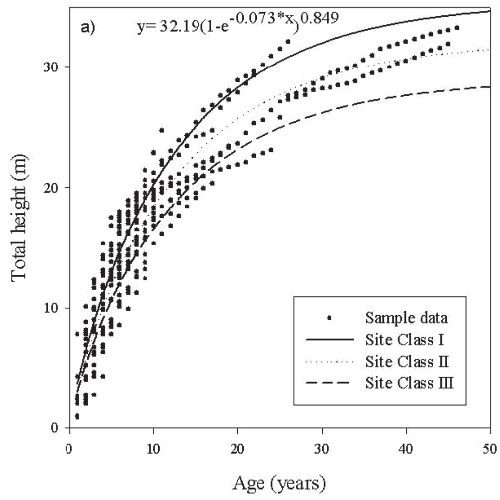

Fig. 5a. Fitted curve for the relationship between age and total height for *T. grandis* in Costa Rica.
Curve for Site Class I corresponds to 100% of the potential, Site Class II corresponds to 80% of the potential (mother curve), and Site Class III to 60% of the potential. *For model description see Tables 2.*

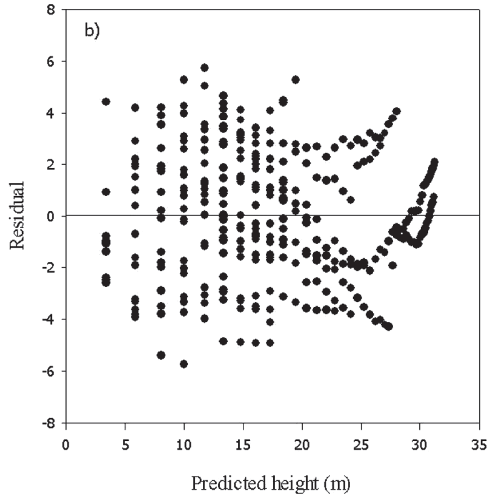

Fig. 5b. Residual distribution for the relationship between age and total height.

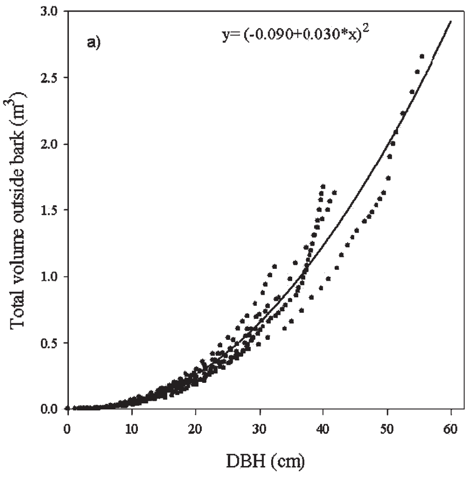

Fig. 6a. Fitted equation for the relationship between DBH and total volume over bark for *T. grandis* in Costa Rica. *For model description see Table 2.*

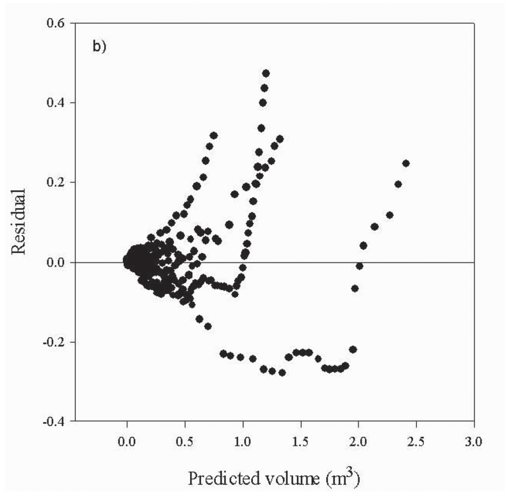

Fig. 6b. Residual distribution for the relationship between DBH and total volume over bark.

Table 2. Models (and regression statistics) developed in this study using a stem analysis database of *T. grandis* trees from Costa Rica.

Model	r^2	r^2-adjust	RMSE
1. $DBH=53.769*(1-e^{-0.043*AGE})^{0.904}$	0.977	0.918	12.598
2. $H=32.190*(1-e^{-0.073*AGE})^{0.849}$	0.984	0.921	5.565
3. $VOL=(-0.090+0.030*DBH)^2$	0.975	0.961	0.009

Kanninen (2005) with that developed in the present study using stem analysis data is shown in Figure 7. In general, both models show a very similar trend, presenting an average difference of 3.4% in their estimations with a maximum difference of 5.3% between 0 and 10 years of age. The comparison of the total height equation (for the relationship between age and total height) from Perez and Kanninen (2005) with that developed in the present study using stem analysis data is shown in Figure 8. In general, both models present a similar trend; however the model developed by Perez and Kanninen (2005) follows a lower trajectory, estimating in general lower values than the model developed in the present study. An average difference of 15.0% was found between predictions, with a maximum difference of 25.6% between 0 and 10 years of age.

The comparison of the volume equation (for the relationship between DBH and total volume over bark) from Perez and Kanninen (2003) with that developed in the present study using stem analysis data is shown in Figure 9. In general, both models present an almost identical trend, presenting an average difference of 1.9% in their estimations.

Discussion

According to Prodan *et al.* (1997) the necessary or desirable size of a sample for developing a growth model is close to 500 trees, well distributed in DBH and height ranges of the stand. In Costa Rica and many other countries in Central America, the collection of large databases demands higher costs and time frames than usually available in research projects. Perez (2005) faced several limitations when developing stand growth scenarios for *T. grandis* in Costa Rica.

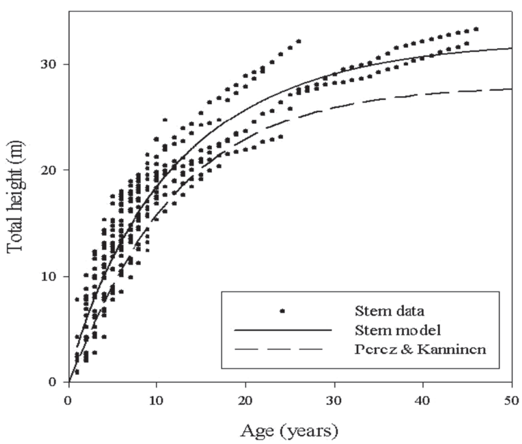

Fig. 7. Comparison of Perez and Kanninen (2003) and the model developed with stem analysis data ("Stem model") for the relationship between age and DBH for *T. grandis* in Costa Rica.

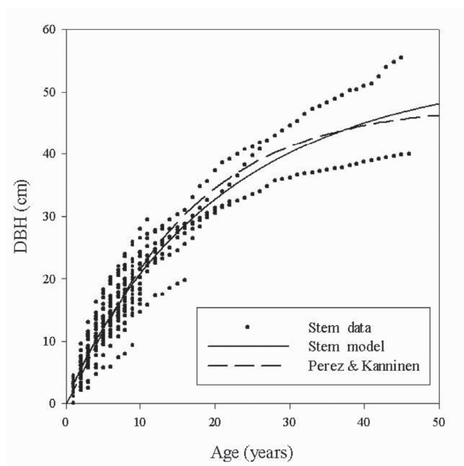

Fig. 8. Comparison of Perez and Kanninen (2003) and the model developed with stem analysis data ("Stem model") forthe relationship between age and total height for *T. grandis* in Costa Rica.

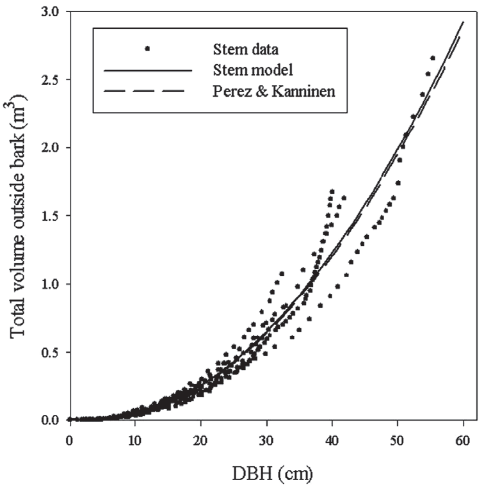

Fig. 9. Comparison of the Perez and Kanninen (2003) model and the model developed with stem analysis data ("Stem model") for the relationship between DBH and total volume over bark for *T. grandis* in Costa Rica.

The stem analysis of *T. grandis* trees is possible to carry out in the Central and Pacific regions of Costa Rica due to the marked dry period of 5-6 months per year. In the Atlantic and North region of the country, the fragmentary and unmarked dry period does not allow the formation of yearly growth rings and consequently restricts the construction of tree growth patterns. Other native species, such as *Bombacopsis quinata,* sometimes develop false growth rings even within the regions with a marked dry period, complicating the retrospective analysis of the stem (Perez, 1998).

The 25 trees used for developing the growth models were collected in different regions of the country, representing different climate, soil, and management conditions. Consequently, the present report should be considered as a preliminary approach towards the use of stem analysis for supporting or replacing growth models developed from stand-based databases. Consequently, this study limits to illustrate the methodology of stem analysis and its potential use for developing growth models. Stem analysis and PSP observations might follow the same overall growth relationships (age-DBH, age-height, age-volume) but their variability would be expected to be different. Specifically, stem analysis is less subjected to uncorrelated measurements and sampling errors (Garcia, 2005).

Garcia (2005) found statistical differences in the height-age pattern of the stem analysis and the PSP data sets when testing height growth models using databases from PSP stem analysis, and a combination of both. From a practical point of view, however, it is not obvious as to which data set is the correct one, or the best. Stem analysis is prone to biases due to changes in dominance of sample trees not representing the stand top height, and possibly to measurement and calculation procedures. In contrast, PSP data cover 11 much narrower ranges of age, measurement error is higher, and there may be some bias associated to plot size. Both data provide useful information and separate models for stem analysis and PSP fit each data set much better than a common model.

The model for predicting DBH from age using stem analysis data showed a similar trend as that developed previously for teak in Costa Rica using PSP and TSP data by Perez and Kanninen (2005). The model presents a similar goodness of fit and residual distribution as that originally developed with sample plot data. Drake *et al.* (2003) implemented stem analysis for defining the moment of thinning in a 24-year-old Douglas fir stand in Chile. Through a reconstruction of the Current and Mean Annual Increments in DBH, the authors defined the best moment of thinning (which already occurred years before) and consequently the intensity that they should apply to improve the actual plantation status. Further equations for estimating total height and volume helped to define the best intensity of thinning.

The model for predicting total height from age using stem analysis data differed from that developed previously for teak in Costa Rica using PSP and TSP data by Perez and Kanninen (2005). The model presents a similar goodness of fit and residual distribution; however the parameter "a" of the equation representing the top height is higher in the former. The slope and curvature of the equations also differ, influenced by the different distribution of datasets. In both cases, the limited availably of growth data (ages higher than 10 years) may be influencing the encountered differences. Nevertheless, a difference of 3.0 m in estimating the total height of a 20-year-old stand is not very critical, considering the implied errors of height measurements as well as the inherent height variability. Many studies have used stem analysis data for developing height and site index models (Dyer and Bailey, 1987; Garcia, 2005; Rayner, 1991). Friedl *et al.* (1997) implemented the technique of stem analysis for developing a pruning methodology for *Pinus taeda* in Argentina. The use of height-age relationships obtained from stem analysis helped to define the moments and intensities of pruning, as part of a comprehensive analysis of stem profile and knot-free core projections.

The model for predicting total volume from DBH using stem analysis data showed a very similar trend than that developed previously for teak in Costa Rica using PSP and TSP data by Perez and Kanninen (2003). The model presents a similar goodness of fit and residual distribution as that originally developed with sample plot data. In addition, the model of Perez and Kanninen (2003) has been previously compared with models developed in Costa Rica and elsewhere and has been found to be one of the best models available for the estimation of total volume of teak in Costa Rica (Gomez and Mora, 2003). Consequently, it can be assumed that the volume equation developed using stem analysis information is suitable for predicting total volume of teak trees in Costa Rica.

CONCLUSIONS

- Stem analysis has proven to be a useful tool for creating a growth database in the absence of consecutive measurements or for supporting existing chronological databases.
- Single-tree growth reconstruction presents some sample limitations (related to tree selection criteria) but reduces the error of sampling and measurement.
- Previously developed models for teak in Costa Rica using sample plot databases were satisfactorily "duplicated" by models developed with stem analysis data.
- Present models were developed using a database of harvested trees in different regions in Costa Rica, therefore the use of these models should be preceded by a local calibration if high precision is desired.
- When data collection is difficult and limited by economical, time-framing, data availability, or other similar reasons, techniques such as stem analysis provide a feasible solution for developing management tools of similar quality than those developed when database is not a limitation.
- It is recommended to enlarge the present study with more stem analysis coming from trees older than 15 years.

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Optimum Thinning Schedule for Teak Plantations

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ABSTRACT

Optimum stand density trajectories worked out for even aged teak stands in Kerala, India based on a growth simulation model are described. The model consisted of diameter and volume increment equations based on Richards function which included site index, initial diameter, age and stand density as predictors. The parameters of the model were estimated using data from permanent sample plots. The simulation studies with the model indicated that starting with an appropriate initial density depending upon the site quality class, a gradual increase in the stand density over the cropping phase is ideal for maximizing the net present value (NPV) of cash flows from a teak plantation. The consequences of changing timber price, variable input cost and changes induced by management interventions on the cash flow and rotation age were also investigated. In general, the rise in NPV was dramatic with increasing timber price. The rise in input cost brought down the NPV. Positive changes in growth rate of diameter due to management interventions brought in only marginal increases in the NPV. Similarly, the effect of change in timber price on optimal rotation age was much larger when compared to that of input cost or growth rate of trees.

Keywords: Teak, growth model, simulation, optimum thinning schedule, rotation age, NPV

INTRODUCTION

Teak (*Tectona grandis* Linn. f) is an important plantation species indigenous to Myanmar, Peninsular India, Indonesia, Laos and Thailand. It is one of the most valuable timber species in the tropics where it is grown in over 2.25 million ha (Pandey and Brown, 2000). In India, teak plantations extend over one million ha. Kerala has a unique place in the history of teak plantations that the first ever teak plantation in India was raised in this part of the country in 1844.

In India, generally, teak is raised under rain-fed conditions with less intensive management. Site preparation, planting, initial tending and thinning are the major cultural operations practiced in teak plantations. Planting is done at 2 m x 2 m spacing followed by a series of thinnings and final felling at the rotation age suited to the local conditions. The traditional stocking guides in India are those available in the All India Yield Table (FRI, 1970), which prescribes fully stocked stands at any age of the crop. However, recent studies conducted at the Kerala Forest Research Institute (KFRI) have revealed a different strategy to be followed in order to maximize the returns from a teak plantation. The approach has been to develop a growth simulation model first and then to utilize the model to study the consequences of following different thinning schedules on the development of stand attributes and cash flows.

Growth simulation model

The model consisted of the following equations:

$$\frac{dD}{dt} = Z = a_2 H^{b_3} D^p e^{-qt} e^{-S_t/c_2} e^{-S_m/c_3} \qquad (1)$$

where,

Z = Mean annual increment in diameter at breast height (m)

H = Top height at the base age of 50 years (m)

D = Quadratic mean diameter of teak (m)

t = Age (year)

S_t = Stand density of teak

S_m = Stand density of miscellaneous species including teak coppice

a_2, b_3, c_2, c_3, p and q are parameters

$$\frac{dv}{dt} = v' = a_1 b_1 D^{b_1 - 1} Z e^{S_t/c_1} e^{S_m/c_4} \qquad (2)$$

where,

v' = 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

The density S in Equations (1) and (2) was taken as follows (Zeide, 2002).

$$S = N\left(\frac{D}{25.4}\right)^b \qquad (3)$$

where,

N = Number of trees per ha

D = Quadratic mean diameter of trees in cm

b = Rate of tree mortality caused by the increase in tree size

For the simulation, one more equation had to be used which described the diameter jump due to thinning. The equation was,

$$D_a = D_b \left(1 + Z/D_b\right)^{b_4} \qquad (4)$$

where,

D_b = Mean diameter before thinning

D_a = Mean diameter after thinning

Z as defined earlier

b_4 is a parameter to be estimated.

The parameters of the above equations were estimated using re-measured data from 69 permanent sample plots laid out by KFRI in different parts of the State.

Optimum density trajectories

Out of the thousands of possible thinning schedules generated during simulation, the best one was selected based on the net present value (NPV) of cash flows. The age at which NPV got maximized was adjudged as the optimal rotation age. The thinning schedules were specified in terms of changes to be made in relative density ($I = S/S_{max}$) over a rotation period. The estimate of S_{max} (S_{max} = $1/(1/c_2\ 1/c_1)$ where c_1 and c_2 are parameters in Equations (1) and (2) was 830. The optimum density trajectories worked out in terms of relative density and its changes over a rotation period under different site quality classes and discount rates are listed in Table 1 along with main physical and financial attributes relating to the stands at the rotation age.

All the optimal density trajectories worked out, pertaining to different site quality classes and interest levels, involved increasing stand density at a slow rate over the rotation period. The rate at which initial density had to be raised in order to achieve the optimum was the same for any site quality class although the initial density levels differed by site quality classes. The optimal rotation age though stable over site quality classes

Table 1. Optimal density trajectories under different site quality classes and interest rates

Site quality class	Interest rate (%)	Initial relative density	Five yearly rate of change in relative density (%)	Optimal rotation age (year)	NPV at optimal rotation age ('000 Rs)	Crop diameter at optimal rotation age (cm)	MAI in volume at optimal rotation age ($m^3 ha^{-1}$)
I	2	0.41	3	65	3677	67.0	8.868
	3	0.41	3	55	2243	62.1	9.094
	4	0.41	3	45	1484	55.5	9.121
	5	0.41	3	40	1039	51.5	9.022
II	2	0.35	3	65	2082	56.7	5.866
	3	0.35	3	55	1253	52.4	6.015
	4	0.35	3	45	819	46.9	6.038
	5	0.35	3	40	565	43.5	5.980
III	2	0.28	3	65	935	45.2	3.418
	3	0.28	3	55	545	41.8	3.509
	4	0.28	3	45	345	37.3	3.533
	5	0.28	3	40	228	34.6	3.509
IV	2	0.21	3	65	229	32.6	1.614
	3	0.21	3	55	111	30.1	1.663
	4	0.21	3	45	55	26.9	1.687
	5	0.21	3	40	22	24.9	1.686

varied with interest rates. Higher interest rates suggested lowering of rotation age, which is reasonable from economic point of view. Taking a particular case, with an inflation-free interest rate of 5 percent, the optimal rotation age to be adopted is 40 years, which is lower than the currently followed spans in Kerala but with lower interest rates, the rotation age jumps to 55 or 65 years. Another interesting finding was that the optimum thinning schedules avoid thinning at 5 years when the initial planted number is 2500 trees per ha. This may be a consequence of the price structure of teak poles with larger poles fetching higher price at a rate high enough to justify the waiting time.

As a specific case of illustration, the number of trees to be retained at different age levels and the corresponding stand development along with the NPV are shown in Table 2 for site quality I.

Sensitivity analysis

The above calculations were carried out under constant prices for timber and stable input costs and management levels. However, these are subject to changes and so the consequences of such changes were also investigated. A programme was made which allowed varying levels of these factors during simulation. However, since the number of levels for these factors and the resulting number of combinations are so huge, only a limited set of levels were tried to understand the general trends. Three levels each for increase in price, input cost and growth rate due to management interventions were selected. These levels were 0, 3 and 6 percent of annual change, which generated 27 combinations. For each combination, the best thinning schedule was identified and the corresponding NPV and other stand features at rotation age were worked out. All the projections

Table 2. Development of stand attributes under optimal density along with NPV at 3 percent discount rate for site quality class I.

Age (year)	Relative density	Number of trees ha^{-1}	Crop diameter (cm)	MAI in volume (m^3ha^{-1})	NPV of cash flows ('000 Rs)
5	0.41	2500	5.4	6.739	-13
10	0.43	643	15.5	6.124	266
15	0.44	361	25.0	7.393	724
20	0.45	255	33.6	8.619	1258
25	0.47	201	41.4	9.587	1778
30	0.48	170	48.3	10.299	2231
35	0.49	150	54.5	10.792	2594
40	0.51	137	59.9	11.106	2860
45	0.52	128	64.6	11.279	3036
50	0.54	122	68.7	11.339	3131
55	0.56	118	72.4	11.312	3160
60	0.57	115	75.5	11.217	3138

were made keeping the discount rate at 3 percent for site quality class II at low weeding intensity. The results of this exercise are depicted in Figure 1. This serves as an illustration of the possible changes. Similar trends can be expected at other levels of discount rate and site quality class.

In general, NPV rises with increasing timber price dramatically. The rise in input cost brings down the NPV. Positive changes in growth rate of diameter due to management interventions bring in marginal increases in NPV as seen from Figure 1. However, the effects may not be comparable directly because of the differences in the units. One message that comes out of the exercise is that NPV is very sensitive to changes in timber price than to that in input cost or growth rate of trees.

With increase in timber price, the optimal rotation age switched over to 70 years from the 55 years that was prevailing with stable prices. Perhaps the wait is worth as it fetches higher price for larger diameter trees. However, the rise in input cost over time brought down the optimal rotation age when

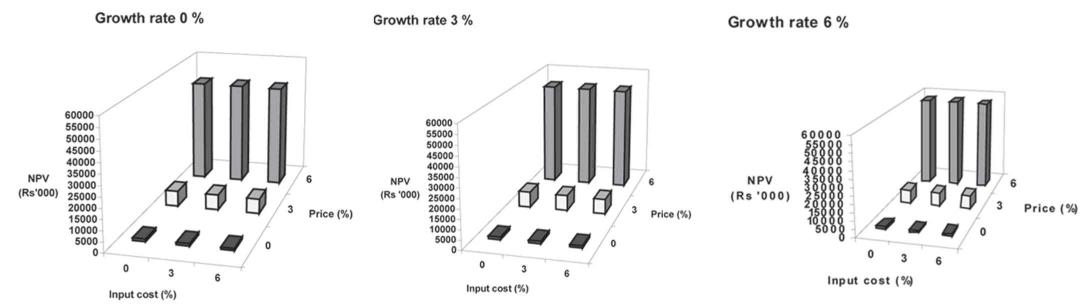

Fig. 1. Change in NPV due to the changes in timber price, input cost and growth rate of trees

timber prices were stable. When timber prices were made to increase, the rotation age was brought up to 70 years even with the rise in input costs. The logic is that it is not economical to wait for long as the input cost reaches exorbitant rates unless otherwise there is an associated increase in timber prices. A positive change in growth rate of diameter due to management interventions did not make any change in optimal rotation age. In short, the effect of change in timber price on optimal rotation age was much larger when compared to that in input cost or growth rate of trees.

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Hybcheck- The Biopesticide for Managing Teak Defoliator (*Hyblaea Puera* Cramer): An Announcement

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ABSTRACT

The teak defoliator (*Hyblaea puera* Cramer) is the most serious pest of the teak tree diminishing both the quantity and quality of timber. Outbreaks of the insect occur many times a year in teak plantations of all age classes. Managing the pest using chemical pesticides is hazardous to the forest ecosystem and the biodiversity it holds. This paper announces the arrival of Hybcheck- a Baculovirus based microbial pesticide for managing teak defoliator populations. Hybcheck is a freeze-dried powder formulation containing virulent polyhedra of the Nuclear Polyhedrosis Virus which is highly specific to the teak defoliator. The NPV is a double stranded DNA virus with molecular weight ranging from 79.37-112.14 kbp. Field trials during outbreaks showed that the product was able to provide 70 percent foliage protection. The product has sufficient shelf life and is able to kill the pest insect within 48 hours of application. Being a naturally occurring pathogen, application of Hybcheck helps to amplify the natural inoculum load in the ecosystem. When fed at a sublethal dose, Hybcheck will get transmitted from one generation to the next in a process called as vertical transmission which would trigger epizootics of NPV in the outbreak populations of the insect.. Through this first contribution to eco-friendly pest management, Hybcheck is a step towards green certified timber products from teak plantations.

Keywords: Biopesticide, Hybcheck, *Hyblaea puera*, teak defoliator.

INTRODUCTION

The teak defoliator, *Hyblaea puera* Cramer- first recognized as a pest of teak (*Tectona grandis* Linn.f) at the Nilambur plantations by Bourdillon (1898) is now ranked as the most serious pest of the living teak tree. This pest defoliates the tree almost completely causing 44% decline in its potential volume increment (Nair *et al*., 1985). When the population density of the pest is very high, the terminal bud is eaten off leading to forking of the main bole which considerably affects the form of the tree and diminishes growth. Multiple outbreaks are a regular annual feature in teak plantations with a maximum recorded frequency of 6 in a year. Efforts to control this pest have focused on chemical pesticides like the aerial application of Endrin at Konni and Malathion, (Basu Chawdhury, 1971), Carbaryl and Fenitrothion at Madhya Pradesh (Singh *et al*., 1978). This is considered undesirable owing to the environmental hazard involved. The use of natural enemies like the larval parasitoid *Sympiesis hyblaeae*, egg parasitoids *Trichogramma dendrolimi*, *T. embryophagum* (Sudheendrakumar, 1997) is made difficult because of inability to predict outbreaks. The bacteria *Bacillus thuringiensis* var *thuringiensis* and *Enterobacter aerogenes* are also infectious to teak defoliator (Sudheendrakumar, 1988) but have a broad host spectrum much like the chemical pesticides, making them unsuitable for the use in the forest ecosystem. The occurrence of individual trees unattacked by teak defoliator amidst completely defoliated trees gave some hope of identifying teak defoliator resistant teak. However it was found that the trees escaped outbreaks not due to genetic resistance but what can be called as phonological (?) resistance wherein the trees without tender foliage during the arrival of moths for egg laying, escapes defoliation (Nair *et al.*, 1997). No resistance has thus been observed in teak, against the teak defoliator. In this paper we unveil and describe the biopesticide Hybcheck which can be safely used to manage teak defoliator populations.

ORIGIN

Large scale deaths of teak defoliator larvae characterized by cessation of feeding, flaccidity and subsequent liquefaction of body tissues have been reported by Stebbing as early as 1903. However, the discovery of the causative pathogen had to wait until a systematic screening of microbial pathogens of teak defoliator was undertaken in the Nilambur teak plantations in 1985. Several dead insects with characteristic symptoms as observed by Stebbing were collected and microscopic observations of tissues revealed the presence of refractile polyhedral inclusion bodies which stained blue in Giemsa and measuring 0.9-2.4 µm in diameter in the scanning electron micrograph. NPV extracted from the diseased larvae was used for pathogenicity tests. Healthy laboratory reared teak defoliator larvae were fed with teak leaves sprayed with an aqueous suspension of NPV. The feeding rate of the larvae declined on the second day and the larvae stopped feeding on the third day. The larvae become sluggish with flaccid bodies and died within 4-5 days.

MODE OF ACTION

The NPV which enters the insect gut lyses in the alkaline environment of the mid gut releasing virions. Virions invade the columnar cells of the midgut epithelium and release the DNA into the nucleus of the midgut cells. At this point, a virogenic stroma can be observed in the host cell nucleus, during which the viral DNA takes over control of the cellular machinery to reproduce itself. The progenies which are released to the haemocoel from the midgut cells are not the PIB, but what is called the Extra Cellular Virus. They are a thousand times more infectious than the PIB and mediate disease spread within the insect body. A rapid spread of infection in the insect body leads immediately to cessation of feeding and later on to death. However, this route of entry and spread of infectious particles can be bypassed as in the case of AcMNPV, where some of the parental virions pass through the plasma membrane reticular system of the midgut cells and directly infect the haemocytes.

In the case of *Hyblaea*, we observed that within 4 hours of ingesting PIBs, infectious particles are present in the haemolymph. This suggests that the source of infection could be parental nucleocapsids that pass directly into the haemolymph through the midgut. The time required for viral replication and production of PIBs is less than 4 h in the case of HpNPV infection in *Hyblaea puera*. Even in the fully mature larvae of the teak defoliator, HpNPV can cause a kill in 60-72 hours, making it one of the fastest acting insect viruses.

MASS PRODUCTION

Baculoviruses can be produced only in live host cells. For producing adequate quantity of HpNPV for field application, healthy *Hyblaea puera* larvae reared in the laboratory or collected from the field are fed with low dose of HpNPV and the virus produced in the insect is harvested. The protocol for production of Hybcheck which includes the inoculation dose, incubation time, extraction and purification have been standardized by KFRI. A three piece rearing tube made of polypropylene has been specially designed for the rearing and incubation of teak defoliator larvae. The statistics of mass production of Hybcheck is given in Table 1.

Early fourth instar larvae falling in the weight range of 0.027 - 0.036 g have been found ideal for mass producing HpNPV. Of the various methods of inoculation, spraying the inoculum to artificial diet surface has been found to be the method with least loss of inoculum. When an input dose of 1 x 10^5 PIBs/larvae is given and the larvae incubated for a period of 72 h, the NPV retrieved from a single larva is 3.3 x 10^9 PIBs. This is a magnification of HpNPV quantity by 33,000 times.

FORMULATION

There are more reasons than one for converting the crude virus into a formulated product. Formulation prevents replication of any contaminant microorganisms during the storage period and improves shelf life by providing protection against extreme temperatures and incident ultraviolet radiation. The biological activity of the virus is better retained when formulated. The formulation can also contain additives like stickers, spreaders, wetters, thickeners and protectants which provide hassle-free application of the virus which can persist long at the target site.

Seven types of formulations have been synthesized, five being wettable powders, one, flowable concentrate and one microencapsulated product. Laboratory bioassays indicated that the wettable powder synthesized using freeze drying procedure provided the best retention of biological activity of NPV.

APPLICATION

The freeze-ried formulation of HpNPV was field tested in the Valluvasery teak plantations of Nilambur. The formulation was mixed in water at a dosage of 2 x 10^4 PIBs/ml. Each tree within the treatment plot was individually sprayed using a motorized high volume sprayer. Two controls were set- one untreated plot and a plot sprayed with unformulated NPV. It was found that the formulated product could provide 18.47% additional foliage protection than the unformulated HpNPV (Mahiba, 2005). Hybcheck was put to use in controlling the epicentre populations of teak defoliator during the year 2006 and Nilambur North and South Forest Divisions and for protecting young plantations, thereafter.

Table 1. Hybcheck mass production statistics

1	Ideal stage of the insect	Early fourth instar
2	Ideal weight of the insect	0.027-0.036 g
3	Inoculation method	Spraying on to artificial diet in rearing tubes
4	Input dose of HpNPV	1 x 10^5 PIBs / larvae
5	Incubation period	72 h
6	HpNPV yield	3.3 x 10^9 PIBs / larvae

ADVANTAGES

The major advantages of Hybcheck are the following:

a. Target specificity

Hybcheck possesses the target specificity demanded by a pesticide to be used in the teak ecosystem. Cross infectivity studies on insects like *Achaea janatha, Atteva fabriciella, Catopsilla crocale, Eligma narcissus, Eutechtona macheralis* and *Bombyx mori* were all tested negative. It has been proved to cause no cytotoxic effect on Sf 9 (*Spodoptera frugiperda* ovarian), Hep2 (Human larynx) ad Vero (African Green Monkey kidney) cell lines. It was also found safe against the Indian Mynah during our *in vivo* studies.

b. Horizontal transmission

Within a large population if a few larvae are infected by the virus, they die within 2-3 days and a large amount of virus is released in the field. This secondary inoculum spreads the disease to healthy insects within the population. Thus when we use HpNPV, unlike the inert chemical pesticides, a magnified effect is seen. Horizontal transmission helps us to device a variety of spray schedules-from lattice spraying to strip spraying.

c. Vertical Transmission

By way of trans-ovum (egg surface contamination) and trans-ovarian (presence of virus within the egg) modes, HpNPV can transmit from one generation to the next. This happens when the late larval instars imbibe sub-lethal dose of HpNPV. The larvae do not die but live on, infected. The virus particles will either be in the inert phase or in the sub-lethal infection phase while the larvae mature to pupae and then to adult. If the virus is in the inert mode, it gets transmitted from the female adult to the eggs by trans ovarian transmission and if in the sub–lethal infection mode, it will be transferred to the next generation by egg surface contamination.

d. Magnification

Giving a hundred viral particles to the teak defoliator will cause infection, and by the time it dies, there will be 1300000000PIBs within it. Once dead, the virus will be released which would cause infection in other healthy insects. Thus, unlike other pesticides, more Hybcheck works to suppress the insect population than we apply. This amplification is the major factor which makes the Hybcheck able to contain large scale epidemics.

e. Fast kill

Hybcheck kills the host insect faster than any other known Baculovirus. While most of the Baculovirus take more than 100 hours to kill the host insect, Hybcheck does it in 60-70 hours depending on the larval age.

f. Ease of application

Hybcheck can be applied using a variety of spraying equipments ranging from high volume, low volume and ultra low volume applicators.

CONCLUSION

Hybcheck is a new addition to the repertoire of measures undertaken in tropical forestry to reduce environmental hazards. The *Hyblaea* pest complex is prevalent in all teak growing countries in varying population levels. While in South and South-east Asian countries teak defoliator outbreaks are regular annual feature, in Latin American countries, isolated outbreaks have been reported and in Africa, outbreaks have not been reported in spite of the long presence of the insect. Hybcheck holds the promise to contain teak defoliator populations below economic threshold levels without environmental hazards.

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Regeneration of Trees in the Teak Plantations of Parambikulam Wildlife Sanctuary, Kerala, India

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ABSTRACT

The Parambikulam Wildlife Sanctuary is located in the Palakkad District of Kerala, India. Substantial teak bearing forests of Parambikulam valley have been clear-felled in the past for timber. Subsequently, most of the clear-felled forest areas were planted with teak. At present, teak plantations occupy about 87 km^2, out of the 285 km^2 area of the Sanctuary. The oldest plantations in the Sanctuary are those raised in 1916 and the youngest in 1983. The management plan of the Sanctuary proposes re-conversion of the teak plantations by promoting the growth of indigenous species. Therefore, a study was undertaken to assess the regeneration of tree species in the teak plantations of the Sanctuary. The study revealed that in the teak plantations almost all tree species of the neighboring natural forests have regenerated and some have attained the size of trees. Regeneration of indigenous species has been better in the plantations adjacent to semi-evergreen forest. The number of species regenerated in the plantations near moist deciduous forests is 43 while it is 50 in the plantations near semi-evergreen forests. Among the regenerated species, teak is the second dominant species in all plantations except in the age group 1955-1975, where it is the fourth dominant species. In the moist deciduous forests of the Sanctuary, teak is the fifth dominant species (with 11 trees/ha) among the 29 tree species, while teak is only the 49th species (with 4 trees/ha) among the 69 species in the semi-evergreen forests. The average number of seedlings of indigenous species in the plantations varies from 4213 per ha near moist deciduous (30 species) to 1765 near semi-evergreen forests (66 species). However, 85 percent of the seedlings are below 1 m height indicating the heavy mortality of young seedlings.

Keywords: Teak plantation, Parambikulam, natural regeneration, indigenous species.

INTRODUCTION

Plantation forestry is an alternative measure to meet the demand for the desired species. However, it has several demerits. Being generally monocultures, pests and diseases are associated with plantation species. Moreover, plantations are generally known to adversely affect the biodiversity of the forests. This has led to the concept of managing natural forests, keeping their original structure and diversity undisturbed and promoting natural regeneration. The concept of protecting biodiversity is being increasingly felt nowadays. Thus the practice of sustainable management and utilization of natural forest resource is given greater attention.

Wildlife Sanctuaries and National Parks are essentially meant for conserving biological diversity and natural ecosystems. In the State of Kerala, about 24 percent of the forests have been brought under protected areas through the establishment of 12 Wildlife Sanctuaries and two National Parks. The Parambikulam Wildlife Sanctuary is one among them. The flora of the Sanctuary has been recently studied. The Sanctuary possesses an amazingly rich flora including several endemic as well as rare and threatened species (Sasidharan, 2002). In the Sanctuary, teak is the major plantation species, occupying 87 km^2 out of the 285 km^2 area of the Sanctuary.

The Management Plan of the Sanctuary proposes reconversion of the plantations and to promote the growth of indigenous species through appropriate management practices (Uniyal, 1987). A study was taken up to assess the regeneration and growth patterns of indigenous tree species in plantations of different age groups and in the neighbouring natural forests.

STUDY AREA

The Parambikulam Wildlife Sanctuary is located in the Chittur Taluk of Palakkad district, Kerala, India, between longitudes 76^0 35' and 76^0 50' East and latitudes 10^0 20' and 10^0 26' North. Topographically, the Sanctuary exhibits hilly terrain with characteristic distribution of undulating plain areas with *Vayals* (marsh lands) interspersed in the valleys. The Kuchimudi peak (1169 m) is the North-eastern mark of the Sanctuary. From here the hills drop steeply down the Thekkady-Keerapadi valley in the South-west and again rise precipitously up to Pandaravaramalai. The hills slope down relatively gently towards South to Thunacadavu Valley of Sungam area. Here, the valley is fairly large and abruptly ascends southwards to Vengoli malai (1224 m). From the North-west, the Nelliampathy hills descend gradually and open up in Thuthampara, Tellikkal and Parambikulam valley. This is the widest valley area in the Sanctuary. The valley gives way to the rising hills in Poopara and Karimala areas where the highest peak ‘Karimala Gopuram’ (1430 m) and its associated hills constitute the southern boundary of the Sanctuary. The valleys are low lying, having a gentle undulating surface and are covered with the artificially regenerated teak plantations. The distribution of *Vayals* is significant here. The altitude varies from 300 m to 1430 m, but the larger chunk of the Sanctuary has an average height of about 600 m (Uniyal, 1987).

The water from the West flowing rivers of the Sanctuary is collected in three dams commissioned under Parambikulam Aliyar Project (Tamil Nadu) during early 1960s. These are Parambikulam, Thunacadavu and Peruvaripallam. All the three dams are located in Parambikulam-Thunacadavu valley and a substantial quantity of water is diverted to the State of Tamil Nadu through tunnels and open channel systems.

The area gets South-west and North-east monsoons, South-west being the most active. About 80 percent of the Sanctuary area lies in the windward side and therefore the Sanctuary receives heavy rainfall during the South-west monsoon. Average annual precipitation is 1723 mm.

The maximum temperature fluctuates between 24 and 33° C and minimum between 20 and 25° C. In the hills it would be still lower during night. February, March and April are the hottest months. The relative humidity is low. November and December are fairly cool in the valley during mornings and late evenings but are comfortably warm during day hours. Dry season lasts for 5-7 months.

Vegetation

Natural vegetation of the Sanctuary is a combination of Malabar and Deccan elements.

Microclimatic fluctuations coupled with edaphic, topographic and biotic factors have provided the Sanctuary with a high floral diversity.

By following Chandrasekharan (1962) and Champion and Seth (1968) the natural vegetation of the Sanctuary can be classified into West coast tropical evergreen forests, West coast tropical semi evergreen forests, Southern moist mixed deciduous forests, Southern dry mixed deciduous forests, low altitude marshy grasslands *(vayals)*, moist bamboo brakes and reed brakes. Teak is the major plantation species which covers an area of about 87 km^2.

MATERIALS AND METHODS

Details pertaining to the teak plantations in the Sanctuary such as year of planting, extent, silvicultural thinning operations, etc. were compiled from the management plans and relevant records available. The oldest teak plantations now in Parambikulam were raised in 1916 and youngest in 1983. In order to study regeneration pattern of the indigenous species, their succession, etc. the plantations were categorised into four broad age classes of 20 years interval. Thus, the plantations in the Sanctuary are grouped into the age classes 1916-1935, 1936-1955, 1956-1975, 1976 and above. Based on the extent of area, year of planting and silvicultural operations carried out, 67 sample plots were laid out in these plantations. For determining the frequency, density and dominance of trees, sample plots of 30 m x 30 m were laid out. These sample plots were further divided into nine subplots of 10 m x 10 m. All trees greater than 10 cm gbh were enumerated from the nine subplots within 30 m x 30 m plots. Enumeration of plants below 10 cm gbh was carried out in the 10 m x 10 m subplots at the opposite ends (extremity of the diagonal line). Plants of tree species below 10 cm gbh were classified into different height classes such as <20 cm, 20-40 cm, 40-60 cm, 60-80 cm, 80-100 cm, 1-2 m, 2-3 m and >3 m. Enumeration of shrubs was carried out in 5 m x 5 m sample plots within 10 m x 10 m subplots at the opposite ends.

To compare the composition and the regeneration pattern in the natural forests and teak plantations, 17 sample plots of 30 m x 30 m were laid out in the natural forests adjacent to the plantations. Enumeration of trees, seedlings, and shrubs was carried out in the same way as in the plantations.

The data generated from the sample plots in the plantations and natural forests were analysed to find out the number of teak trees per ha; the number of indigenous trees per ha, their density, frequency, relative density, relative frequency, relative basal area and importance value index (Mueller-Dombois and Ellenberg, 1974). The Maturity Index values of regeneration in different age classes were worked out for qualitative comparison (Pichi-Sermolli, 1948). The seedlings were analysed to find out the number of each species belonging to various height classes and their dominance in plantations and natural forests. The shrubs were analysed to find out their number per ha as well as the percentage of each species. The percentage of *Eupatorium* and *Lantana*, the major exotic weeds in the plantations and natural forests was assessed.

RESULTS

Composition of trees in teak plantations of different age class

In the age class 1916-1935, the average number of teak trees is 65/ha and the average number of other trees is 170/ha (belonging to 16 species). In the age class 1936-1955, the average number of teak trees is 112/ha and the average number of other trees is 131/ha (belonging to 14 species). In the age class 1956-1975-near moist deciduous forests, the average number of teak trees is 258/ha and the

Table 1. Composition of trees in teak plantations; Age class: 1916-1935

Species	D	F	RD	RF	RBA	IVI	IND
Tectona grandis	72.22	100	27.66	16	85.6	129.26	65
Cassia fistula	61.11	100	23.4	16	1.13	40.53	55
Catunaregam torulosa	37.5	75	14.36	12	0.13	26.49	34
Terminalia paniculata	20.83	37.5	7.98	6	5.83	19.81	19
Casearia wynaadensis	19.44	50	7.45	8	0.67	16.12	18
Diospyros montana	13.89	50	5.32	8	0.17	13.49	13
Xylia xylocarpa	11.11	50	4.25	8	1.68	13.93	10
Dalbergia latifolia	5.56	25	2.13	4	3.09	9.22	5
Tabernaemontana heyneana	5.56	25	2.13	4	0.09	6.22	5
Trewia nudiflora	2.78	25	1.06	4	0.01	5.07	3
Lagerstroemia microcarpa	2.78	12.5	1.06	2	1.14	4.2	3
Dillenia pentagyna	1.39	12.5	0.53	2	0.24	2.77	1
Syzygium cumini	1.39	12.5	0.53	2	0.13	2.66	1
Wrightia tinctoria	1.39	12.5	0.53	2	0.09	2.62	1
Antidesma acidum	1.39	12.5	0.53	2	0	2.53	1
Bauhinia malabarica	1.39	12.5	0.53	2	0	2.53	1
Grewia tiliifolia	1.39	12.5	0.53	2	0	2.53	1
Total			**100**	**100**	**100**	**300**	**235**

D- Density, F- Frequency, RD-Relative Density, RF- Relative Frequency, RBA- Relative Basal Area, IVI- Importance Value Index, IND- Individuals per ha

average number of other trees is 216/ha (belonging to 43 species). In the age class 1956-1975-near semi-evergreen forests, the average number of teak trees is 225/ha and the average number of other trees is 368/ha (belonging to 50 species). In the age class 1976 and above the average number of teak trees is 260/ha and the average number of other trees is 176/ha (belonging to 7 species).

Data on density, frequency, relative density, relative frequency, relative basal area and importance value index of teak and other trees inplantations of the four age classes are provided in Tables 1, 2, 3, 4 and 5.

Regeneration of tree species in teak plantations

In the age class 1916-1935, the average number of seedlings is 4213/ha (representing 30 species). Among the seedlings, 68 percent belong to the height classes below one metre (Figure 1). *Catunaregam torulosa, Tectona grandis, Syzygium cumini, Grewia tiliifolia, Bauhinia malabarica* and *Cassia fistula* are the dominant species. In the age class 1936-1955, the average number of seedlings is 1765/ha (representing 37 species). Among the seedlings, 84 percent belong to the height classes below one metre (Figure 2). *Catunaregam torulosa, Tectona grandis, Zizyphus glabrata, Dalbergia latifolia, Grewia tiliifolia* and *Xylia xylocarpa* are the dominant species. In the age class 1956-1975-Near moist deciduous forests, the average number of seedlings is 2982/ha (representing 53 species). Among the seedlings, 84 percent belong to the height classes below one metre (Figure 3). *Catunaregam torulosa, Tectona grandis, Zizyphus glabrata, Xylia xylocarpa, Bauhinia racemosa, Persea macrantha* and *Grewia tiliifolia* are the dominant species. In the age class 1956-1975 near semi-evergreen forests, the average number of seedlings is 3859/ha (representing 66 species). Among the seedlings, 81 percent belong to the

Table 2. Composition of trees in teak plantations; Age class: 1936-1955

Species	D	F	RD	RF	RBA	IVI	IND
Tectona grandis	124.79	100	46.2	18.57	88.17	152.94	112
Cassia fistula	34.19	84.62	12.66	15.72	1.41	29.79	31
Diospyros montana	24.79	61.54	9.18	11.43	0.53	21.14	22
Xylia xylocarpa	22.22	38.46	8.23	7.14	2.67	18.04	20
Trewia nudiflora	14.53	38.46	5.38	7.14	0.43	12.95	13
Casearia esculenta	13.68	46.15	5.07	8.57	0.24	13.88	12
Lagerstroemia microcarpa	9.4	30.77	3.48	5.71	2.92	12.11	8
Terminalia paniculata	6.84	30.77	2.53	5.71	2.74	10.98	6
Holarrhena antidysenterica	5.13	23.08	1.9	4.29	0.11	6.3	5
Dillenia pentagyna	4.27	23.08	1.58	4.29	0.44	6.31	4
Wrightia tinctoria	3.42	23.08	1.27	4.29	0.08	5.64	3
Antidesma acidum	2.56	15.38	0.95	2.86	0.01	3.82	2
Tabernaemontana heyneana	2.56	7.69	0.95	1.43	0.05	2.43	2
Lagerstroemia reginae	0.85	7.69	0.31	1.43	0.18	1.92	1
Actinodaphne malabarica	0.85	7.69	0.31	1.43	0.01	1.75	1
Total			**100**	**100**	**100**	**300**	**243**

D- Density, F- Frequency, RD-Relative Density, RF- Relative Frequency, RBA- Relative Basal Area, IVI- Importance Value Index, IND- Individuals per ha

height classes below one metre (Figure 4). *Cinnamomum malabathrum, Pterospermum reticulatum, Zizyphus glabrata, Tectona grandis, Actinodaphne malabarica, Catunaregam torulosa,* and *Grewia tiliifolia* are the dominant species. In the age class 1976 and above, the average number of seedlings is 2975/ha (representing 16 species). Among the seedlings, more than 85 percent belong to the height classes below one metre (Figure 5). *Catunaregam torulosa, Cassia fistula, Tectona grandis, Dalbergia latifolia* and *Tamarindus indica* are the dominant species.

DISCUSSION

In the teak plantations of all age classes, the number of naturally regenerated trees per ha is more than the number of existing teak trees. In Orukomban and Karimala Ranges in the age class 1956-1975 near semi-evergreen forests the average number of indigenous trees (50 species) per ha is 368 and near moist deciduous forests 216 trees per ha belonging to 43 species. However, their total basal area is very low when compared with the basal area of teak. The average number of seedlings of tree species per ha in the plantations this age class near semi-evergreen forests is 2982 (53 species) and 3859 (66 species) near moist deciduous forests. Thirty two tree species growing in the neighbouring semi-evergreen forests and 8 in the moist deciduous forests have not regenerated in the plantations. Teak is the second dominant species among the regeneration except in the plantations of the age class 1955-1983. Among the established seedlings (>1 m height) teak is the most dominant species in all the plantations.

On compariing the dominant tree species based on importance value index (IVI), species with high ‘ecological efficiency’ with varying conditions for the period of 67 years (*ie.*, 1916-1983) were found to be *Tectona grandis, Cassia fistula, Casearia esculenta* and *Catunaregam torulosa*. The qualitative similarity of 60 percent was observed with the oldest age class of 1916-1935 to that of

Table 3. Composition of trees in teak plantations – near moist deciduous forests; Age class: 1956-1975

Species	D	F	RD	RF	RBA	IV	IND
Tectona grandis	286.83	100	55.63	14.36	82.06	152.05	258
Cassia fistula	24.69	66.67	4.79	9.57	1.06	15.42	22
Terminalia paniculata	22.22	29.63	4.31	4.26	5.48	14.05	20
Wrightia tinctoria	21.4	22.22	4.15	3.19	0.53	7.87	19
Xylia xylocarpa	18.11	40.74	3.51	5.85	2.27	11.63	16
Diospyros montana	17.28	48.15	3.35	6.92	0.35	10.62	16
Catunaregam torulosa	14.81	37.04	2.87	5.32	0.14	8.33	13
Lagerstroemia microcarpa	14.4	51.85	2.79	7.45	1.56	11.8	13
Chionanthus mala-elengi	11.93	7.41	2.31	1.06	0.32	3.69	11
Macaranga peltata	9.88	18.52	1.92	2.66	2.03	6.61	9
Trewia nudiflora	9.47	25.93	1.84	3.72	0.29	5.85	9
Ixora brachiata	9.05	7.41	1.76	1.06	0.11	2.93	8
Tabernaemontana heyneana	9.05	37.04	1.76	5.32	0.2	7.28	8
Casearia esculenta	5.76	25.93	1.12	3.72	0.07	4.91	5
Phyllanthus emblica	3.7	14.81	0.72	2.13	1.01	3.86	3
Zizyphus glabrata	3.7	11.11	0.72	1.6	0.08	2.4	3
Alangium salvifolium	3.29	7.41	0.64	1.06	0.02	1.72	3
Schleichera oleosa	3.29	11.11	0.64	1.6	0.06	2.3	3
Blepharistemma serratum	2.88	3.7	0.56	0.53	0.02	1.11	3
Mallotus philippensis	2.88	14.81	0.56	2.13	0.03	2.72	3
Dalbergia latifolia	2.47	11.11	0.48	1.6	0.93	3.01	2
Antidesma acidum	2.06	14.81	0.4	2.13	0.01	2.54	2
Bauhinia malabarica	2.06	7.41	0.4	1.06	0.21	1.67	2
Glochidion ellipticum	2.06	3.7	0.4	0.53	0.04	0.97	2
Grewia tiliifolia	1.65	7.41	0.32	1.06	0.53	1.91	1
Vitex altissima	1.65	3.7	0.32	0.53	0.05	0.9	1
Stereospermum colais	1.23	3.7	0.24	0.53	0.16	0.93	1
Casearia wynaadensis	0.82	3.7	0.16	0.53	0.04	0.73	1
Neolitsea cassia	0.82	3.7	0.16	0.53	0.02	0.71	1
Adina cordifolia	0.41	3.7	0.08	0.53	0.04	0.65	1
Aporusa lindleyana	0.41	3.7	0.08	0.53	0	0.61	1
Bridelia retusa	0.41	3.7	0.08	0.53	0.12	0.73	1
Carallia brachiata	0.41	3.7	0.08	0.53	0	0.61	1
Cordia dichotoma	0.41	3.7	0.08	0.53	0.02	0.63	1
Dillenia pentagyna	0.41	3.7	0.08	0.53	0.02	0.63	1
Litsea coriacea	0.41	3.7	0.08	0.53	0	0.61	1
Mallotus tetracoccus	0.41	3.7	0.08	0.53	0	0.61	1
Radermachera xylocarpa	0.41	3.7	0.08	0.53	0.02	0.63	1
Santalum album	0.41	3.7	0.08	0.53	0	0.61	1
Sapindus laurifolius	0.41	3.7	0.08	0.53	0	0.61	1
Spondias pinnata	0.41	3.7	0.08	0.53	0.01	0.62	1
Syzygium cumini	0.41	3.7	0.08	0.53	0	0.61	1
Terminalia bellirica	0.41	3.7	0.08	0.53	0.02	0.63	1
Terminalia crenulata	0.41	3.7	0.08	0.53	0.06	0.67	1
Total			**100**	**100**	**100**	**300**	**474**

D- Density, F- Frequency, RD-Relative Density, RF- Relative Frequency, RBA- Relative Basal Area, IVI- Importance Value Index, IND- Individuals per ha

Table 4. Composition of trees in teak plantations – near semi-evergreen forests; Age class: 1956-1975

Species	D	F	RD	RF	RBA	IVI	IND
Tectona grandis	249.67	100	37.9	9.09	70.82	117.8	225
Trewia nudiflora	47.06	64.71	7.14	5.88	1.25	14.27	42
Diospyros montana	27.45	52.94	4.17	4.81	0.83	9.81	25
Tabernaemontana heyneana	23.53	52.94	3.57	4.81	0.58	8.96	21
Litsea coriacea	20.92	47.06	3.18	4.28	0.33	7.79	19
Macaranga peltata	20.26	52.94	3.08	4.81	4.53	12.42	18
Hydnocarpus pentandra	16.99	11.76	2.58	1.07	0.6	4.25	15
Aporusa lindleyana	16.34	29.41	2.48	2.67	0.34	5.49	15
Lagerstroemia microcarpa	16.34	58.82	2.48	5.35	2.57	10.4	15
Wrightia tinctoria	16.34	23.53	2.48	2.14	0.53	5.15	15
Pterospermum reticulatum	14.38	58.82	2.18	5.35	0.38	7.91	13
Chionanthus mala-elengi	13.73	29.41	2.08	2.67	0.33	5.08	12
Polyalthia fragrans	13.73	5.88	2.08	0.53	0.08	2.69	12
Actinodaphne malabarica	12.42	35.29	1.89	3.21	0.67	5.77	11
Grewia tiliifolia	12.42	23.53	1.89	2.14	2.5	6.53	11
Cinnamomum malabathrum	11.76	29.41	1.79	2.67	0.86	5.32	11
Mallotus philippensis	10.46	29.41	1.59	2.67	0.07	4.33	9
Xylia xylocarpa	9.8	11.76	1.49	1.07	1.18	3.74	9
Cassia fistula	9.15	35.29	1.39	3.21	0.78	5.38	8
Blepharistemma serratum	7.84	5.88	1.19	0.53	0.06	1.78	7
Terminalia paniculata	7.84	23.53	1.19	2.14	2.56	5.89	7
Cleistanthus collinus	7.19	17.65	1.09	1.6	0.31	3	6
Dalbergia latifolia	7.19	23.53	1.09	2.14	4.37	7.6	6
Alangium salvifolium	6.54	29.41	0.99	2.67	0.08	3.74	6
Dillenia pentagyna	5.23	17.65	0.79	1.6	0.39	2.78	5
Bauhinia malabarica	3.92	5.88	0.6	0.53	0.36	1.49	4
Ixora brachiata	3.92	11.76	0.6	1.07	0.03	1.7	4
Schleichera oleosa	3.92	11.76	0.6	1.07	0.17	1.84	4
Zizyphus glabrata	3.92	17.65	0.6	1.6	0.06	2.26	4
Mallotus tetracoccus	3.27	5.88	0.5	0.53	0.03	1.06	3
Olea dioica	3.27	23.53	0.5	2.14	0.26	2.9	3
Persea macrantha	3.27	17.65	0.5	1.6	0.14	2.24	3
Pterospermum rubiginosum	3.27	5.88	0.5	0.53	0.4	1.43	3
Sapindus laurifolius	3.27	17.65	0.5	1.6	0.03	2.13	3
Adina cordifolia	2.61	5.88	0.4	0.53	0.08	1.01	2
Flacourtia montana	2.61	5.88	0.4	0.53	0.23	1.16	2
Callicarpa tomentosa	1.96	11.76	0.3	1.07	0.09	1.46	2
Glochidion zeylanica	1.96	5.88	0.3	0.53	0.41	1.24	2
Baccaurea courtallensis	1.31	5.88	0.2	0.53	0.04	0.77	1
Bischofia javanica	1.31	5.88	0.2	0.53	0.18	0.91	1
Canthium travancoricum	1.31	5.88	0.2	0.53	0.06	0.79	1
Careya arborea	1.31	11.76	0.2	1.07	0.05	1.32	1
Chukrasia tabularis	1.31	5.88	0.2	0.53	0.01	0.74	1
Psidium guajava	1.31	5.88	0.2	0.53	0.01	0.74	1
Santalum album	1.31	5.88	0.2	0.53	0.06	0.79	1
Catunaregam torulosa	0.65	5.88	0.1	0.53	0.01	0.64	1
Dimocarpus longan	0.65	5.88	0.1	0.53	0.05	0.68	1
Drypetes oblongifolius	0.65	5.88	0.1	0.53	0	0.63	1
Syzygium cumini	0.65	5.88	0.1	0.53	0.19	0.82	1
Solenocarpus indica	0.65	5.88	0.1	0.53	0.03	0.66	1
Spondias pinnata	0.65	5.88	0.1	0.53	0.01	0.64	1
Total			**100**	**100**	**100**	**300**	**593**

D- Density, F- Frequency, RD-Relative Density, RF- Relative Frequency, RBA- Relative Basal Area, IVI- Importance Value Index, IND- Individuals per ha

Table 5. Composition of trees in teak plantations; Age class: 1976 and above

Species	D	F	RD	RF	RBA	IVI	IND
Tectona grandis	288.89	66.67	59.54	18.18	49.92	127.64	260
Cassia fistula	129.63	66.67	26.72	18.18	36.71	81.61	117
Wrightia tinctoria	44.44	66.67	9.16	18.18	5.61	32.95	40
Syzygium cumini	3.7	33.33	0.76	9.09	5.18	15.03	3
Casearia wynaadensis	7.41	33.33	1.53	9.09	0.89	11.51	7
Cordia dichotoma	3.7	33.33	0.76	9.09	1.35	11.2	3
Psidium guajava	3.7	33.33	0.76	9.09	0.2	10.05	3
Dalbergia latifolia	3.7	33.33	0.76	9.09	0.14	9.99	3
Total			**100**	**100**	**100**	**300**	**436**

D- Density, F- Frequency, RD-Relative Density, RF- Relative Frequency, RBA- Relative Basal Area, IVI- Importance Value Index, IND- Individuals per ha

1936-1955 and 1956-1975, whereas only 40 percent similarity was observed when compared to the youngest age class 1976 and above. It is also observed that high weed growth of *Lantana* and *Eupatorium* in 1976 and above plantations. The low similarity value between high age group (1916-1935) and lowest age group (1976 and above) may due to the high weed growth, affecting the tree regeneration. The quantitative similarity studies in terms of number of individual species per unit area reveals that the difference between the oldest plantation in Parambikulam (*ie.*, 1916-1935) and forest plantation (*ie.*, 1976 above) is of 1.9 times. The respective values in 1936-1955 and 1956-1975 age class are 16.8 and 28.6 percent respectively (Table 6). The Maturity Index studies (Pichi-Sermolli, 1948) based on 10 dominant species in different age classes reveals that the oldest age

Table 6. Percentage of seedlings of different height classes in the plantations

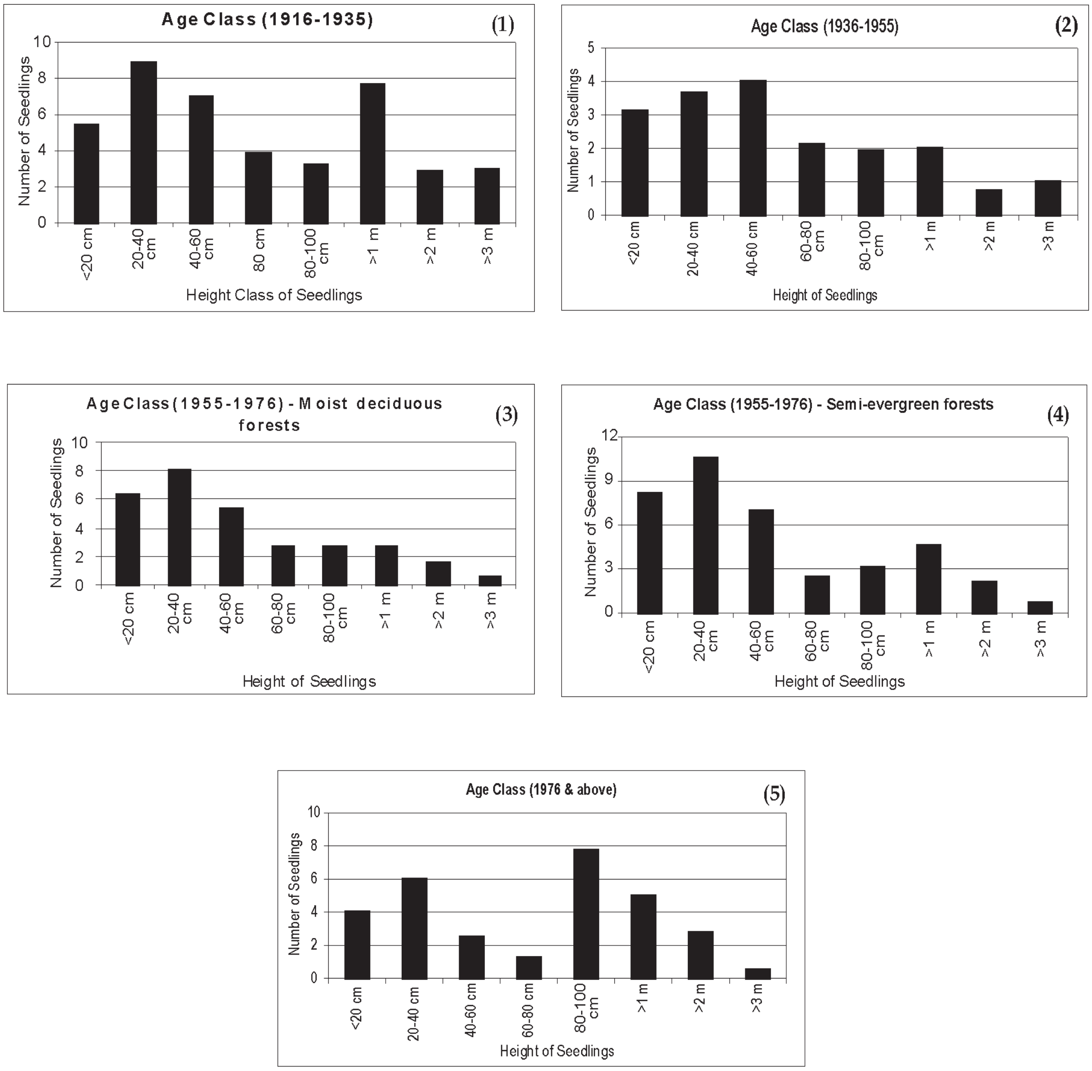
Height class (cm)	Age class (percent)			
	1916-1935	**1936-1955**	**1956-1975**	**1976 and above**
<20	12.9	17.6	21.2	13.4
20-40	21.2	20.7	26.8	20.2
40-60	16.6	22.7	17.8	8.4
60-80	9.3	12.0	9.0	4.2
80-100	7.7	10.9	9.1	26.1
> 100 (established seedlings)	32.2	16.1	16.0	27.7

Table 7. Maturity Index value of four age classes

No	Age class	Maturity Index (%)
1.	1916-1935	53.5
2.	1936-1955	47.7
3.	1956-1975	42.2
4.	1976 and above	45.8

group is having the Maturity Index of 53.5 (Table 7) indicating a more stable status of succession when compared to the youngest plantations.

Comparison of regeneration status of tree species in the four age classes reveals that species



Figs. 1-5. Regeneration of tree species in teak plantations of different age classes and natural forests

like *Catunaregam torulosa, Tectona grandis, Grewia tiliifolia, Xylia xylocarpa* along with habitat specific species like *Diospyros montana, Persea macrantha* and *Tamarindus indica* comprise the ‘Character Species’ covering major seedlings population of the classes (79 percent of class: 1916-1935; 74 percent of class: 1936-1955; 69 percent of class: 1956-1975 and 84 percent of class: 1976 and above). The structural manipulation of more desired species among the species mentioned above may enhance the qualitative status of vegetation in term of economic viability. The dominance of seedlings and saplings of *Catunaregam torulosa* among regeneration indicates fire incidence in the plantations.

In the Parambikulam Sanctuary the major weed is *Eupatorium odoratum*. Frequency of *Lantana camara* var. *aculeata,* though present in the plantations and natural forests, is less when compared with that of *Eupatorium*. In the teak plantations of the age class 1916-1935, *Eupatorium* forms 51.32 percent and *Lantana* 1.06 percent among the shrubs. In the age class 1936-1955, *Eupatorium* forms 53.24 percent and *Lantana* 6.08 percent. In the age class 1956-1975, *Eupatorium* forms 67percent and *Lantana* 25 percent among the shrubs.

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Effect of Elevated CO_2 Concentration on Initial Growth of Teak (*Tectona grandis*) Seedlings

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ABSTRACT

Teak (*Tectona grandis*) is a reputed timber known for its strength, durability and attractive appearance, and is one of the most favored timbers all over the world. The ever-increasing demand for teak timber has resulted in large-scale plantations both within and outside its range of natural distribution. In India, every year teak plantations are raised in more than 50,000 ha. Robust and healthy teak seedlings are pre-requisite for any successful afforestation and plantation programmes. Growing of plants in an elevated CO_2 concentration is found to increase the growth rate of tree seedlings. The ambient CO_2 is enhanced by trapping the CO_2 released during dark respiration of the seedlings and also from soil respiration. Hence, trenches of 2.5 m length, 0.75 m width and 1 m depth were made in a place exposed to sunlight. The trenches were covered by polythene sheets from 4.00 pm to 9.00 am everyday. Watering was done daily. The treatments consisted of control (ambient condition), elevated CO_2 treatment + organic matter (3, 6, 9, 12 and 15 kg organic matter) and elevated CO_2 treatment + no organic matter. The experiment was carried out in Completely Randomized Design with three replications. The growth parameters such as plant height, collar diameter, number of leaves, leaf area, total dry weight, sturdiness quotient and Seedlings Quality Index were recorded every month up to six months of planting. The growth was found to be higher in the treatment of elevated CO_2 + 3 kg organic matter. The increase in plant height, collar diameter and total dry biomass due to elevated CO_2 treatment with 3 kg OM was 53.34, 24.6 and 56.76 percent over control. The sturdiness quotient (6.72) of teak seedlings was also higher in the treatment. This higher growth rate of teak seedlings may be attributed to the higher levels of CO_2 concentration in addition to the higher relative humidity and temperature build up in the closed chambers. But exposure of seedlings to elevated CO_2 and adding more quantities of OM (>3 kg) did not result in significantly higher growth rate. Hence, it can be concluded that exposure of seedlings to the limited concentration of CO_2 will increase the plant growth rate in the initial stages.

Keywords: Biomass, seedling growth, CO_2 concentration, height and diameter, early growth.

INTRODUCTION

In the wake of global climate change, increase in CO_2 concentration in the atmosphere and its influence on ecosystem has inculcated a great deal of research during the last two decades. A lot of innovative techniques have been developed in order to use this increased CO_2 in a more useful way. One of the techniques is to create artificial condition to mimic the green house effect occurring in the atmosphere. Plants or terrestrial ecosystems are known to be one of the major sinks of CO_2. Again, when plants are exposed to elevated CO_2 concentration growth and productivity increases substantially. In plant system, higher growth rate and high biomass accumulation is due to the influence of CO_2 on various metabolic activities of plant (Devakumar *et al*., 1998).

Deforestation and burning of fossil fuels are two major reasons for accumulation of CO_2 in the atmosphere leading to global climatic changes. Currently, CO_2 concentration in the atmosphere is around 360 ppm and it is increasing at a rate of 1.8 ppm per year. Hence, afforestation is practically feasible way to address the global climatic changes especially in tropical countries. In India every year teak plantations are raised in more than 50,000 ha. Robust and healthy teak seedlings are pre-requisite for any successful afforestation and plantation programmes. Quality of teak products essentially depends on the quality of the wood, even though the processing technology is also an important factor (Chandrasekharan, 2003). Apart from that in the present crisis of global warming huge amount of carbon can be stored in the stem for its rotation period of 70-80 years and also later in the furniture or other byproducts.

Teak is the most widely cultivated quality hardwood species and has many advantages as a plantation grown species. Hence, in order to produce healthy and quality planting material a carbon enrichment technique is the best. The new technique is adopted to trap the CO_2 released during dark respiration of plants and soil respiration in trenches covered with polythene sheet which is efficient in enhancing CO_2, temperature and relative humidity (Prasanna *et al*., 1990).

MATERIALS AND METHODS

The experiment was conducted in Forest nursery at College of Forestry, Sirsi, Uttara Kannada district, Karnataka in 2006. The ambient CO_2 was enhanced by trapping the CO_2 released during dark respiration of the seedlings and soil respiration. One-month-old seedlings of teak grown in polybags were placed in the rectangular trenches measuring 2.5 m length, 0.75 m width and 1 m depth made in a place exposed to open sunlight. All the four sides of the cut ends of the trench were provided with a single layer of lining with bricks to avoid sliding of the edges. There were seven treatments consisting of seedlings exposed to ambient conditions (control), elevated CO_2, elevated CO_2 with 3, 6, 9, 12 and 15 kg organic matter spread uniformly all along the floor. All the trenches were covered with polythene sheet of 125 gauges mounted on bamboo structure. Seedlings were exposed to elevated CO_2 between 4 pm to morning 11 am. Water was sprinkled on the organic matter layer in trenches to stimulate soil respiration. The experiment was laid out in a Randomized Complete Block Design with three treatments. The plant growth parameters were recorded after 3 months of planting. To estimate the dry weight, different components of seedlings were oven dried at 60^0C for 48 hrs. The statistical analysis was carried out following Fischer's method (Snedecor and Cochran, 1967). Seedlings Quality Index (QI) was calculated following Dickson *et al.* (1960).

RESULTS AND DISCUSSION

The seedling growth parameters of *Tectona grandis* varied significantly due to their exposure to elevated CO_2 concentrations (Table 1). The growth parameters of teak seedlings were found to be higher in the treatment elevated CO_2 treatment with 3 kg organic matter. The higher seedling height due to elevated CO_2 treatment with 3 kg organic matter was significantly higher (20.90 cm) followed by elevated CO_2 treatment with 12 kg organic matter (19.14 cm) compared to control (13.63 cm) and elevated CO_2 treatment without organic matter (16.80 cm). Other growth parameters such as collar diameter, leaf area and root growth were also significantly higher due to exposure to elevated CO_2 concentration with 3 kg organic matter compared. The increase in plant height, collar diameter and total dry biomass due to elevated CO_2 treatment with 3 kg organic matter

Table 1. The growth and quality parameters of *Tectona grandis* seedlings as influenced by elevated CO_2 concentration

Treatments	Plant height (cm)	Collar diameter (mm)	No. of Leaves	Leaf Area (cm^2)	Root Length (cm)	No. of roots	Shoot biomass (g)	Root biomass (g)	Total biomass (g)	Sturdiness Quotient	Dickson's Quality Index
T_1 – Control (Ambient conditions)	13.63	2.48	2.88	16.25	8.83	5.33	1.39	3.14	4.81	5.56	0.81
T_2 – Elevated CO_2 treatment with 3 kg organic matter	20.90	3.09	3.60	46.91	11.08	11.17	3.52	4.08	7.54	6.72	0.90
T_2 – Elevated CO_2 treatment with 6 kg organic matter	17.52	2.92	3.71	53.80	9.13	8.50	2.46	3.78	6.23	6.00	0.94
T_2 – Elevated CO_2 treatment with 9 kg organic matter	17.33	2.71	4.09	49.96	10.45	8.00	2.58	3.63	6.20	6.39	0.87
T_2 – Elevated CO_2 treatment with 12 kg organic matter	19.14	2.90	3.63	36.02	9.80	10.67	3.08	3.08	6.96	6.60	0.94
T_2 – Elevated CO_2 treatment with 15 kg organic matter	18.22	2.93	5.67	44.46	11.00	10.17	2.62	3.97	6.59	6.22	1.70
T_2 – Elevated CO_2 treatment without organic matter	16.80	3.05	3.76	51.15	10.82	9.17	1.98	2.48	4.46	5.44	0.71
SEm (±)	0.66	0.16	0.45	1.42	0.87	1.44	0.38	0.86	1.88	0.025	0.19
CD (5%)	2.04	0.48	1.39	4.35	2.65	4.40	1.16	NS	NS	0.07	NS

was 53.34, 24.6 and 56.76 percent over control. The sturdiness quotient (6.72) of teak seedlings was also higher due to elevated CO_2 treatment with 3 kg organic matter indicating better quality of these seedlings. This higher growth rate of teak seedlings may be attributed to the higher levels of CO_2 concentration in addition to the higher relative humidity and temperature build up in the closed chambers. But exposure of seedlings to higher elevations by adding more quantities of organic matter (>3 kg) has not resulted in significantly higher growth rate. Hence, it can be concluded that exposure of seedlings to the limited concentration of CO_2 will increase the plant growth rate in the initial stages. Similarly, there was significant increase in collar diameter of both the species due to elevated CO_2 concentration. This might be due to increased use CO_2 for carbon assimilation. Evidences from literature show that it is possible to increase the biomass production by growing plants under elevated CO_2 (Kimball, 1983; Devakumar *et al*., 1996). The extent of increase in leaf area was to the tune of 231.1 percent in teak. Similar results of increased leaf area in plants grown under higher concentrations of CO_2 were reported by other workers (Ackerly *et al*., 1992; Masle *et al*., 1993). This higher leaf area has led to higher photosynthesis and in turn higher biomass production of 56.8 percent over ambient conditions. The elevated CO_2 treatment with organic matter resulted in higher collar diameter (3.09 cm), root length (11.08 cm) and number of roots (11.17) over ambient conditions.

The seedlings produced due to elevated CO_2 treatment with organic matter had significantly higher Sturdiness Quotient of 6.72 and Dickson's Quality Index of 0.90 indicating better quality of planting stock. Thus, it is evident that growth and quality of seedlings of *Tectona grandis* can be improved by exposing them to elevated CO_2 concentration using simple technique described in the study. This study clearly indicated that elevated CO_2 concentration by adding organic matter spreading in the trench substantially increases the concentration of the gas. When teak seedlings were exposed to such higher concentration of CO_2 the growth and development increases upto certain stage; higher to the optimum levels of CO_2 is harmful to the seedling which is reflected in poor growth performance.

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Assessment of Teak (*Tectona grandis*) Stands in Karnataka

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ABSTRACT

An extensive survey was undertaken by the Tree Improvement and Seed Production (TISP) wing of the Western Ghats Forestry Project for identification of the teak seed stands and plus tree selection. The survey could identify eight stands out of which two were located in Shimoga Circle and six in Uttara Kannada Circle in Karnataka. These plantations were enumerated for the assessment. Five percent sampling was done with 20m x 20m quadrats laid out systematically at an approximate distance of 80 m. However, care was taken to cover almost all the diversity with regard to species and topography. Out of these eight stands, three stands located in Chordi, Ganeshgudi and Gunjavathi were found to be the best teak stands. The investigation in these three stands indicated that, there were 8, 13 and 14 composite species associated with teak in Gunjavathi, Chordi and Ganeshgudi, respectively. The average stand height was 14.25, 17.43 and 23.61 m in Gunjavathi, Chordi and Ganeshgudi with 622, 444 and 610 trees per ha, respectively. Higher GBH and height were recorded in Ganeshgudi (92.79 cm and 30.21 m), followed by Chordi (87.88 cm and 16.82 m) and Gunjavathi (71.76 cm and 17.77 m). Teak trees in Ganeshgudi stand had clean bole height of 20.30 m with smaller branch diameter of 4.76 m and branch angle of 40.8^0. This stand had larger crown diameter (9.0 m) as compared to the other two stands. The stand had low density of teak with 168 individuals per ha with total basal area of 67.74 m^2 as compared to Gunjavathi (337/ha with BA of 13.82 m^2) and Chordi (336/ha with BA of 20.83 m^2), and hence Ganeshgudi stand had low IVI value of teak (67.74) and Gunjavathi 148.12 and Chordi 171.9. The observations indicated that, the Ganeshgudi stand is better as compared to other stands.

Keywords: Teak seed stands, plus tree selection, Shimoga, Karnataka, composite species.

INTRODUCTION

Teak (*Tectona grandis*) is paragon among Indian timbers because of its versatile use, easy workability and consistent resilience. It is one of the most favored timbers all over the world which is known for its strength, durability and attractive appearance. Obviously, it constitutes high-class furniture and one of the most sought after hardwoods in the international market (Ball *et al.*, 1999). The ever-increasing need for teak timber has resulted in large-scale plantations both within and outside its range of natural distribution. Besides raising large scale plantations of teak, it has become necessary to increase productivity. It is well recognized that intensive forest management activities will not yield maximum returns unless genetically superior trees are also used (Vasudeva *et al.*, 2005). It is also equally well accepted that no matter how excellent trees may be genetically, maximum production cannot be achieved unless good management practices are adopted along with improved plants. 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 (Katwal, 2003). The Tree Improvement and Seed Production (TISP) wing of the Western Ghat's Forestry Project has adopted both short term and long term strategies such as identification of the seed stands and plus tree selection respectively to achieve the main objectives of the project. Keeping these points in view, the present study was proposed to screen and assess teak stands for many of the phenotypic traits for supply of seeds for future afforestation of plantation programmes.

MATERIALS AND METHODS

An extensive survey was undertaken in Shimoga and Uttara Kannada circles of Karnataka to locate seed stands of teak for future afforestation or plantation programmes. Based on the superior phenotypic traits eight seed stands were screened out of which, two were located in Shimoga circle and six in Uttara Kannada circle. These plantations were enumerated with sampling intensity of 5% by laying quadrats of size 20m X 20m systematically at an approximate distance of 80 m. However, care was taken to cover almost all the diversity with regard to species and topography. These stands were enumerated and best three seed stands were identified based on cumulative value of various traits. These three stands located in Chordi, Ganeshgudi and Gunjavathi were found to be the best teak stands.

RESULTS AND DISCUSSION

Assessment of entire stand

The entire stands consisting of teak and other tree species were assessed in Gunjavathi, Chordi and Ganeshgudi forest areas in Shimoga and Uttara Kannada circle in Karnataka. Investigation of teak seed stands of Ganeshgudi indicated that, *Xylia xylocarpa* was most predominant species with Importance Value Index (IVI) value of 89.65 due to higher number of trees (163), total basal area (12.51 m^2) and frequency value (100%) (Table 1). It was followed by *Tectona grandis* which had 945 individuals with total basal area of 11.42 m^2 having frequency value of 100 percent. *Tectona grandis* had higher crown diameter (9.0 m) compared to *Xylia xylocarpa* (8.35 m). The least IVI was found in *Terminalia bellerica* (1.85).

In Gunjavathi, teak was represented by higher number of individuals of 323 with total basal area of 13.82 m^2 (Table 2). The average height and GBH was 17.77 m and 71.76 cm respectively. It had significantly higher bole height of 6.71 m and IVI value of 148.12 indicating substantially higher relative density, frequency and abundance. It was followed by *Anogeissus latifolia* with IVI value of 43.06 and *Terminalia paniculata* with IVI value of 41.04 and least IVI value of 1.36 was observed in *Butea frondosa* which had frequency value of 4.17 percent. Teak had maximum crown diameter of 6.67 m indicating its potential for larger scale seed production.

In Chordi also, teak was found to be predominant species with IVI value of 171.91 due to substantially higher number of trees (336), total basal area (20.83 m^2) and frequency value (100 %) (Table.3). It was followed by *Terminalia paniculata* (IVI = 37.11), *Xylia xylocarpa* (IVI = 22.72), *Lagerstroemia lanceolata* (IVI=37.11) and *Dalbergia latifolia* (IVI=16.77). The least IVI was found in *Lannea coromandelica* (1.95). The predominance of teak and its chief associates may be due to their adaptability and ecological success in these site conditions.

Assessment of entire stands of teak indicated that, there was 8, 13 and 14 composite species having an average stand height of 14.25, 17.43 and 23.61 m at Gunjavathi, Chordi and Ganeshgudi respectively (Table 4). These stands had density

Table 1. Composition and structure of teak seed stand situated in Ganeshgudi

Species	No. of trees	GBH (cm)	Height (m)	Bole ht (m)	Branch		Crown dia (m)	Basal area / tree	Total basal area	Freq (%)	Abund-ance	Rel density	Rel freque-ncy	Rel domina-nce	IVI
					Dia (cm)	Angle (^{0})									
Xylia xylocarpa	163.00	73.38	24.27	12.85	4.66	33.74	8.35	0.04	12.51	100.00	11.64	47.80	20.29	21.56	89.65
Tectona grandis	94.00	92.79	30.21	20.30	4.76	40.80	9.00	0.07	11.42	100.00	6.71	27.57	20.29	19.88	67.74
Terminalia paniculata	32.00	82.14	23.91	13.06	5.41	43.75	9.63	0.05	30.08	85.71	2.67	7.38	17.39	5.30	30.07
Lagerstroemia lanceolata	18.00	103.81	31.28	18.56	7.28	35.00	10.56	0.09	2.75	57.14	1.29	5.28	11.59	4.76	21.63
Maragouri	16.00	51.21	13.00	7.63	4.25	43.13	6.81	0.02	0.61	42.86	2.67	4.69	8.70	1.04	14.43
Dalbergia latifolia	4.00	82.43	25.50	16.75	6.75	35.00	8.00	0.05	0.38	58.57	1.00	1.17	5.80	0.67	7.64
Grewia tileifolia	4.00	104.41	24.25	9.75	10.00	30.00	13.00	0.09	0.61	21.43	1.33	1.17	4.35	1.07	6.50
Mallotus phillippinensis	3.00	73.79	17.50	9.00	7.57	45.00	9.50	0.04	0.22	14.29	1.00	0.88	2.90	0.40	4.18
Gound	2.00	84.78	26.50	17.50	5.00	25.00	10.50	0.06	0.23	7.14	1.00	0.88	1.45	0.35	2.68
Germal	1.00	65.94	18.00	7.00	5.00	10.00	5.00	0.04	0.07	7.14	1.00	0.29	1.45	0.11	1.85
Pterocarpus marsupium	1.00	97.34	32.00	23.00	7.00	60.00	11.00	0.08	0.15	7.14	1.00	0.29	1.45	0.24	1.98
Sagadi	1.00	103.62	34.00	25.00	4.00	45.00	7.00	0.09	0.17	7.14	1.00	0.29	1.45	0.27	2.01
Schleichiera oleosa	1.00	72.22	21.00	10.00	4.00	45.00	13.00	0.04	0.08	7.14	1.00	0.29	1.45	0.13	2.87
Terminalia bellerica	1.00	50.24	17.00	7.00	4.00	10.00	6.00	0.02	0.04	7.14	1.00	0.29	1.45	0.06	1.85

Table 2. Composition and structure of teak seed stand situated in Gunjavathi

Species	No. of trees	GBH (cm)	Height (m)	Bole ht (m)	Branch		Crown dia (m)	Basal area / tree	Total basal area	Freq (%)	Abund-ance	Rel density	Rel freque-ncy	Rel domina-nce	IVI
					Dia (cm)	Angle (^{0})									
Tectona grandis	323.00	71.76	17.77	6.71	8.88	36.38	6.67	0.04	13.82	100.0	13.46	54.10	25.00	69.02	148.12
Anogeissus latifolia	103.00	49.53	14.69	5.46	6.81	32.52	6.18	0.02	2.18	58.33	7.50	17.59	14.58	10.84	43.06
Terminalia paniculata	74.00	53.95	14.06	5.35	5.27	35.61	5.74	0.02	1.77	79.17	3.90	12.40	19.79	8.85	41.04
Xylia xylocarpa	47.00	42.64	11.91	3.72	5.81	36.81	5.06	0.02	0.74	33.33	5.88	7.87	8.33	3.67	19.87
Terminalia crenulata	23.00	54.35	13.65	4.70	7.13	38.91	5.09	0.02	0.58	50.00	1.92	2.85	12.50	4.05	19.40
Dalbergia latifolia	17.00	75.41	17.82	5.63	9.35	33.29	6.53	0.05	0.81	50.00	1.42	3.85	12.50	2.88	19.23
Careya arborea	7.00	44.43	11.00	4.71	6.71	39.29	6.14	0.02	0.11	25.00	1.17	1.17	6.25	0.56	7.98
Butea frondosa	1.00	54.00	17.00	1.06	3.00	20.00	5.00	0.02	0.02	4.17	1.00	0.17	1.04	0.15	1.36

Table 3. Composition and structure of teak seed stand situated in Chordi

Species	No. of trees	GBH (cm)	Height (m)	Bole ht (m)	Branch		Crown dia (m)	Basal area/tree	Total basal area	Freq (%)	Abund-ance	Rel density	Rel freque-ncy	Rel domina-nce	IVI
					Dia (cm)	Angle (^{0})									
Tectona grandis	336.00	87.88	16.82	7.44	5.61	45.67	8.53	0.06	20.83	100.00	13.44	75.68	130.49	82.74	171.91
Terminalia paniculata	39.00	64.69	15.18	6.10	3.82	46.03	8.67	0.03	1.29	76.00	2.05	8.78	23.17	5.16	37.11
Xylia xylocarpa	27.00	44.26	12.89	4.15	3.04	37.30	6.70	0.02	0.43	52.00	2.08	6.08	15.85	0.79	22.72
Lagerstroemia lanceolata	23.00	92.73	20.00	9.27	13.33	33.00	9.00	0.07	1.56	36.00	2.50	5.18	10.98	6.28	22.44
Dalbergia latifolia	11.00	71.64	19.73	9.27	3.55	54.09	6.73	0.04	0.45	32.00	1.36	2.48	12.50	1.79	16.77
A. musa	1.00	93.00	17.00	6.00	12.00	30.00	15.00	0.07	0.07	4.00	1.00	0.23	1.22	0.27	1.72
Bilvara	1.00	204.00	26.00	6.00	8.00	45.00	9.00	0.33	0.33	4.00	1.00	0.23	1.22	1.32	2.77
Careya arborea	1.00	44.00	9.00	9.00	3.00	30.00	4.00	0.02	0.02	4.00	1.00	0.23	1.22	0.06	1.51
Cassia fistula	1.00	48.00	13.00	6.00	2.00	90.00	5.00	0.02	0.02	4.00	1.00	0.23	1.22	0.07	1.52
Embelica offcinalis	1.00	28.00	9.00	5.00	2.00	10.00	3.00	0.01	0.01	4.00	1.00	0.23	1.22	0.02	1.47
Garuga pinnata	1.00	150.00	24.00	6.00	10.00	20.00	15.00	0.18	0.18	4.00	1.00	0.23	1.22	0.71	2.16
Grewia tileifolia	1.00	95.00	18.00	5.00	8.00	30.00	15.00	0.07	0.07	4.00	1.00	0.23	1.22	0.29	1.74
Lannea coromandelica	1.00	126.00	26.00	6.00	6.00	45.00	10.00	0.13	0.13	4.00	1.00	0.23	1.22	0.50	1.95

Table 4. Assessment of entire stands and teak trees in selected three teak seed stands in Shimoga and Uttara Kannada Circles Karnataka

Particulars	Gunjavathi	Chordi	Ganeshgudi
	I Entire stand		
1. Composite species	8.0	13.0	14.0
2. Stand height (m)	14.25	17.43	23.61
3. Tree density / ha	622.0	444.0	610.0
4. Total basal area (m^2)	20.02	25.38	32.41
	II Teak trees in the stand		
1. GBH (m)	71.76	87.88	92.79
2. Height (m)	17.77	16.82	30.21
3. Bole length (m)	6.71	7.44	20.36
4. Branch diameter (cm)	8.88	5.61	4.76
5. Branch angle (^{0})	36.38	45.67	40.80
6. Crown diameter (m)	6.67	8.53	9.00
7. Density / ha	337.0	336.0	168.0
8. Basal area / tree (m^2)	0.041	0.062	0.068
9. Total basal area / tree (m^2)	13.817	20.832	11.424
10. IVI	148.12	171.91	67.74
11. Health	> Moderate	> Moderate	Good

of 622, 444 and 610 trees per ha with basal area of 20.02, 25.38 and 32.41 sq. m. per ha, respectively.

Assessment of teak trees in the stand

The assessment of teak trees in the stand indicated that the higher GBH and height was recorded in Ganeshgudi (92.79 cm and 30.21 m) followed by Chordi (87.88 cm and 16.82 m) and Gunjavathi (71.76 cm and 17.77 m). The teak trees in Ganeshgudi stand had higher clean bole height of 20.30 m with smaller branch diameter of 4.76 cm and branch angle of 40.8^0 stand had larger crown diameter (9.0 m) compared to other two stands. This stand had low density of teak with 168 individuals per ha with total basal area of 67.74 m^2 compared to Gunjavathi (337/ha with BA of 13.82 m^2) and Chordi (336/ha with BA of 20.83 m^2) and hence Ganeshgudi stand had low IVI value of teak (67.74) compared to Gunjavathi (148.12) and Chordi (171.9). The visual experience could rate the Ganeshgudi stand as good, whereas other stands were moderate in their health.

CONCLUSION

The assessment of teak stands indicated that, three seed stands, i.e., Ganeshgudi, Gunjavathi and Chordi could be selected as seed stands and seeds can be collected from these stands for future afforestation or plantation programmes.

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Site Management of Planted Teak for Optimal Land Use

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ABSTRACT

In Kerala, teak (*Tectona grandis* Linn.f.) occupies an area of about 57,855 ha and constitutes about 50 percent of the area under forest plantations. Since there was wide variation in site quality classes in teak plantations, an attempt was made to study the site management of planted teak belonging to young age classes for optimal land use. Teak plantations in the major teak growing Forest Divisions of Kerala, *viz*., Achencoil, Konni, Ranni, Thenmala, Nilambur (North and South) and Wynad (North & South) were selected for the study. One plot was taken for every 10 ha with a maximum of 10 plots in any one plantation. Girth at breast height of all trees in the plots was measured. Height measurements were made on subsamples of trees in each plot. One soil pit was taken from each plot and samples collected from 0-20, 20-40 and 40-60 cm layers. The soils were analyzed for physical and chemical properties. In order to identify the factors by which the soils under different site quality classes differed, discriminate analysis was done. It was found that there was no general trend with respect to variation in soil properties in relation to different site quality classes. However, it was observed that soil physical properties and nutrients were the discriminating factors by which soils belonging to various site quality classes differed significantly. The study thus revealed that site management of planted teak for optimal land use was confined mainly to soil physical properties and nutrients, which calls for intensive soil working and nutrient management.

Keywords: Site management, optimal land use, discriminant analysis, soil physical properties, nutrients, intensive management.

INTRODUCTION

Teak (*Tectona grandis* Linn. f.) planting in India started in 1840s and increased to significant levels from 1865 onwards within as well as outside its natural distributional range. In Kerala, teak plantations occupy an area of about 57,855 ha (Prabhu, 2003) which is nearly 50 percent of the area under forest plantations in the State.
Although comprehensive studies on soil properties in teak plantations are available (Alexander *et al.*, 1980; Balagopalan and Alexander, 1984), very little information is available in India, on the site management of planted teak for optimal land use. Kadambi (1972) noted high SiO_2/R_2O_3 ratio in the soil, alluvial site, high content of bases, especially Ca and Mg, good moisture availability, sandy loam texture and good drainage are the factors helpful for high quality of teak.

An increase in gravel content and exchange acidity values and decrease in sand, silt, pH and exchangeable bases in lower site quality teak plantations was found by Alexander *et al.* (1987).

They also noted that soil variables accounted for 31 percent variation in top height. The present study attempts to evaluate the soil properties in teak plantations belonging to young age classes and to assess the site management of planted teak for optimal land use.

MATERIALS AND METHODS

The study was restricted to teak plantations in the younger age group 5-25 years in the major teak growing Forest Divisions, *viz*., Wynad (North and South), Nilambur (North and South), Ranni, Konni, Thenmala and Achencoil in Kerala. The reason for selecting this age group was that the first and second mechanical / silvicultural thinnings would be over during the period 5-25 years after the establishment.

In each of the selected plantations, plots were marked along a randomly laid out transect running through the centre of the plantations. The transects were mostly along the longer direction of the plantation. The number of plots varied proportionally with the size of the plantations. Roughly one plot was taken for every 10 ha with a maximum of 10 plots in any one plantation. The plots were circular with a radius of 10 m.

Girth at breast height of all trees in the plots was taken at 1.37 m above ground level. Height (total height) was measured on a subset of trees in the plots. Trees having the largest height, smallest height and three trees in between the range were selected for measurement of height in each plot. The site quality was worked out as per the procedure provided in KFRI (1997).

The details with respect to Divisions, Ranges, name of plantations and number of plots, age and site quality classes are shown in Table 1. One soil pit was taken from each plot and samples collected from 0-20, 20- 40 and 40-60 cm layers. The samples were air dried, passed through 2 mm sieve and gravel content (particles > 2 mm) was found out. Analyses were carried out for particle-size separates, bulk density (BD), particle density (PD), soil pH, organic carbon (OC), maximum water holding capacity (WHC), available N, P, K, Ca and Mg and $CaCO_3$ as per standard procedures given in ASA (1965) and Jackson (1958).

In order to assess the site management of planted teak for optimal land use, site quality classes was used as criterion. For comparing the site quality classes, univariate analysis was carried out for each of the soil properties. As this analysis ignores the correlation among the several soil properties, step-wise discriminant analysis was done to identify the factors by which the soils under different site quality classes differ significantly (Jeffers, 1978).

In the step-wise discriminant analysis, the variables are added to the discriminant function one by one until it is found that adding more and more variables does not give significantly better discrimination. By this method, a reduced set of variables is identified, which is almost as good as and - sometimes better than - the complete set of variables and moreover the variables have got more discriminating power.

After the discriminant functions were developed through the step-wise estimation method, they were subjected to ‘rotation’ to redistribute the variance. Basically rotation preserves the original structure and reliability of the discriminant models while making them easier to interpret substantially. In the present study, the most widely used procedure, VARIMAX rotation was employed (Norusis, 1988).

Table 1. Details of plantations selected for the study

Division	Range	Name of plantation	No. of plots	Age (as on Jan 1997)	Year of plantation	Site quality class
Achencoil	Kallar	Panathoopu	10	15	1981	1
		Chittar North	2	17	1979	2
		Chittar North	9	24	1972	2
Konni	Konni	Kummanoor	2	16	1984	2
		Kummanoor	4	17	1983	3
	Mannarappara	Chembala	2	16	1980	2
		Chembanaruvi	4	17	1979	2
		Chembala	6	21	1975	1
Ranni	Vadaserikkara	Adukuzhy	3	13	1983	2
Thenmala	Arienkavu	Palaruvi	2	6	1990	1
		Edapalayam	2	13	1983	3
		Thalappara	2	14	1982	2
		Ariankavu	3	16	1980	2
		Thalapara	3	21	1975	3
	Thenmala	Choodal	3	19	1977	2
Nilambur(South)	Karulai	Pulimunda	2	10	1986	2
		Nedumkayam	2	11	1985	1
		Nedumkayam	4	19	1977	3
		Ezhuthukkal	5	15	1981	2
		Ezhuthukkal	6	23	1973	2
		Ingar	3	17	1979	1
		Ingar	2	21	1975	3
		Ingar	1	24	1972	3
Nilambur(North)	Nilambur	Aravallikkavu	2	9	1987	2
		Kanakkuthu	2	20	1976	2
	Edavanna	Elanjeri	1	9	1987	1
		Moolathumanna	2	13	1983	2
		Ramallur	1	15	1981	2
		Ex Manjerikov	1	19	1977	3
		Ex Manjerikov	2	20	1976	3
	Vazhikkadavu	Kariyanmuriyu	3	23	1973	2
Wayanad(South)	Chethaleth	Palakolly	2	16	1980	2
		Madaparamaba	2	18	1978	3
Wayanad(North)	Begur	Alathur	9	6	1990	3
		Begur	3	19	1977	3

Step-wise discriminant analysis was carried out separately, by considering the soils in 0-60 cm layer and independent variables as sand, silt, bulk density, particle density, maximum water holding capacity, soil pH, organic carbon, available N, P, K, Ca and Mg and $CaCO_3$.

RESULTS AND DISCUSSION

The mean values of different soil properties are given in Table 2. It was found that at Achencoil, there was not much difference between site quality classes I and II with respect to most of the soil properties except available K which was more in site quality class I. Soils were sandy loam and slightly acidic in all the site quality classes.

At Konni, there was not much difference between site quality classes I, II and III with respect to most of the soil properties except available N, K, Ca and Mg which were lowest in site quality class I. Soils were loamy in all site quality classes and medium acidic in site quality I while in site quality classes II and III, the soils were slightly acidic.

In the teak plantations at Ranni belonging to site quality classes II and III, there was not much difference in site qualities with respect to most of the soil properties except available K which was lowest in site quality III. The soils were loamy and medium acidic.

There was not much variation among the site quality classes I, II and III with respect to most of the soil properties in the teak plantations at Thenmala, except available N and soil pH. Available N was more in site quality class III. Soils were loamy in all site quality classes and medium acidic in site quality classes I and II while in site quality class III, the soils were slightly acidic.

Soils in the teak plantations at Nilambur (North and South) Forest Divisions belonging to site quality classes I, II and III showed not much variation among the different site quality classes with respect to soil properties. Soils were loamy and medium acidic in all site quality classes.

In the teak plantations at Wynad (North) Forest Division, the soils were loamy and medium acidic in the site quality class III. In the Wynad (South) Forest Division, the soils were loamy in site quality classes II and III and medium acidic in site quality II and slightly acidic in site quality class III. Available N, K, Ca and Mg were more in site quality class II.

When the overall mean values of soil properties in the 0-60 cm layer under different site quality classes were compared (Table 3), it was found that, in general, the soils were loamy and medium acidic in the different site quality classes I, II and III. There was no definite pattern for the other soil properties.

The univariate analysis of variance on each of the soil properties indicated that two of the 13 variables, *viz*., particle density and available P, showed significant difference between the three site quality classes (Table 4). Since there were three groups, two discriminant functions could be derived and they explained 93.3 percent and 6.7 percent of the total variance, respectively.

The step-wise discriminant analysis revealed that the four independent variables, *viz*., particle density, bulk density, available P and Ca, could discriminate between the three site quality classes (I, II and III) significantly. The coefficients of the discriminant functions are reported in Table 4.

In order to find the contribution of the variables to each function, the correlation coefficients (rotated discriminant function loadings) between the variables and the functions were examined (Table 4) and also the group centroids (mean discriminant score).

The first discriminant function was found to be highly negatively correlated with bulk density and positively with available Ca (absolute correlation value >0.5), implying that change in site quality brings about changes largely in the status of the above two soil variables, *viz*., bulk density and available Ca.

The mean discriminant score was high in site quality class II (0.259) followed by site quality

Table 2. Mean values of soil properties in the 0-60 cm layer in teak plantations belonging to different site quality classes in various Divisions in the age group 5-25 years

Division	Site quality class	Sand (—-	Silt %	Clay -—)	BD	PD	WHC %	pH	OC%	N (—-	P —-	K ppm	Ca —-	Mg -—)	$CaCO_3$ %	Number of plots
Achencoil	I	76	12	12	1.11	2.26	39.45	6.2	1.03	69	8	57	52	16	0.014	10
	II	76	12	12	1.10	2.25	38.70	6.2	1.08	67	8	48	54	18	0.013	11
Konni	I	71	17	11	1.07	2.20	40.82	6.3	0.85	69	9	28	31	17	0.010	6
	II	72	15	13	1.10	2.23	40.95	5.9	0.81	73	10	45	46	24	0.011	8
	III	74	13	12	1.07	2.13	40.50	6.1	0.85	77	10	44	43	23	0.014	4
Ranni	II	72	17	11	1.04	2.18	40.07	6.0	1.31	68	12	52	39	30	0.007	3
Thenmala	I	71	15	14	1.09	2.24	42.46	5.8	1.12	49	13	51	40	22	0.016	2
	II	74	13	13	1.07	2.21	41.07	6.0	1.06	51	10	55	40	27	0.013	8
	III	72	15	13	1.10	2.13	41.66	6.2	0.96	58	11	52	45	25	0.010	5
Nilambur (N)	I	73	14	13	1.12	2.25	38.44	5.9	0.76	45	8	53	38	22	0.008	1
	II	73	13	14	1.13	2.27	39.07	5.9	0.72	47	9	55	41	24	0.008	10
	III	74	14	12	1.16	2.30	38.33	5.9	0.74	42	9	53	38	22	0.008	3
Nilambur (S)	I	74	14	12	1.14	2.29	39.28	5.9	0.77	44	9	57	43	33	0.009	5
	II	74	12	14	1.13	2.31	39.56	6.0	0.78	46	10	57	44	34	0.009	13
	III	74	12	14	1.15	2.23	39.40	5.9	0.78	47	12	61	45	33	0.010	7
Wynad (N)	III	72	16	12	1.13	2.22	42.00	6.0	1.30	47	9	53	38	24	0.008	12
Wynad (S)	II	73	14	13	1.15	2.21	40.10	6.0	1.06	57	10	77	66	48	0.010	2
	III	75	13	12	1.07	2.17	42.13	6.1	1.09	50	12	56	47	32	0.012	2

Table 3. Overall mean values of soil properties in the 0-60 cm layer in different site quality classes corresponding to the age group 5-25 years

Site quality class	Sand (—-	Silt %	Clay -—)	BD	PD	WHC %	pH	OC%	N (—-	P —-	K ppm	Ca —-	Mg -—)	$CaCO_3$ %	Number of plots
I	74	13	13	1.11	2.26	39.60	6.0	0.87	54	9	53	43	24	0.011	24
II	74	13	13	1.10	2.25	39.93	6.0	0.95	57	9	52	45	26	0.011	55
III	73	14	13	1.12	2.20	40.47	6.0	0.96	55	10	53	43	26	0.010	33

Table 4. Summary of interpretative measures in respect of soil variables obtained from three different site quality classes (I, II and III)

Soil variables	Rotated Discriminant function loadings		Univariate F ratio	Standardized discriminant function coefficients	
	Function 1	Function 2		Function 1	Function 2
BD	-.528	-.372	0.851	-.572	-.685
PD	.197	-.750	4.439**	.934	-.028
WHC	-.042	.186	1.659	NI	NI
CaCO3	.289	.198	.304	NI	NI
N	.227	.212	0.592	NI	NI
P	-.138	.663	3.148*	-.355	.563
K	.016	.109	0.011	NI	NI
Ca	.542	.247	1.206	.485	.599
Mg	.017	.120	0.482	NI	NI
Sand	.280	-.087	0.366	NI	NI
Silt	-.140	.067	0.759	NI	NI
OC	.087	.086	0.784	NI	NI
pH	.282	-.092	0.123	NI	NI

NI: Not included in the stepwise solutions ** Significant at P= 0.01 * Significant at P= 0.05

classes I (-0.134) and III (-0.591). This shows that bulk density was high in site quality class III while available Ca was more in site quality class II.

The second discriminant function was positively correlated with available P and negatively with particle density. The mean discriminant score was high in site quality class III (0.472) followed by site quality classes II (-0.125) and I (-0.427) and hence available P was high in site quality class III and low in site quality I whereas particle density was high in site quality class I and low in site quality class III.

The four soil properties, *viz*., bulk density, particle density and available P and Ca, correlated with the discriminant functions, together represent a major portion of the important soil physical properties and nutrient status. Discriminant analysis identified soil variables, *viz*., bulk density, particle density and available P and Ca, by which the soils of teak plantations belonging to the age group 5-25 years under the three site quality classes, *viz*., I, II and III, differed significantly. It was found that in the 0-60 cm layer, the soil properties particle density, bulk density and available Ca discriminated the soils under different site quality classes.

This showed that there was no general trend with respect to the variation in soil properties in relation to different site quality classes. In the age group 5-25 years, soil physical properties and nutrients were the discriminating factors by which the soils belonging to site quality classes I, II and III differed significantly. The study thus revealed that site management of planted teak for optimal land use was confined mainly to soil physical properties and nutrients.

It has been reported by Dreschel and Zech (1994) that in order to manage sites of planted teak for optimal land use, Ca is one of the soil nutrients. Similar results were also obtained by Marcelino *et al*. (2001) and Tanaka *et al.* (1998) for teak in South and South East Asia and Murugesh *et al.* (1999) in India. Observations on similar lines were also made by Marquez *et al.* (1993).

It is a common phenomenon in teak plantations that the litter is either removed from the site by local people for green manure or burnt annually in man made fire. This might have caused the soils to be more and more compact by exposing the surface layer to environmental factors. In addition to this, there is poor incorporation of nutrients into the soil due to the very low litter decomposition. Another reason for the compaction and poor nutrient status is the complete removal of thinning residues from the site. On the basis of the study in teak plantations belonging to different site quality classes, it is recommended that steps should be taken to minimize soil compaction and also to enhance the nutrient status of the soil by retaining the litter and thinning residues in the soil and also by controlling forest fire. In addition to the above, retaining calcium content in the soil at optimum level by application of lime is required for site management of planted teak for optimal land use

CONCLUSIONS

The study in different site quality classes of teak in Kerala showed that

1. There was no general pattern with respect to variation in soil properties in relation to different site quality classes.
2. Site management of planted teak for optimal land use was confined mainly to soil physical properties and nutrients.
3. Calcium content in the soils being the discriminating factor between site quality classes, it is recommended that calcium in the soil should be retained at optimum level for management of soils of teak plantations for sustainable productivity.

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Genetic Diversity and Contemporary Gene Flow in Teak

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ABSTRACT

A thorough knowledge on gene diversity, genetic structure and contemporary gene flow is desirable in formulating the guidelines for genetic conservation of teak and for seed orchard management as well as in teak improvement programmes. The gene diversity in natural teak populations in India was studied using DNA markers. The results of the study show high within-population diversity. There is an indication that natural teak populations in certain geographic areas have different alleles and genetic structure. The data collected through micro satellite marker studies reveals a high rate of pollen dispersal in teak forests. The study also highlights that many male parents pollinate the flowers of a single tree and even a single flower. The pollen was found dispersed to more than 350 m in natural teak areas. The high rate of pollen flow ensures the high gene diversity in teak.

Keywords: Genetic diversity, contemporary gene flow, genetic conservation, teak improvement programme, DNA markers, micro satellite markers.

INTRODUCTION

Teak is an important timber naturally occurring in forests of India, Myanmar, Northern Thailand and Laos. As a relatively fast growing high quality hardwood species, teak (*Tectona grandis* L. f.) is widely planted in its original area of distribution and in other countries in tropical Asia, Africa and Latin America. Teak genetic resources have been altered during the last few decades through uncontrolled logging and movement of planting materials.

Molecular markers have indicated that tree populations generally contain a large amount of diversity. Both the type of alleles and the frequency distribution of each allele can differ substantially among populations from different areas. Knowledge of the genetic variation within and between populations across the entire range is important for the effective utilization and conservation of species. The distribution of the diversity is naturally controlled by the breeding system of the species and the gene flow. The factors determining the level and structure of genetic variation within plant species include evolutionary history, population density, mating system, and mechanism of gene flow (Loveless, 1992).

The genetic diversity of teak from India, Thailand and Indonesia has been estimated by isozyme variation of provenances (Kertadikara and Prat, 1995). Overall understanding of the genetic diversity for teak is still fragmentary (Kjaer and Siegismund, 1996; Chantragoon and Szmidt, 2000; Nicodemus *et al.*, 2005; Lowe *et al.*, 2005) and a clear picture about the relationship with location and climatic changes is still lacking.

The information regarding the distance of seed and pollen dispersal helps in estimating the minimum area required for conservation of a viable population. This information is also necessary for the scientific management of seed orchards especially in forest trees. Studies on breeding system in teak were conducted in different countries which show that teak is partially self incompatible and prefers cross pollination, but due to lack of effective pollinators, seed setting is found to be very poor (Hedegart *et al.*,1976; Palupi and Owens,1996 a,b; Tangmitcharoen and Owens,1997; Indira and Mohanadas, 2002; Mohanadas *et al.*, 2002). But detailed information on the mating system including chances of multiparental mating was not available earlier. The distance of pollen flow and seed dispersal in natural teak forest were also not known. Co-dominant markers like micro satellites are generally employed for estimating the distance of pollen and seed migration as well as contemporary gene flow. Keeping these as objectives, the present study was undertaken at Kerala Forest Research Institute, Peechi, Kerala to assess the genetic diversity in natural teak populations in India and to study the mating system and contemporary gene flow using micro satellite markers.

GENETIC DIVERSITY

Materials

Natural teak forests were identified from states of Kerala, Orissa, Madhya Pradesh and Gujarat representing South, East, North and West of India respectively (Figure 1). In Kerala, two populations were taken from each of the four natural teak growing areas viz. Konni, Thrissur, Nilambur and Wayanad Forest divisions. Only two populations were selected from each of the other states. They were from Khurda (Orissa), Jabalpur (Madhya Pradesh) and Valsad (Gujarat) Forest Divisions. Hence, a total of 14 populations were sampled. From each population, 35-40 adult trees were randomly selected. Juvenile leaves were collected for DNA extraction.

Fig. 1. Map of India showing areas of sample collection

Methods

Genomic DNA was extracted using modified CTAB method (Doyle and Doyle, 1987). DNA extraction kit (Qiagen DNeasy® plant kit) was used in few samples where modified CTAB method did not give satisfactory results. The quality and quantity of DNA was checked in agarose gel. Ultra Lum Total lab software was used to quantify the DNA so as to make 30ng DNA uniformly in each sample.

Hyper variable micro satellite markers were used for both of the studies. They were co-dominant markers and considered as neutral. Hence, they are suitable for genetic diversity estimation, paternity analysis and pollen flow studies. Four micro satellite markers namely AC01, AC28, AG04 and AG14 designed for teak (Genbank/EMBL/DDBJ accessions AJ511746, AJ511764, AJ539416 and AJ539417 respectively) were used for genetic diversity studies.

DNA extracted from all the selected trees from fourteen populations in seven Forest Divisions in four states of India as mentioned earlier were amplified using the four micro satellite markers. The quality of amplified DNA was checked on 1.5%agarose. Then the amplified samples were denatured at 98^0 C for 10 minutes. The electrophoresis was performed on 4.5% denaturing polyacrylamide gel containing 7.5M urea at 90W for $1^1/_2$ hours. After electrophoresis silver staining was done to visualize the bands and photographs of the gels were taken.

Clear bands seen on the gel were scored for allelic polymorphism based on the position of bands on the gel and the heterozygosity/ homozygosity was noted. The allele identification was completed for all the markers. The molecular inventories of all the trees in all the selected populations were statistically analyzed using the softwares, Fstat 2.9.3.2. (Goudet, 2002), Cervus 3.0 (Marshall *et al.*, 1998) and Structure Version 2.2 (Pritchart *et al.*, 2000).

RESULTS AND DISCUSSION

From the present study, it is observed that all the markers exhibited very high polymorphism and AC01, AC28, AG04 and AG14 have shown 8, 7, 7, and 8 alleles respectively. Hence, they are suitable for assessment of genetic diversity and other related parameters.

Allelic richness

Allelic richness is a measure of the number of alleles independent of sample size, hence allowing comparison between different sample sizes. From this study it is clear that allelic richness was highest in Thrissur (Table 1) and lowest in the disturbed population at Wayanad (Population 2). The lowest allelic richness in this population may be due to the human disturbance.

Table 1. Allelic richness and gene diversity

Genetic parameter	Allelic richness		Gene diversity	
Populations	**1a**	**2b**	**1a**	**2b**
Thrissur	5.91	5.74	0.61	0.60
Konni	4.31	5.06	0.64	0.65
Nilambur	4.52	4.53	0.59	0.53
Wayanad	5.08	4.10	0.53	0.54
Khurda	5.46	5.48	0.72	0.63
Jabalpur	4.62	4.95	0.64	0.48
Valsad	4.97	5.09	0.66	0.58

a: *undisturbed population* **b**: *disturbed population*

Gene diversity

The results show that the estimated gene diversity is higher in populations at Khurda in Orissa followed by Konni Division in Kerala (Table 1). But studies using nuclear gene markers showed that Konni populations have the highest gene diversity (0.703 and 0.628) whereas, Khurda populations to be the least diverse (0.326 and 0.24) (Nair; unpublished). In the present study, the disturbed population at Jabalpur exhibited lowest gene diversity (0.48). Out of the total gene diversity of 0.765, within population diversity was found to be 0.599 or 78.3 percent.

Population genetic structure

The STRUCTURE analysis showed geographical patterns based on the allele frequencies. In the present study the analysis showed four clusters comprising the fourteen populations (Figure 2). One cluster comprised the northern and western populations, i.e. Madhya Pradesh and Gujarat. The eastern population from Orissa formed a second cluster. The populations from southern India were split in two clusters with the Nilambur Division separated from the rest of Kerala. The separation of the Nilambur stands could be due to the recent evolutionary changes, though wood analysis has also indicated the uniqueness of the Nilambur teak provenance (Bhat *et al*., 2007). (Note that the two Nilambur populations are separated from other Kerala populations). Other populations from Kerala namely Thrissur, Wayanad, and Konni show genetic similarity. But in each of the locations, there are no apparent differences between the paired populations.

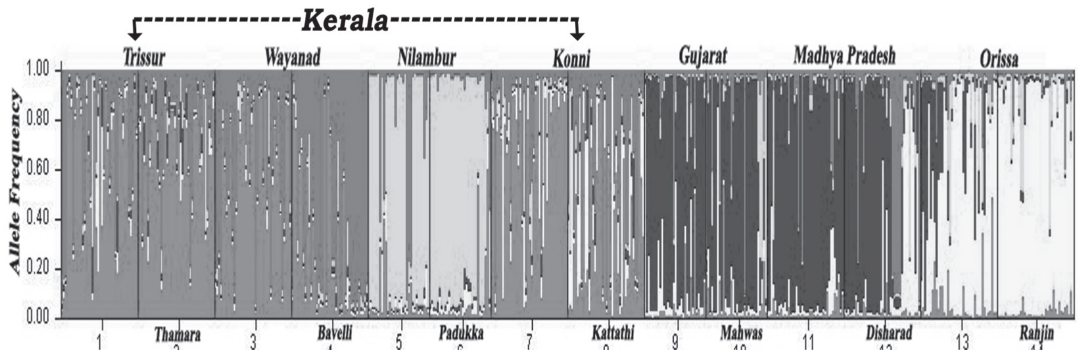

Fig. 2. Bar diagram showing geographical patterns in the allele frequency.

The natural distribution of teak in Indian region is significant in the context that this is considered as a known centre of its genetic diversity (Hedegart, 1975; Dogra, 1981). India has maximum genetic variability with distribution over 8.9 million ha area. Although detailed studies on the distribution of genetic variability in teak are limited, considerable variation in quantitatively inherited traits in *T. grandis* has been reported in provenances from natural populations in India, Thailand, and Laos (Kjaer *et al*., 1996). However, little information is available on their genetic relationships. Population structure and patterns of diversity of teak population have been studied using molecular markers like isozyme, RAPD and AFLP in recent years (Changtragoon and Szmidt, 2000; Kertadikara and Prat, 1995; Kjaer and Suangtho, 1995; Nicodemus *et al.,* 2003; Shrestha *et al*., 2005). All these studies, though with few populations and samples, showed that there is significant genetic diversity within the teak populations. The study with ten populations of teak from Western Ghats and Central Indian regions, Nicodemus *et al.* (2003) showed that 78% of variation exists within the population and rest between populations. Changtragoon and Szmidt, (2000) also reported 79 percent gene diversity within populations after analyzing 16 teak populations in Thailand using RAPD markers. Surprisingly, the present study also showed that 78 percent of total genetic diversity is within populations.

Genetically broad populations should be maintained as a basis for present and future conservation practices. Populations with low genetic variability have a reduced potential to adapt to environmental changes (Ellstrand and Elam, 1993). Thus, genetic variation is important for the long-term survival of a species (Falk and Holsinger, 1991).

CONTEMPORARY GENE FLOW

Materials

A continuous patch of 10 ha of natural teak forest at Thamaravellachal of Peechi – Vazhani Wildlife Sanctuary in Kerala, India was selected. All the 174 adult teak trees in the population were marked. The latitude and longitude were noted using GPS coordinates and the plot was mapped using the software Map Info Professional. Young leaves were collected from all adult teak trees and 100 seedlings on the forest floor to examine the seed movement. Seeds were collected from 9 randomly selected mother trees to study the pollen dispersal. The seeds were put for germination and juvenile leaves were collected from them. Embryos were also used for DNA extraction where seeds did not germinate.

Eight micro satellite primers AC01, AC28, AG04, AG14, AG16, ADHMS AC44 and CPIMS designed by Hugo Volkaert were used for DNA fingerprinting. Power to discriminate among male parents depends on the number of markers, amount of allelic variability and frequency of alleles in the population, since it is essential for studies on pollen movement.

Methods

DNA was extracted from all the individual trees, seedlings and seeds and was amplified using the eight micro satellite markers. The CPIMS did not amplify properly for most of the samples and thus the further analysis was restricted to 7 micro satellite loci. DNA amplifications and finger printing were done as per the methods explained earlier. As mentioned above all the 174 adult trees, 180 embryos/seedlings as well as 100 seedlings on forest floor were DNA fingerprinted. Clear bands seen on the gel were scored. The heterozygous and homozygous individuals were identified, as the micro satellite markers are co-dominant. The allele identification was completed for all the markers. The number of alleles per locus varied and ranged from two to seven.

The data collected with respect to all adult trees and progenies were analyzed through the soft ware Cervus version 3.0. and Fstat version 2.9.3. The genotypic fingerprints of each of the seedlings/embryos were compared with all the adult trees to find out the potential pollen parents or pollen donors. Through maximum likelihood method, by comparing each and every band, the male parent could be identified. From this, the distance between seed parent and the pollen parent was measured, which gave the details on pollen dispersal. The percentage of natural crossing and selfing as well as the frequency of multi-parental mating were estimated from the data generated through parentage analysis.

Through the analysis of the fingerprints, the parents of the seedlings in the forest floor were identified. Out of the two parents the parent nearest to the seedlings was selected as the mother parent as is generally done. Once the parents are identified the distance of seeds moved from the mother parent could be measured and thereby, the details on seed dispersal could be obtained.

RESULTS AND DISCUSSION

Pollen dispersal

The result of the analysis pointed out the identity of pollen parents and thereby the distance of pollen transfer could be calculated. The maximum distance of pollen flow estimated was 414 m and the main distance range of pollen flow was 151- 200 m (Figure 4). Here, out of the total 180 progenies, 42 have their male parents within the main distance range (151-200), which contributes to 23.33 percent of the total progenies. This was followed by the male parents within a range of 101-150 m which constitutes 17.78 percent of the progenies. Only one of the progenies had its pollen parent in the maximum distance of 414 m, which represents only 0.56 percent of the total. Most of the progenies (70%) had their pollen parents below 200 m distance.

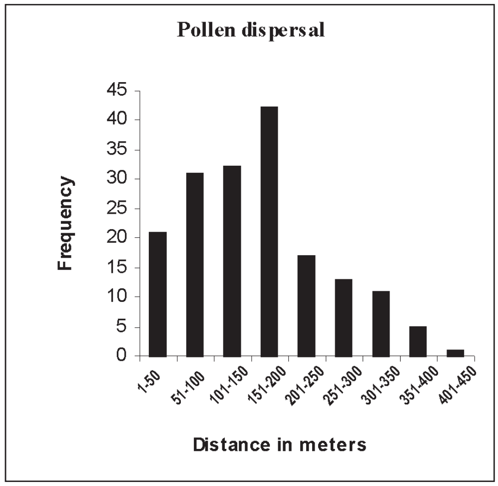

Fig. 4. Distance of pollen dispersal

Cross pollination explicitly dominated in the sample progenies. Out of the total 180 progenies, 173 were cross fertilized (96.11 percent) and rest was self fertilized. The increased percentage of cross- pollination helps the teak to be highly diverse genetically.

The results also showed that most of the individual mother trees were pollinated by many pollen donor trees leading to multi-parental mating (Figure 3). The number of pollen donors to a mother tree ranged from six to ten to produce 10 progenies. Out of the total nine mother trees, four received pollen from 10 different trees to produce 10 seeds, by which all the seeds turned to be non identical and diverse. Moreover, out of the total 26 multi- seeded fruits, each of the 23 fruits (88 % of multi-seeded fruits) contained seeds with different male parents indicating that seeds even within a fruit are non identical and even a single flower is fertilized by different pollen parents.

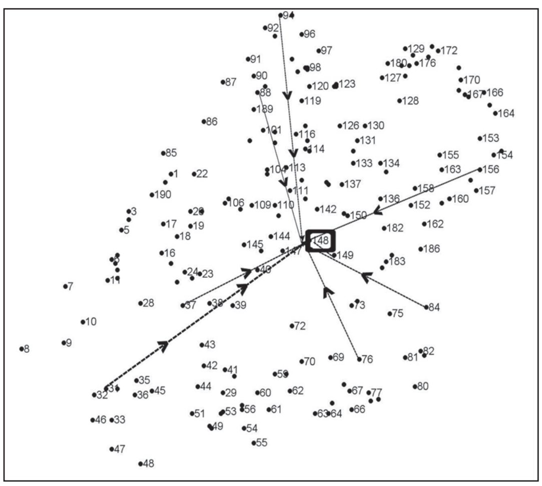

Fig. 3. Pollen flow from different pollen donors to mother tree

Out of the total 91 male parents, 68 percent trees crossed with only one female parent. Each of the 23 percent male donors crossed with two female trees, 5 percent with three female trees, 2 percent with five female parents, and 1 percent each with six and seven female parental trees. A maximum of seven different female parents were pollinated by a single male parent (Figure 5). The high out crossing rate, self incompatibility and high rate of multi-parental mating are the important reasons for maintaining the high within population genetic diversity exhibited by the natural teak populations.

Seed dispersal

The DNA fingerprinting of 100 seedlings on the forest floor followed by parentage analysis showed that the main distance of seed dispersal from their

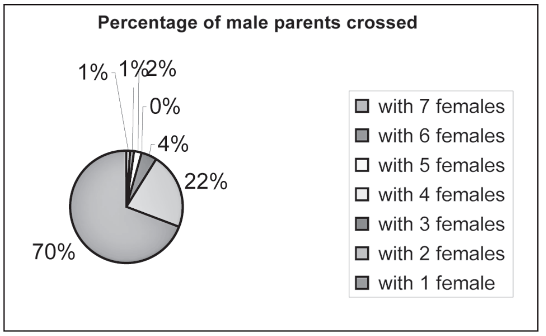

Fig. 5. Proportion of multiple tree mating

mother parents was within a range of 51 to 100 m. Maximum number of seeds (34 seedlings/34 percent) were dispersed in this distance range. Twenty two percent of the seeds were dispersed to 101-150 m range. Four seeds were dispersed to the maximum distance range of 251-300 m (Figure 6). The maximum distance of seed dispersal observed in this plot was 291 m and minimum distance was 8 m.

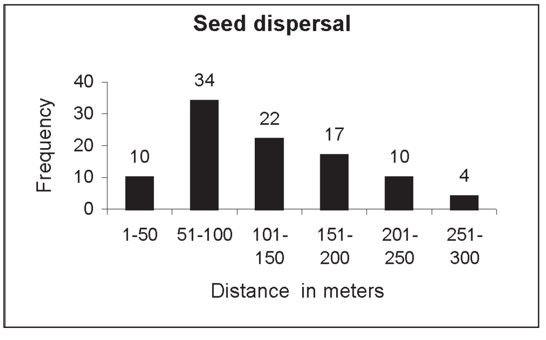

Fig. 6. Distance of seed dispersal

The results indicated that, in this natural teak population, the distance of pollen flow is more than the seed movement. Hence, the highest contribution in maintaining genetic diversity happens to be from pollen transfer. Teak seed is mainly gravity dispersed, though the seed readily float and could be dispersed further by water run-off during heavy rain. For partially or fully outcrossed species, gene flow via pollen is generally believed to occur at much greater rates than gene flow via seed (Levin and Kerster, 1974; Handel, 1983). In most studies on tropical plant species, gene flow through pollen acts over longer distances than through seed dispersal, with most seeds getting dispersed only over a short distance or just dropping under the parent plant (Dick, 2001; Burczyk *et al*., 2004; Difazio *et al*., 2004; Trapnell and Hamrick, 2004).

The high outcrossing rate (96%) observed among the teak trees in this natural teak population is in agreement with the earlier report in teak through Isozyme studies (89-95%) by Kjaer and Suangtho (1995). An individual mother tree received pollen from many male parents and in one tree up to 10 pollen donors contributed to produce 10 seeds (100% seeds of the individual tree are non identical). It ensures very high within family variations. It is also revealed that there was very high mixing of alleles to produce the next generation, which will surely lead to high genetic variations. Hence, the mating system analysis again proved that teak is mainly an outcrossing species and more than 90 percent of the total seeds produced are from cross pollination, thus indicating that seeds from seed orchards or seed stands must be genetically diverse without much inbreeding.

Nason *et al.* (1998) found that mother trees in *Ficus dugandii* had numerous pollen donors and observed up to 11 pollen donors to produce 15 fruits and a single male parent donating pollen to 11 female trees, leading to high genetic diversity.

The high gene flow rate (Nm) ranging from 10 to 25 in teak (Sabna Prabha, unpublished) must be the reason for the high within population diversity and low genetic differentiation. But substantial gene flow from domesticated populations especially clonal populations, into natural reserves may reduce genetic diversity and integrity of subsequent generations and may have negative impacts, especially if immigrant genes are maladapted to local environmental conditions (Adams and Burczyk, 2000).

Comparison of contemporary gene flow will be useful for drafting the guidelines for forest management and conservation of genetic diversity. The seed and pollen dispersal curve are important tools in estimating a minimum area that is required for conservation of viable population of trees. Pollen dispersal curve is also necessary for estimating the buffer zone to be given in the orchards, which is essential for the scientific management of seed orchards. The contamination percentage of foreign pollen and the precision rate of cross-pollination within a seed orchard also could be estimated.

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Diseases of Teak in India and their Management

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ABSTRACT

Teak (*Tectona grandis*) suffers from a large number of diseases and disorders, which cause negligible to considerable damage to trees in stands and seedlings in nurseries throughout India. Diseases affecting teak stands are broadly grouped into: diseases of wider occurrence, serious diseases of restricted occurrence, and potentially serious diseases. Foliage diseases like leaf spot and leaf blight caused by *Phomopsis tectonae, P. variosporum*, *Phoma glomeratum*, *P. eupyrena* and *Colletotrichum* state of *Glomerella cingulata* are widely distributed in teak stands. Teak foliage rust caused by *Olivea tectonae* occurs throughout the range of distribution of teak in India and causes severe premature defoliation of the affected plants. Phanorogamic parasite, *Dendrophthoe falcata* var. *pubescens* causes severe damage to the teak stands, especially in older ones. Serious diseases of restricted occurrence include root-, butt- and heart-rot diseases and die-back caused by *Phialophora richardsiae* associated with an insect borer, *Alcterogystia cadambae*. Potentially serious diseases affecting teak stands include pink disease caused by *Corticium salmonicolor*, bacterial wilt caused by *Pseudomonas tectonae* and stem canker and die-back caused by *Phomopsis tectonae.* Among these, pink disease has emerged as a serious threat to young teak stands, especially those raised in high rainfall areas. The paper discusses various diseases affecting the teak stands and seedlings in nurseries, analyses the impact of introduction of root trainer technology in planting stock production system, and suggests available disease management measures.

Keywords: Teak stands, nursery, diseases, pathogens, fungi, bacteria, disease management.

INTRODUCTION

Teak (*Tectona grandis* L. f.), the prime forestry species in India, is one of the most sought after hardwoods all over the world. There are about 8.9 million ha teak bearing forests in India within the precipitation range of 800 to 2500 mm per annum (Tewari, 1992). A total of about 1.5 million ha of teak plantations exist in India and about 5000 ha of teak plantations are raised annually (Subramanian *et al*., 2000). Teak shows poor growth in dry localities and thrives best in moist, warm and tropical climate. Productivity of teak plantations is alarmingly declining in areas, which have long history of teak cultivation (Katwal, 2005). Even though, many factors such as silvicultural measures, genetic make up of the plant and edaphic factors are partly responsible for the drastic reduction in stand productivity, pests, diseases and disorders play the most critical role, especially in warm humid tracts (Nair, 2005). Even though, teak is a hardy species, it suffers from a large number of diseases, which cause minor to considerable damage to the crop in nurseries, young plantations in establishing phase, as well as in old plantations and natural stands (Bakshi, 1976; Ghosh *et al*., 1984; Sharma *et al*., 1985; Mohanan *et al*., 1997; Jamaluddin, 2005). Fungi, bacteria and phanerogamic parasites are the agents associated with various diseases and disorders in teak. The diseases affecting teak in plantations and natural stands can be broadly grouped into: diseases of wider occurrence, serious diseases of restricted occurrence, and potentially serious diseases. The paper discusses diseases and disorders affecting the teak in stands as well as in nurseries and presents available disease management measures.

DISEASES OF WIDER OCCURRENCE

Foliage diseases

Foliage diseases (leaf spot, leaf blight, powdery mildews, leaf rust) caused by various fungi widely occur in teak plantations through out the country (Sharma *et al.*, 1985; Jamaluddin, 2005; Mohanan *et al.*, 2005). Leaf spot (target spot) and leaf blight caused by *Phomopsis tectonae* and *P. variosporum* occur in both plantations and natural stands. The disease appears during July-August and persists till the leaves are shed in December-January/ February. The leaf spot causes considerable reduction in photosynthetic areas, where >50 percent of the leaf area is covered with necrotic lesions, leaves defoliate prematurely. In young plantations, especially, where the canopy is almost closed before the first thinning, Phomopsis leaf spot emerges as a major foliage disease.

Colletotrichum state of *Glomerella cingulata* causes foliage disease and occurs in teak stands throughout the country. The disease is widespread in teak stands in both dry and wet tracts (Bakshi *et al.*, 1972; Sharma *et al.*, 1985; Mohanan and Yesodharan, 2005). The disease causes angular to irregular dark brown necrotic lesions, which spread in due course under conductive environments and result in severe leaf spot leading to leaf blotch.

In 1- to 2-year-old plantations, *Phoma eupyrena* and *P. glomeratum* cause severe damage to the crop. The fungi cause dark grayish brown necrotic patches on the foliage, which often spread to the entire leaf lamina. The infected leaves show upward curling and become brittle and withered in due course (Mohanan and Yesodharan, 2005). Disease management measures against *Phoma* leaf infection are usually not adopted, except in severely diseased 6-month to 1-year-old plantations. Fungicides like Mancozeb (Indofil) @ 0.2% a.i. are applied as foliar spray to control the disease.

Teak rust fungus *Olivea tectonae* occurs throughout the range of distribution of teak in India and causes severe foliage rust and thereby premature defoliation of the affected plants. The rust infection appears as dull green scattered flecks on the upper surface of the leaves corresponding to the yellowish orange uredinia on the lower surface. The infection spreads and the flecks enlarge and become necrotic. In severe infection, the entire lower surface of the leaf becomes covered with yellowish orange rust spores. Possibility of occurrence of different physiological strains of *O. tectonae* has been reported (Sharma *et al.*, 1985). Disease severity varies from locality to locality and year to year from low to severe depending on the climatic conditions. The disease is favored by dry hot weather and can cause severe infection of teak stands in dry teak areas in the country (Bakshi *et al.*, 1972). Even though, the leaf rust occurs throughout the year, build-up of rust infection occurs towards November-December, when the senescence of leaves either sets in or about to take place. Therefore the impact of rust infection on growth of plants is not very significant and management measures are not usually required. In high humid tracts, hyper parasitic fungi like *Acrmonium recifei* and *Cladosporium oxysporum* infect the rust fungus and check the build up of the rust inoculum. Until recently, the disease has been recorded only in India, Indonesia, Sri Lanka, Bangladesh, Taiwan, and Thailand (Bakshi, 1976; Sharma *et al*., 1985). Recently, the disease has been recorded in Costa Rica, Ecuador, Mexico, and Australia (Arguedas, 2004; NAPPO, 2005; Daly *et al*., 2006). Considering the fact that teak is widely planted in South and Central America, and the climatic conditions are apparently suitable for development and spread of the disease, *O. tectonae* is considered as a serious threat to the teak stands. In Central America, where about 76,000 ha of teak is planted out, the impact of rust disease on growth of the plantations, *i.e*., about 30 percent of growth reduction, has been reported (Daly *et al*., 2006).

Phanerogamic parasites

Dendrophthoe falcata var. *pubescens*, a phanerogamic parasite causes serious problem in teak plantations, especially in the older plantations (Bakshi, 1976; Ghosh *et al*., 1984). The parasite also attacks several other tree species and more than 340 hosts which include several common horticultural and forestry species have been recorded (Balasundaran and Ali, 1997). The parasite (mistletoe), a woody evergreen plant attacks the main trunk and branches and draws nutrients from the teak trees. Economic impact of mistletoe infestation includes reduction in tree vigor and growth increment, poor fruit and seed setting, drying of branches and ultimately death of the affected trees; the timber quality including strength property of the wood is also affected.

Parasite infestation occurs usually in more than 7-year-old teak stands and about 85 percent infestation is recorded in teak stands in different localities in the Kerala State (Balasundaran and Ali, 1989). In mistletoe parasitism, there is xylem to xylem contact between host and parasite, co-ordinate growth of host and parasite xylem, and apoplastic continuum between the host and parasite. The movement of sap into the parasite is driven primarily by a water potential gradient created by transpiration loss of water from leaf surface of the parasite. Both the entophyte and aerial part of the mistletoe influence disease development and host response. Typical swelling and hypertrophy of the host is brought about by increased cambial activity at the point of haustorial attachment. Die-back of infected branches is a typical symptom.

Management of mistletoes in severely infested teak plantations is achieved by removal of the parasites by lopping off the infested branches. The physical removal of the parasite is recommended to be carried out during each thinning operations and also to be continued after final thinning once in five years until final felling.

As mistletoe attack is a continuous menace and the conventional method of its removal has several drawbacks, chemical control of the parasite is also recommended. Spraying of chemicals like ammonium sulphate, potassium dichromate, copper sulphate, and weedicide like 2, 4-D is practiced to a certain extent (Bakshi *et al*., 1972). This method has limited success because of the incomplete effect on the parasite, harmful effect on the host tree and possible environmental hazard. Controlling the parasite without harming the host through infusion of selective weedicides like Afalon (Linuron), Dalapon (dichloropropionic acid), Gramoxone (paraquat), sencor (metribuzin), Tolkan (isoproturon) into the trunk of the infected trees have been attempted on a trial scale. Among these weedicides, infusion of 100 to 500 ml aqueous solution of metribuzin (0.025-0.05% a.i) is found effective in killing the parasite selectively (Ghosh *et al*., 1984; Balasundaran and Ali, 1989).

SERIOUS DISEASES OF RESTRICTED OCCURRENCE

There are a few diseases of restricted distribution which cause extensive mortality of trees in certain localities. Mostly it is attributed to the microclimatic and edaphic factors prevailing in the area, restricted occurrence of the pathogen, virulence of the pathogen, etc.

Root, butt and heart rot

Root, butt and heart rot caused by decay fungi (*Polyporus zonalis, Peniophora rhizomorpha-sulphurea, Perenniporia tephropora, Phellinus caryophylli*, *Fomes lividis*, *Fomitopsis* sp.) have been reported from various teak growing areas (Bakshi *et al.*, 1972; Harsh and Tiwari, 1995). *F. livide*s causes white spongy rot and *P. zonalis* causes white mottled rot. In Madhya Pradesh, about 38-88 percent old teak trees were found affected by heart rot fungi entailing an average loss of about 11 percent wood volume (Harsh and Tiwari, 1995). Severe disease incidence has been reported in plantations prone to annual forest fires. The infection causes decay of heartwood and affects the timber quality. Disease management measures suggested include protecting the plantations from forest fire by taking proper fire lines during the summer months.

Dying of teak

Extensive dying of teak in 20- to 30-year-old coppice crop, in natural teak stands, and young 5- to 8-year-old plantations in Mahrashtra and Madhya Pradesh States have been reported. As teak is shallow rooted and drought sensitive, mortality was ascribed as due to drought as well as the unsuitable site conditions. So far, no pathogens could be detected as associated with the disease.

Die-back

Die-back of teak caused by a fungus, *Phialophora richardsiae* associated with an insect borer, *Alcterogystia cadambae* (= *Cossus cadambae*) occurs in certain localities in the Kerala State (Sharma *et al.*, 1985). Severe infection occurs in plantations close to the human settlements. The insect borer (vector) plays a major role in spreading the fungus and the disease; the insect causes extensive damage to the wood by making numerous bore holes and galleries. Management of the insect-fungus disease complex by controlling primarily the insect vector has been suggested (Mathew, 1990).

POTENTIALLY SERIOUS DISEASES

Pink disease

Pink disease caused by *Corticium salmonicolor* affects young (1- to 3- year-old) plantations situated in high rainfall (2000-2500 mm/annum) tracts. The pathogen causes longitudinal canker on the main shoot at 1 to 1.5 m height. Under conducive microclimate (90-95% R.H., 28-32 ^{0}C temperature), the disease spreads both vertically and horizontally in the plantations causing multiple cankers on the main shoots covering >70% of the plants in the area. Stem cankers extend and longitudinal splitting of the bark, exposes the wood tissues, followed by partial to complete girdling of the stem at the cankered area. Severe infection leading to large-scale mortality of plants in 1.5- to 2-year-old plantations has been reported (Mohanan, 2007). Chemical control by application of fungicide (Bordeaux paste 10%, or Tridemorph 0.1% a.i. as brush on formulation) has been suggested for managing the disease.

Bacterial wilt

The disease caused by a bacterium, *Pseudomonas tectonae* affects 1- to 2-year-old teak plantations. Even though, the bacterial diseases in teak were recorded during 1980s in Kerala State (Sharma *et al*., 1985) with little consequences, over the years, the disease incidence and severity have increased in plantations, especially those raised in high rainfall areas (> 2500 mm per annum). The disease also occurs in other teak growing States (Jamaluddin, 2005). The bacterium is soil-borne and causes severe vascular wilt leading to death and decay of the affected plants. Bacterial wilt manifests as yellowing of the mature lower leaves and scorching and browning of leaf tissues in between the veins. The younger leaves and terminal shoot become flaccid and drooping. The affected plants show either a gradual loss of turgidity of the leaves or sudden acute wilting. The root and rootlets of the affected plants show brownish black discoloration. In advanced stage of infection, the diseased plants with pronounced symptoms of wilt get dried up. Foliage infection occurs as grayish brown to grayish black irregular lesions on the mature foliage, which spread to the entire leaf lamina; the infection also spreads to the petiole and then to the stem. Severe infection leads to necrosis of foliage and stem. The pathogen spreads through water/soil and enters the plant roots through injuries or wounds caused during planting operations or soil work. Strict quality control over the planting stock and selection of disease-free planting material are recommended. In plantations, plants at initial stage of infection can be saved by application of bactericide (Streptomycin sulphate 90% w/w + Tetracycline hydrochloride 10% w/w) at the rate of 6 g per 8 l of water. However, severely affected plants should be rouged and replaced. For casualty replacement, planting should be done in a separate pit dug away from the pit of the diseased plant. Planting in water logged areas should be avoided; weeding and soil working have to be carried out carefully to avoid injury to the plant root system.

Phomopsis canker and die-back

Occurrence of canker and die-back disease in young (1.5- to 2-year-old) teak plantations has been reported from different parts of the country (Jamaluddin, 2005; Mohanan, 2007). Severe incidence of disease occurs in plantations situated in high rainfall areas (>2000 mm per annum) and those under high input management system, where high dose of fertilizer application was carried out. The disease manifests in the form of longitudinal cankers on main shoot and branches; longitudinal splitting of the bark and partial to complete girdling of the cankered areas occurs resulting in die-back of the affected branches/main shoots. The causal fungus is *Phomopsis tectonae*. Application of Mancozeb (@0.2% a.i.) has been recommended for controlling the disease (Dadwal and Jamaluddin, 1989; Mohanan, 2007).

DISEASES IN TEAK NURSERIES

Teak seedlings are affected by various pathogens in conventional seed-bed nurseries and root trainer nurseries. Most of the diseases occurring in seed-bed nurseries also occur in root trainer nurseries, but the severity varies depending on the local environmental factors, growing medium used in the root trainers and nursery management practices adopted (Soni and Jamaluddin, 1998; Mohanan, 2000; Mohanan *et al*., 2005b).

Seedling damping-off

Damping-off occurs in seed-bed nurseries. The disease affects the emerging and 10- to 20-day-old seedlings; fungal pathogens like *Rhizoctonia solani*, *Fusarium solani* and *Fusarium oxysporum* are associated with the disease (Mohanan *et al*., 2004).

Seedling collar rot

The fungus, *Rhizoctonia solani* causes collar rot in 1- to 2-month-old seedlings. The infection spreads very fast in seed-beds with high density of seedlings and high soil moisture regime. The disease causes large-scale mortality of seedlings (Mohanan *et al*., 1997).

Seedling wilt

Seedling wilt occurs in both seed-bed and root trainer nurseries. Seedlings of 1- to 4-month-old are affected by the disease and exhibit symptoms of vascular wilt. In advanced stage of infection, the tuberous portion of the affected seedling root becomes spongy and discolored. In seed-bed nurseries, disease occurs in small patches consisting of 5-10 seedlings and under conductive environmental conditions spreads to the entire seed-bed and causes large-scale mortality. The causal agent is a bacterium, *Pseudomonas tectonae* (Mohanan, 2007).

Foliage infection

Teak seedlings are affected by a large number of fungal pathogens which cause leaf spot, leaf blotch, leaf blight, web blight, leaf rust and powdery mildews. Common leaf spot and leaf blotch causing pathogens include: *Glomerella cingulata (Colletotrichum gloeosporioides), Sclerotium rolfsii, Phomopsis tectonae, P. variosporum, Cercospora tectonae, Corynespora cassicola, Curvularia lunata, Phoma glomerata*, and *P. eupyrena*. Powdery mildew caused by *Uncinula tectonae* occurs in nursery located in warm humid tracts; leaf rust caused by *Olivia tectonae* occurs in seed-bed nurseries. Recently, in root trainer nurseries, *Phoma glomerata* and *P. eupyrena* have been emerged as major foliage pathogens (Mohanan *et al*., 2005).

Seed diseases and disorders

Fungi belonging to various groups cause diseases and disorders in seeds and affect the seed development and seed germination. Fungi like *Phoma glomeratum, Phomopsis tectonae* and *Fusarium solani*, have been recorded as affecting the developing fruits and ovules and causing emptiness in the locules, shriveling and discoloration of the developing seeds (Chacko *et al*., 2002; Mohanan *et al*., 2005). Seed-borne fungi also cause diseases in emerging seedlings in the nursery. More than 24 field and storage fungi, bacteria (*Pseudomonas* sp.) and actinomycetes have been recorded as associated with discoloration and rot of teak seeds (Sharma and Mohanan, 1997).

Disease management in teak nurseries

Generally, nursery diseases can be managed either by prophylactic fungicidal / bactericidal treatments (chemical control) (Sharma *et al*., 1985; Dadwal and Jamaluddin, 1989), by modification of the nursery management practices, especially by optimizing the seeding rate and watering schedule with the local edaphic and climatic conditions (cultural control) or by employing antagonistic microorganisms (biocontrol) (Mohanan, 2000, 2007), and application of mycorrhizae (bio-fertilizer) (Mohanan, 2005).

Chemical control

Collar rot and damping-off of seedlings caused by *Rhizoctonia solani* can be controlled by application of systemic fungicides like Vitavax (carboxin)@

0.05% a.i.(Mohanan *et al*., 2005). Most of the foliage disease of teak seedlings can be effectively controlled by foliar application of systemic fungicide, Bavistin (Carbendazim)@ 0.01% a.i. or broad spectrum fungicide like Dithane M45 (Indofil, Mancozeb)@ 0.05% a.i. Bacterial wilt of seedlings can be controlled by application of bactericide (Plantamycin 0.01% a.i. or Streptomycin sulphate 90% w/w + Tetracycline hydrochloride 10% w/w)@ 6g per 8 litre of water. (Jamaluddin, 2005; Mohanan, 2007a). Since, the bacterium, *Psuedomonas tectonae* is a wound pathogen and infection occurs mainly through the injuries caused by the white grub infestation, the disease can be avoided by proper prophylactic insecticide treatments.

Cultural control

Seedling diseases can be avoided by regulating the shade over the nursery beds, regulating the seedling density in the seed-beds, and also the watering regime. In root trainers, good quality sterilized growing medium (potting mixture) should be used. As the bacterial seedling wilt occurs under high soil moisture regime or water logged conditions, the disease can be avoided by selecting good sites for raising seed-beds and by making raised and properly leveled seed-beds with well-drained soil. Weeding in nurseries may also cause mechanical injury to seedling root system, hence weeding should be carried out carefully. As the infection is systemic, severely affected seedlings should be uprooted and burnt and the suspected seedlings should not be used for the preparation of stumps or for outplanting.

Biological control

Biocontrol agents like *Trichoderma viride, T. harzianum* and *Pseudomonas fluorescence* have been used in seed-bed nurseries to reduce the seedling damping-off and collar rot (Mohanan, 2001, 2007a). Application of efficient strains of vesicular arbuscular mycorrhizal fungi (VAM) like *Glomus fasciculatum, G. botryoides, G. mosseae, Acaulospora appendicula* in 10- to 15-day-old root trainer seedlings has been suggested for managing the seedling root diseases as well as for improving the quality of planting stock (Mohanan, 2005).

INTRODUCTION OF ROOT TRAINER NURSERY AND ITS IMPACT ON SEEDLING HEALTH

Even though, forest tree seedling production system has been revolutionized in many countries, in India, production of planting stock is still largely dependent on conventional methods. However, very recently root trainers were introduced in the forestry sector and presently this technology is being widely used in many states for growing planting stock of selected forestry species (Mohanan, 2003; Mohanan and Sharma, 2005). Even though, different types of root trainers are available for growing seedlings, reusable trays containing cells from which seedlings can be removed at the planting site are the most preferred. For raising teak seedlings, root trainers with cell volume 150 cc are being used. However, optimum container size varies depending on growing density, desired size of the seedlings, type of growing medium, environmental conditions, and length of growing period. Introduction of root trainer technology has a major impact on nursery management. Recently, a comparative account of the disease situation in root trainer and conventional teak nurseries has been made (Mohanan, 2000, 2003). As soil-less or soil-free growing media are used in root trainers, common soil-borne diseases like damping-off, seedling blight and seedling wilt seldom occur. More over, even if foliage diseases occur through air-borne inocula, the affected seedlings can easily be removed from the blocks and replaced with healthy seedlings, thereby avoiding the spread of the diseases in nursery. The new technology is very efficient and suitable for raising teak planting stock on a large-scale and offers planting stock improvement employing mycorrhizae, biofertilizer and bio pesticide manipulation, since the root trainer technology gives more emphasis to healthy root system of the planting stock.

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Clonal Plantations of Teak through Macro- and Micropropagation

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ABSTRACT

Cloning of superior teak (*Tectona grandis* L. f.) trees and mass production of improved planting stock is essential for raising clonal teak plantations. Several research institutes and industrial establishments attempted cloning of genetically superior teak trees which involve macro- and micro- propagation methods. A unique technique developed and standardized for clonal propagation of teak, in Kerala Forest Research Institute (KFRI) is described. Plus trees of teak, 40 to 50-years–old, were cloned through the technique which involves two major steps, viz., production of juvenile epicormic shoots on branch cuttings obtained from plus trees and rooting of cuttings prepared from these juvenile epicormic shoots. Through this process it takes about 90-days to produce rooted plants from branch cuttings of plus trees. A Patent has been filed for this technique. Following this technique, 30 plus trees of teak were cloned successfully to get true-to-type rooted ramets in sufficient numbers. Hardened ramets, 120-days-old, were field planted at different locations in Kerala during 2000-'05. These cloned ramets showed 99 percent field survival and excellent growth in height and girth after 36 months of growth. The growth of field planted teak clones was found far better than that of the conventional planting materials such as stumps/seedlings. Some of the best teak clones gave MAI of 8.43 $m^3 h^{-1} yr^{-1}$, which is quite a substantial gain over 2.5 $m^3 h^{-1} yr^{-1}$ for seedling-raised plantations in the State. The volume yield has increased by three-or four-fold in clonal plantations compared to seedling crop. Cloning by micro-propagation of selected clones has also been successfully carried out at KFRI. In this method shoot tips and nodal explants were used and up to 4-5 fold multiplication has been achieved through enhanced bud proliferation in the presence of hormones. *Ex-vitro* rooting of micro-shoots to produce plantlets and hardening in mist chamber was achieved with high percentage (>90%) of success. Plantlets were also transferred to the field on a small scale. By the introduction of the clonal teak plantations about 3-4 fold increase in the productivity of teak plantations could be expected. Practical application of these techniques for propagation and establishment of clonal plantations and productivity increase of teak is discussed.

Keywords: *Tectona grandis*, cloning, epicormic shoots, rooted cuttings, micropropagation, clonal plantations.

INTRODUCTION

Teak (*Tectona grandis* L. f.) is one of the most valued timber trees of India. The practice of raising plantations of teak through seedlings or stumps existed since 1840s. 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 as planting stock. Recently use of root-trainer- grown seedlings was standardized as a step towards improving quality of the planting stock as well as economizing on nursery maintenance costs.

TREE IMPROVEMENT EFFORTS

As part of tree improvement programme for improving the productivity of plantation-grown teak, seed production areas of teak and teak seed orchards were established in India at the beginning of the twentieth century itself (Fergusen, 1938). It was expected that open cross pollinated seeds from these orchards would produce high yielding progenies but the poor flowering and low seed production reported from majority of these orchards shattered the expectations of the teak tree improvement workers. Poor flowering and fruiting results in acute shortage of seeds. In teak natural stands and plantations, even though thousands of trees flower and millions of flowers are produced each year, only less than one percent turn to mature fruits (Indira, 2005). In orchards, since the flowering is very poor seeding is still worse leading to acute shortage of good quality seeds. As a result, forest managers are often forced to use whatever seeds available, to raise nursery stock. This results in establishing highly heterogenous and inferior plantations leading to poor productivity.

CLONAL TECHNOLOGY

Tree improvement programme is highly essential for any tree species aiming at increasing the overall productivity in plantations. For achieving quicker genetic gains clonal propagation of superior trees by rooting of shoot cuttings from superior trees is a well established method for tree improvement in many tree species. Teak being one of the important high quality timber species of the country, an area of more than 1.5 million ha is at present under teak and on an average 50,000 ha is planted annually. In spite of the extensive plantations, in general, the average productivity of teak is very low (10 m^3 ha^{-1} $year^{-1}$) in India and it is still lower in Kerala (2.85 m^3 ha^{-1} yr^{-1}). One of the reasons for low productivity is the usage of genetically inferior planting stock for raising plantations (Surendran and Sharma, 2005). Adopting clonal technology and establishing large scale clonal plantations of superior teak clones is the only immediate alternative to increase the productivity of teak plantations.

Even though, 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 teak has not been reported so far.

One of the main requirements for clonal propagation of teak by macro-methods like rooting of shoot cuttings 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.. Considering this, a novel technique was developed and standardized at Kerala Forest Research Institute (KFRI) for clonal propagation of plus trees of teak through production of juvenile epicormic shoots from large branch cuttings, and rooting these juvenile shoots in the mist chamber.

PERFECTING THE CLONAL TECHNOLOGY AND PATENTING

Production of juvenile shoots

Branch cuttings of 3 to 10 cm diameter were collected from the middle and lower parts of the crown of plus trees (age >40 years) selected in different Forest Divisions in Kerala. The branch cuttings were further sized to make cuttings of 50 cm length. 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 cuttings were transferred to a mist propagation unit with intermittent misting (15 seconds misting in every 30 minutes), temperature of 30 ± 2°C and humidity to 85–90. The conditions provided inside the mist chamber are conducive to sprouting of dormant buds present on the branch cuttings and formation of juvenile shoots.

Within 10 -15 days the branch cuttings sprouted and juvenile epicormic shoots started growing. Within a period of 20-30 days majority of the buds present on the cuttings sprouted and produced juvenile shoots. In general, on an average 8-12 healthy juvenile shoots were produced on a single branch cutting.

Rooting of the juvenile shoot cuttings

Juvenile epicormic shoots, 10 to 15 days old and measuring 8-10 cm in height with at least, two or three pairs of leaves, were harvested and made into shoot cuttings, after trimming away the distal 2/3 portion of the leaves, and retaining the apical bud intact. The cut end of the excised shoots was treated with indole butyric acid (IBA) 6000 ppm, prepared in talc. As a prophylactic measure against pathogens, the cuttings were soaked in a solution of Bavistin w/v (0.05 percent) for about 30 minutes, before hormone treatment.

The treated cuttings were inserted into the rooting medium (vermiculite) filled in root trainers having a volume of 300 cm^3 capacity and were kept under intermittent misting in the mist propagation unit. The temperature was regulated at 30±2° C and humidity at 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. Within a period of 10-15 days, the planted juvenile shoot cuttings started developing roots on them. Rooted shoot cuttings/ramets 30-45 days old, were transferred 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 (Figure 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) (Figure 1). Using this technique a total of 30 plus trees located in different Forest Divisions of Kerala were successfully cloned true to type (Table 1).

There are reports on the use of juvenile coppice shoots produced on stumps of felled trees for

Table 1. Number and locations of plus trees used for clonal propagation.

Location (Kerala, India)	Total no. of plus trees identified for cloning	Plus trees cloned
Nilambur	13	10
Konni,Thenmala & Achencoil areas	25	19
Wyanad	2	1
Total	40	30

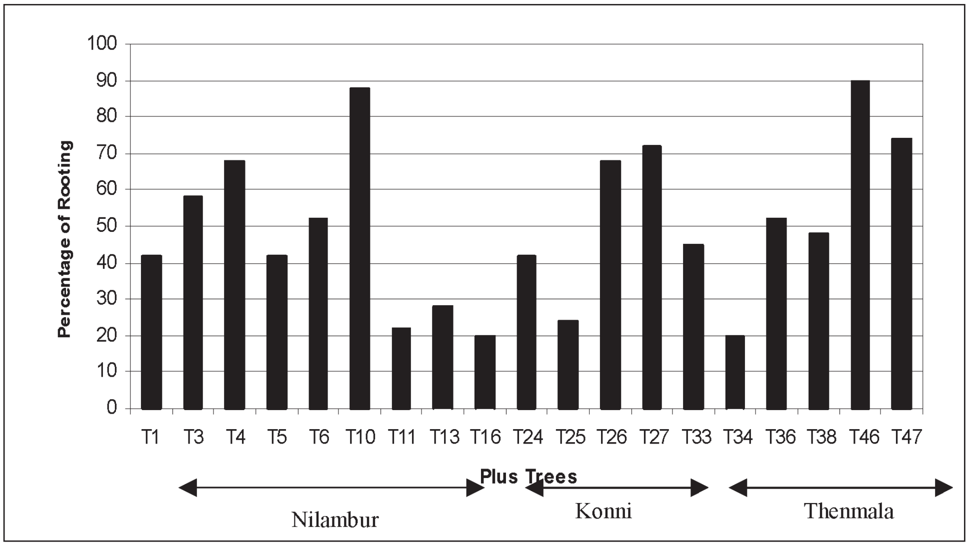

Fig. 1. Percentage of rooting success of cuttings obtained from plus trees of teak from different locations of Kerala.

propagation in eucalypts (Zobel and Ikemori, 1983; Lal, 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 from branch cuttings of plus trees by this method. Since the branch cuttings sprouted and produced epicormic shoots, throughout the year, the method is suitable to produce juvenile shoots, whenever needed.

Rooting of coppice shoot cuttings and of juvenile cuttings of teak seedlings, within a period of 20-25 days were reported by Kaosa-ard *et al*. (1998) and Palanisamy and Subramanian (2001) and the maximum percentage reported was 72-91 percent. In the present method, the initiation of rooting was observed within 15 days after planting in the mist chamber which is shorter than any of 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) teak trees while Nautiyal *et al*. (1991) reported 60 percent rooting in cuttings collected from 16-year-old teak trees and only 10 percent rooting in cuttings collected from 62-year-old trees. Since the juvenile shoots were used for rooting in this method, 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 of any age without resorting to felling.

Hardening and field planting of the rooted ramets

The rooted ramets were transferred to the hardening chamber and were kept there for about 45 days in order to allow them to harden properly. Later the ramets were hardened in the open nursery for a few weeks before being taken to the field for planting out. The growth and survival of rooted juvenile shoot cuttings during hardening was >90 percent in all the plus trees. Thus the time required for producing the clonal ramets from mature cuttings of plus trees was 90 to 120 days.

Patenting

Kerala Forest Research Institute has applied for an Indian Patent for the technique described above for cloning the teak trees (No. 472/MAS/2003) and it is now under consideration.

FIELD PERFORMANCE OF CLONED TEAK

The rooted ramets of 17 clones were field planted in trial plots raised at Chettikkulam in Kerala during October, 2001 following a linear design and at a spacing of 2.5 X 2.5m. Observations were recorded on their growth, survival and field performance.

The growth parameters of teak clones were compared with seed-grown teak in trial plots established by the Kerala Forest Department using stumps, root-trainer seedlings and naked seedlings during October 2000. For all clones and seed-raised plants height and DBH were recorded periodically.

The field survival and successful establishment of cloned teak in the field was 99 percent. The height of ramets was 4.5 meters in some of the clones (e.g., T10, T46, T47) after 11 months growth at Chettikkulam and almost similar rate was maintained in the second year of planting (Figure 3). At the end of the 36 months' growth, the maximum height growth recorded was 8.31 m and dbh 7.90 cm resulting in MAI as high as 8.43

Table 2. Field performance of rooted ramets of teak clones and seed-raised teak planted at Chettikkulam, Kerala, India 3 years after planting.

Clone No.	Height (m)	Dbh (cm)	CV (m^3)	CV/ha	MAI (m^3/ha)
1	6.74	5.25	0.008	09.96	3.32
4	5.93	5.54	0.008	10.48	3.49
5	5.46	5.65	0.008	10.57	3.52
6	5.67	5.34	0.007	09.57	3.19
10	6.37	5.96	0.010	12.50	4.17
11	7.05	6.67	0.013	16.44	5.48
13	6.17	5.80	0.009	11.67	3.89
21	6.40	6.45	0.011	14.85	4.95
24	8.26	7.04	0.015	20.02	6.67
26	6.48	6.31	0.011	14.13	4.71
27	7.58	6.67	0.013	17.10	5.70
34	7.26	6.51	0.012	15.91	5.30
36	7.26	6.47	0.080	15.71	5.24
38	5.08	4.88	0.006	07.72	2.57
44	6.96	7.26	0.015	19.36	6.45
46	8.31	7.90	0.020	25.30	8.43
47	8.12	7.28	0.016	21.20	7.07
Teak stump	**5.22**	**3.38**	**0.006**	**8.50**	**2.50**
Root- trainer seedlings	**5.18**	**2.76**	**0.004**	**5.24**	**1.75**
Naked seedlings	**3.26**	**1.64**	**0.002**	**2.57**	**0.86**

m^3/ha in clone T 46 from Thenmala (Table 2). This was closely followed by clones T 47 and T24 with MAI of 7.07 m^3/ha and 6.67 m^3/ha, respectively. The minimum MAI of 2.57 cm^3/ha was recorded in clone T38 from Konni area, which is similar to MAI of 2.50 cm^3/ha in stump-grown teak control, indicating inferior nature of the plus tree. Among all the three controls, the poorest MAI (0.86 m^3/ha) was in naked seedlings and highest in stump-grown (2.25 m^3/ha) and in between in root-trainer grown (1.75 m^3/ha) seedling control.

CLONAL PLANTATIONS AND INCREASE IN YIELD

In general, the productivity of teak in Kerala in a 53- year rotation period is very low (2.85 m^3 ha^{-1} $year^{-1}$) as compared to the national standard (10 m^3 ha^{-1} $year^{-1}$) (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 be undertaken to increase the productivity of teak as in the case of eucalypts (Zobel and Ikemori, 1983; Lal, 1993). From the growth data obtained for the field planted clones

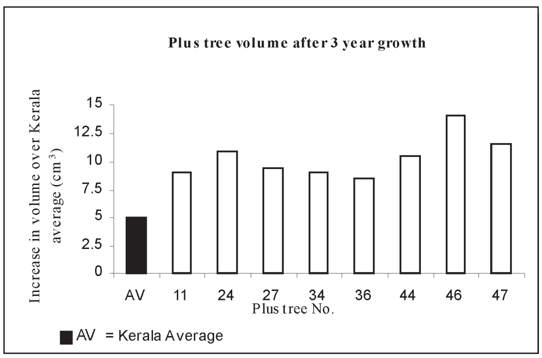

Fig. 2. Increase in conical volume of plus tree clones over ordinary seed- raised plants planted at Chettikkulam, after 36 months' growth.

of teak it is quite apparent that at least 3-4 fold increase in the productivity of teak could be easily achieved by the introduction of the superior clones raised from plus trees (Figures 2, 3). The technique described has great potential and offers the possibility not only to propagate large plus trees aged 40 years or more without felling them, but also to clone the superior trees and to raise plantations and teak seed production areas using the improved planting stock from plus trees.

TISSUE CULTURE FOR MASS PRODUCTION OF CLONES

Since the technique described above for cloning teak requires lopping of branches of plus trees, for raising large-scale plantations, mass production of superior teak clones through tissue culture technique was considered to be an appropriate alternative. Tissue culture of teak for mass production of plantlets from selected trees was initiated as early as 1970's (Gupta *et al.*, 1980; Mascarenhas *et al*., 1993). The results of field trials with micropropagated teak were reported by Nadgauda *et al*., 1997. They reported 4.5 m height and 23.70 cm gbh in 10- year-old field planted tissue cultured teak plants.

KFRI has standardized micropropagation protocols for a few clones (Binoy and Muralidharan, 2005). Explants of the shoot tip are taken from the epicormic shoots developing on branch cuttings collected from the superior trees as described above. Multiple shoots are induced on a solid medium consisting of the minerals and vitamins of the WPM medium (Lloyd and McCown, 1981) supplemented with sucrose 3 % and BA (0.15 – 2.5 mg/l) with or without kinetin (0.15 mg/l). Rooting was induced *ex vitro* by treating the microshoots with IBA (250 mg/l) and transplanting to a 1:1 mixture of vermiculite and sand and hardening under mist for 2-3 weeks (Figure 4).

Fig. 3. View of the clonal garden of teak at Chettikulam
Left. 11 months after planting   Right. 36 months after planting

Fig. 4. Stages in the micropropagation procedure
a. Sprouting in shoot tip explant of teak. **b.** Multiple shoot formation
c. Teak microshoot rooted *ex vitro* **d.** Hardened plantlets of teak.

Efforts are now on to standardize the protocols for at least ten of the best clones and mass produce plantlets of plus trees for raising large-scale superior teak plantations. Reduction in cost of micropropagation is also being attempted through use of cheaper alternatives in media components and culture containers and modifications in the culture procedures.

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Productivity and Quality of Planted Teak

Productivity and Quality of Planted teak

Improvement of Productivity of Teak Stands through Mycorrhizal Manipulation

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ABSTRACT

Teak (*Tectona grandis*) is reported to be an arbuscular mycorrhizal (AM) dependant species. The study presents the results on improving the productivity of teak stands exploiting mycorrhizal potential. AM fungi were retrieved from teak rhizosphere soil collected from different plantations in Kerala, Karnataka and Andhra Pradesh States. A total of 73 Glomalean fungi belonging to six genera were retrieved. The genera *Glomus* and *Acaulospora* were found widely distributed in teak rhizosphere in all the three States. Among 36 *Glomus* species recorded, *G. aggregatum, G. botryoides, G. fasciculatum, G. deserticola,* and *G. mosseae* were the most predominantly distributed ones. Pot cultures of all the retrieved AM fungi were prepared and maintained in the glasshouse for inoculum production. Mycorrhization of teak seedlings employing selected AM fungal inoculum, singly or in combination (20 treatments) was carried out under the nursery conditions. The field performance of mycorrhized and control planting stock was investigated in a trial at Vembooram, Kodanad Forest Range, Kerala. The nursery trial conducted during 2004 confirmed the potential of AM fungi in boosting the seedling growth. The results also substantiate the improvement of quality of planting stock by application of inoculum of *Glomus botryoides, G. fasciculatum, G. macrocarpum, G. mosseae, Acaulospora appendicula, A. scorbiculata, Gigaspora gigantea* and *Scutellospora erythropa* singly or in combination. In field trials highly significant differences were registered in growth performances of mycorrhized seedlings over control sets. Among the 19 AM fungal treatments, inoculum of *G. fasciculatum* mixed with *A. appendicula* or *G. botryoides* recorded maximum plant height, collar diameter and vigour. Plants in *A. appendicula* 1 + *G. fasciculatum* treatment recorded maximum mean height of 123 cm with collar diameter of 2.89 cm within 9 months of field planting, while in non-mycorrhized plants (control), average plant height and collar diameter were only 86 cm and 1.43 cm respectively. For further validating the beneficial effect on improvement of planting stock by mycorrhizal manipulations and thereby boosting the stand growth and productivity, large-scale nursery screening and multi-location field trials with long term monitoring are warranted.

Key words: Teak, AM fungi, mycorrhization, root trainer seedlings, stand productivity, field trial.

INTRODUCTION

Teak (*Tectona grandis* L. f.), is known for its strength, durability and attractive appearance. It is one of the most sought after hardwoods in the international market. The ever-increasing demand for teak timber has resulted in large-scale plantations both within and outside its range of natural distribution. There are about 8.9 million ha of teak bearing forests in India within the precipitation range of 800 to 2500 mm per annum (Tewari, 1991). At present about 1.5 million ha of teak plantations exist in the country and around 50,000 ha of teak plantations are raised annually

(Subramanian *et al*., 2000). 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 growing teak plantations. Nursery technique, choice of site, planting, weeding and maintenance of plantation, thinning, and fixing rotation age dominated the research priorities during the early years. More recently, emphasis has been given to standardize the nursery practices and production of quality planting stock (Chacko *et al*., 2002) and also to improve the productivity of the stand by fertilizer application and irrigation.

Productivity of teak plantations is alarmingly declining in areas that have a long history of teak cultivation. A meager 2.85 m^3 ha^{-1} on an average for a rotation of 53 years, where all thinning schedules were followed has been reported (Chundamannil, 1998). Even though many factors are responsible for the drastic reduction in stand productivity, edaphic factors are considered as the most crucial ones. In general, soil under teak plantations in the Kerala State is reported to be problematic and nitrogen (N) and phosphorus (P) availability are the limiting factors (Balagopalan *et al*., 1998). Application of fertilizers at the early phase of the plantations, soil and water conservation efforts to prevent leaching of nutrients and to increase moisture availability have been proposed as short-term strategy for problematic teak growing areas in the State. Many view improving the soil nutrient status and their mobility by mycorrhizal application in teak as a long-term strategy as well as most self-sustainable.

Recently, the potential for manipulating mycorrhizal association to increase productivity in plantation forestry has become the focus of major research activity. There is also much interest in their potential utilization in agriculture and horticulture (Bagyaraj, 1992). Teak has been subjected to various investigations in India and abroad: on mycorrhizal dependency (Sugavanam *et al*., 1998; Gurumurthy and Sreenivasa, 1988, 2000; Rajan *et al*., 2000; Verma *et al*., 2001; Mohanan 2003), influence in mineral nutrition (Durga and Gupta, 1995; Bhadraiah *et al*., 2002), improvement of seedling growth and biomass (Ramanwong and Sangwaint, 2000; Vijaya and Srivasuki, 2001a,b; Chandra and Ujjaini, 2002; Gong *et al*., 2002), and planting stock improvement (Mohanan, 2005; Mohanan and Sheeba, 2005).

Mycorrhiza-dependent perennial species require a well-balanced and functional mycorrhizal association for a sustainable soil-plant system. The functional diversity of the mycorrhizal fungi provides opportunities for selecting fungi adapted to specific combinations of host / environment / soil conditions in stands or plantations. Selected efficient AM fungal candidates can be employed as an effective biological tool for improving the planting stock. The stand productivity in thereby improved in a most environment-friendly way by avoiding excessive use of chemical fertilizers.

MATERIALS AND METHODS

Retrieval of arbuscular mycorrhizal (AM) fungal spores

Rhizosphere soil of teak from plantations belonging to different age groups (4 to 50 yr) was collected from different Forest Divisions in the Kerala, Karnataka and Andhra Pradesh States. About four kilograms of rhizosphere soil along with young feeder roots was collected from each selected tree from different teak plantations. The soil and root samples collected were transported to the laboratory. Wet-sieving and decanting method (Gerdemann and Nicolson, 1963) with modification and wet-sieving and centrifuging methods were employed for retrieving AM fungal spores from the soil samples.

Selection and propagation of AM fungal inoculum

A total of 127 pot cultures were established from single spore of different species G*lomus, Acaulospora, Gigaspora* and *Scutellospora* retrieved from teak rhizosphere soil from the three States employing the funnel technique. The pot cultures were grown in non-draining buckets (20 cm height and 12 cm dia). Maize (*Zea mays*) was used as host plants. Hoagland's micronutrient solution was applied to the seedlings periodically. The pot cultures were maintained in the glasshouse. *G. botryoides, G. fasciculatum, G. macrocarpum, G. mosseae, A. appendicula, A. rehmii, A. scorbiculata, Gigaspora candida, G. gigantea, S. heterogama* and *S. erythropa* were selected for the nursery trial based on their earlier performance in a glasshouse trial and inoculum was prepared employing 6-month-old (inoculated maize plants) pot cultures. The maize plants were cut at collar region and left for two weeks. During this period, the soil was subjected to drying. AM fungal inoculum includes spores, mycorrhizal root pieces, and organic matter containing hyphae, was prepared by chopping the roots and mixing them with the rhizosphere soil.

Nursery trial

Nursery trials were carried out in the Central Nursery at Chettikulam, Kerala in 2004. Compost made out of forest weeds mixed with soil, sand, coconut coir pith and burnt rice husk (70:10:10:5:5) was used as growing medium. Moisture content and pH of the growing medium were determined. Styroform blocks containing 24 root trainer cells with 150 cc capacity was used for raising the seedlings. The root trainer cells were filled with growing medium. Teak seeds obtained from the Seed Centre, KFRI (Seed lot, 2003, Nilambur) were used; seed pre-treatment was carried out (alternate wet and dry treatment for 7 days) to increase the seed germination. Germinated teak seedlings were transplanted in each root trainer cell. A total of 100 Styroform blocks containing 2400 teak seedlings were kept ready for mycorrhizal treatment. After 10 days of growth in root trainer cells, seedlings were treated with AM fungal inoculum. AM fungal inoculum prepared from the pot cultures of the respective Glomalean fungi was applied at the rate of 1g per cell in the root zone of seedlings. AM fungal inoculum was applied singly in 15 treatments; in two treatments, *Glomus* species and *Acaulospora* species were mixed, while in another two treatments, *Glomus* spp. were mixed. Control (untreated) seedlings were applied with sterilized soil-sand mixture. Five replicates of Styrofoam blocks containing a total of 120 seedlings were maintained for each treatment (Table 1).

Recording growth measurements

All the treated seedlings including the control sets were kept under shadenets (50% light) and watered three times per day regularly. After 30 days of growth under the shadenets, the seedlings in all the treatments were shifted to the hardening area without any shade regulation. Observations on seedling growth (height, leaf pairs, collar diameter) were recorded at 10 days intervals, up to 60 days. Collar diameter of seedlings in all the treated and control sets was measured using calipers; fifteen seedlings from each treatment were used for recording seedling biomass. Root and shoot as well as whole seedling biomass were recorded separately. Ten seedlings from each treatment were used for assessment of root colonization by inoculated AM fungi. The roots of inoculated and uninoculated (control) seedlings were collected after 90 days of growth and processed to detect the root colonization (as in Phillips and Hayman, 1970).

Table 1. Details on AM fungal inocula used for nursery trials.

Treatment No.	AM fungi	Pot culture No.
1	*G. botryoides*	78
2	*G. fasciculatum*	177
3	*G. fasciculatum*	79
4	*G. fasciculatum*	24
5	*G. macrocarpum*	171
6	*G. mosseae*	97
7	*G. mosseae*	13
8	*A. appendiculata*	187
9	*A. appendicula*	21
10	*A. rehmii*	140
11	*A. scorbiculata*	25
12	*Giga spora candida*	40
13	*Gigaspora gigantea*	44
14	*S. heterogama*	28
15	*S. erythropa*	74
16	*A. appendi cula +G. fasciculatum*	187 + 24
17	*G.fasciculatum + G. mosseae*	169 + 97
18	*G. botryoides + G. fasciculatum*	78 + 18
19	*A. appendicula + G. mossease*	69 + 173
20	Control	-

Seedling biomass

After 90 days of growth in root trainers, seedling biomass was recorded by destructive sampling method. Ten seedlings from each treatment were removed from the root trainer cells and wet weight was recorded; the samples were dried overnight in an oven at 60º C and the dry weight was recorded. Mycorrhizal inoculation effect (MIE) was evaluated using the formula:

$$\% \text{ MIE} = \frac{\text{Dry wt. of inoculated plants - dry wt. of uninoculated plants}}{\text{Dry wt. of inoculated plants}} \times 100$$

Field trial

One hectare of clear-felled (first rotation) teak area at Vembooram, Kodanad Forest Range, Kerala was selected for the field trial. Trial plot was aligned and a total of 60 plots were marked with 20 stakes in each plot at 2.5 m distance. Completely randomized block design was followed and for each treatment (total 20 treatments), 3 replications were provided. Soil pits of 30 x 30 x 30 cm were taken at 2.5 m distance and reed bamboo splints were put at the center of each pit. Boundary of each plot was marked using paint marked poles. For each plot, paint-marked iron (T-shaped) labels were placed. Soil samples from three different locations in the selected area were collected and data on soil pH, soil moisture content and status of natural AM fungal flora in the soil were analysed.

Planting of treated seedlings and recording growth measurements

Planting was carried out on 4 and 5 June 2004. A total of 1200 seedlings from 20 treatments were employed for planting. Sixty seedlings from each treatment were used and three replicate plots were kept. The seedlings were carefully removed from the root trainer cells and planted in the soil pit; soil was heaped around the plant to avoid water logging. Observations on plant height, collar diameter, leaf pairs, health and vigour of plants, defoliation, etc. were recorded after three months (August 2004) and nine months (March 2005) of planting. Plots were also visited during June 2005 and observations on growth performances were recorded. Data generated from the nursery and field trials were subjected to ANOVA and DMRT.

RESULTS AND DISCUSSION

AM fungal root colonization in teak in southern states

Young feeder root samples of teak collected from different eco-climatic zones in Kerala, Karnataka and Andhra Pradesh States revealed that all the teak root samples, irrespective of variation in age of the plants, edaphic and climatic factors, showed AM fungal colonization. In teak plantations in the Kerala State, the overall extent of AM fungal root colonization ranged from 7 to 59 percent. From Karnataka State, the mean AM fungal root colonization registered was 24.70 percent. Highest percent (43%) AM fungal root colonization was recorded in samples from 20-year-old plantation at Chaparke, Kundapura Forest Range.

Comparatively a high percent of AM fungal root colonization was recorded in teak plantations in different localities in the Andhra Pradesh State, which ranged from 52 to 74 percent (Figure 1). More than 70 percent AM fungal root colonization was recorded in root samples from the 36-year-old teak plantation at Ebul, R.V. Nagar Forest Range,

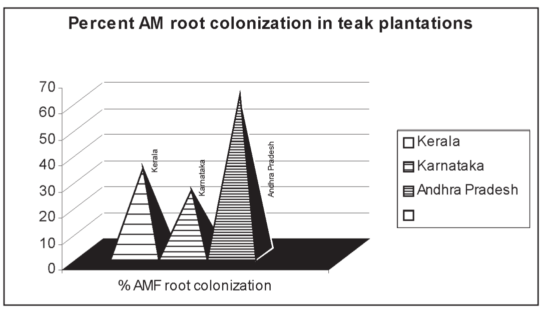

Fig. 1. Average AM fungal root colonization in teak plantations in three States

the 32-year-old teak plantation at Dharakonda, Sileru Forest Range and the 28-year-old plantation at Sileru, Sileru Forest Range. The AM fungal spore density ranged from 28-276, 50-193, and 62-449/10 g soil in samples from Kerala, Karnataka and Andhra Pradesh states respectively. AM fungal root colonization is influenced by various factors including the age of the plants. Formation of vesicles and arbuscules inside the root tissue is governed by host and pathogen factors, especially nutrient status of the host tissues. Edaphic factors, especially soil pH, soil nutrient status and soil moisture content also affect the formation of arbuscules and vesicles. Earlier, an exhaustive study on AM fungal root colonization pattern in teak stands in the Kerala State (Mohanan, 2002; 2003) showed that 1-year-old plantation as well as > 90-year-old plantations exhibited AM fungal root colonization.

From the teak rhizosphere soils collected from Kerala, Karnataka and Andhra Pradesh, a total of 73 species of Glomalean fungi belonging to the six genera - *Glomus, Gigaspora, Acaulospora, Scutellospora, Entrophospora* and *Sclerocystis* were encountered. Among these, *Glomus* species were the most predominant and widely distributed ones (Table 2).

Nursery trial

The results showed that the mycorrhizal treatment has effects on the seedling growth performance. The lowest mean seedling height of 23.92 cm was recorded for the Treatment No. 20 (control), while Treatment No. 8 with *A. appendicula* recorded the maximum mean height. Analysis of variance on data collected on seedling collar diameter after 90 days growth showed no significant differences among various treatments (Table 3). However, in DMRT specific homogeneous groups can be

Table 2. Distribution of AM fungal species in teak plantations

Sl. No	AM fungal genus	No. of species recorded	Remarks
1	*Glomus*	36	Widely distributed
2	*Acaulospora*	12	"
3	*Scutellospora*	10	Limited distribution
4	*Gigaspora*	6	"
5	*Sclerocystis*	7	Limited distribution
6	*Entrophospora*	2	Very limited distribution
	Total	**73**	

identified based on the collar diameter (Table 3). Treatment No. 20 (control) recorded the least collar diameter of 4.86 mm, while highest mean diameter of 5.15 mm was recorded for Treatment No.14 with *Scutellospora heterogama*.

Data on seedling biomass (dry weight) recorded from 90-day-old AM fungi treated and control seedlings showed highly significant differences among the treatments (Table 4). Lowest seedling biomass was recorded for the seedlings in control sets (1.75g), whereas Treatment No. 7 with *G. mosseae* exhibited the highest mean seedling biomass of 3.40 g. In DMRT, Treatments No. 20 (control), Treatment No. 14 (*S. heterogama*) and Treatment No. 7 (*G. mosseae*) stand out as a separate homogeneous group, while all other 17 treatments belonged to the same homogeneous group with < 3.40 g or > 2.65 g seedling biomass. Among the 19 AM fungal treatments, highest percent MIE of 48.53 was registered in seedlings treated with *G. mosseae* (Treatment No. 7) (Table 4).

Root colonization of teak seedlings from various treatments was checked and it was found that seedlings in all the AM fungi treatments were colonized by AM fungi in their feeder roots. Seedlings applied with *S. heterogama* inoculum registered least root colonization (14%), while *G. fasciculatum, G. botryoides, G. macrocarpum* and *G. mossseae* inoculated plants showed highest root colonization which ranged from 54 to 65 percent.

Earlier, mycorrhization of teak seedlings using different AM fungi has been carried out by various workers and varying levels of enhancement of seedling growth has been achieved (Gong *et al*., 2002; Gurumurthy and Sreenivasa, 1998).

Recently, enhancement of growth in tissue cultured teak plantlets through AM fungal treatment has been reported by Ramanwong and Sangwaint (2000). Better growth and performance in teak seedlings inoculated with AM fungi along with a strain of *Azotobacter chroococcum* have been reported (Paroha *et al*., 2000). Maximum root development in seedlings has been recorded either with AM fungi or AM fungi with *Azotobacter*. A similar result has also been recorded by Sugavanam *et al*. (1998) using AM fungi and *Azospirillum* sp. Growth enhancement in teak seedlings in potting medium inoculated with various combinations of AM fungus (*G. macrocarpum*), *Bacillus megaterium* and *Aspergillus niger* has been reported by Vijaya and Srivasuki (2001a, 2001b). Earlier, Verma and Jamaluddin (1995) have also reported improvement of seedling growth and biomass production by mycorrhization of seedlings using *G. fasciculatum* and a mixture of AM fungi. Mixed

Table 3. Effect of AM fungal treatments on growth of teak seedlings

Treatment No.	AM inoculum	Mean seedling height (cm)	Mean seedling collar dia (mm)
T1	*G. botryoides*	25.0030 ^{ab} (1.1212)	4.6162 ^{ab} (0.2422)
T2	*G. fasciculatum1*	26.2598 ^{abcd} (1.3190)	4.6912 ^{ab} (0.2257)
T3	*G. fasciculatum2*	26.0628 ^{abcd} (1.1818)	4.7446 ^{ab} (0.2892)
T4	*G. fasciculatum3*	27.0370 ^{abcd} (1.2238)	4.7446 ^{ab} (0.2591)
T5	*G. macrocarpum*	27.0130 ^{abcd} (1.3253)	4.6988 ^{ab} (0.2406)
T6	*G. mosseae1*	29.0648 ^{bcd} (2.1458)	4.8184 ^{ab} (0.3433)
T7	*G. mosseae2*	29.5260 ^{cd} (1.5833)	4.8466 ^{ab} (0.1609)
T8	*A. appendicula1*	29.8088 ^{d} (1.2213)	5.0548 ^{b} (0.1610)
T9	*A. appendicula2*	28.4398 ^{bcd} (1.1086)	5.0594 ^{b} (0.1456)
T10	*A. rehmii*	25.4702 ^{abc} (0.9289)	5.0074 ^{b} (0.2166)
T11	*A. scorbiculata*	27.3824 ^{abcd} (1.2370)	4.8010 ^{ab} (0.1209)
T12	*Giga spora candida*	28.3220^{bcd} (1.07758)	5.0914 ^{b} (0.0454)
T13	*Gigaspora gigantea*	27.1588 ^{abcd} (1.3422)	5.1132 ^{b} (0.0570)
T14	*S. heterogama*	28.0070 ^{abcd} (1.4608)	5.1502 ^{b} (0.2768)
T15	*S. erythropa*	28.8930 ^{bcd} (1.1314)	4.9748 ^{b} (0.1456)
T16	*A. appendicula1 +G. fasciculatum2*	28.5782 ^{bcd} (1.0378)	4.9430 ^{b} (0.1854)
T17	*G.fasciculatum 3+ G. mosseae2*	27.2410 ^{abcd} (1.2961)	4.9702 ^{b} (0.0827)
T18	*G. botryoides + G. fasciculatum2*	26.8770 ^{abcd} (0.6740)	4.9118 ^{b} (0.1033)
T19	*A. appendicula2 + G. mossease1*	27.6686 ^{abcd} (0.5984)	4.6990 ^{b} (0.1188)
T20	Control	23.9182 ^{a} (0.8019)	4.2378 ^{a} (0.0847
	Mean	**27.3868 (0.2897)**	**4.8587 (0.0443)**

* Figures given in parenthesis are SE; superscripts with same letters for means of seedling height and collar diameter in each treatment do not differ significantly

inoculum of AM fungi has been reported as more effective in boosting the teak seedling growth than the inoculum constituting a single AM fungus. In the present study, all the AM fungi and AM fungal combinations used as inoculum gave good results. Among these *G. mosseae* was the most efficient inoculum which gave maximum seedling height and MIE%. AM fungal mixed inoculum was also found equally effective in boosting the seedling growth as well as improving the seedling quality.

Field trial

During the early field establishment phase (after 3 months of field planting), no significant difference in plant height and collar diameter among the treatments was observed. Height growth was almost uniform except in Treatment Nos. 2, 3, and 17; maximum height was recorded in plants mycorrhized with *G. fasciculatum* and in Treatment with *G. fasciculatum + G. mosseae*.

Table 4. Effect of AM fungal treatments on seedling biomass (dry weight) in root trainers

Treatment No.	AM Fungal inoculum	Mean seedling biomass (dry wt. g)	% MIE*
T1	*G. botryoides*	2.9710 [bc] (0.1342	41.09
T2	*G. fasciculatum1*	2.8190 [bc] (0.0672	37.92
T3	*G. fasciculatum2*	2.9180 [bc] (0.1284)	40.02
T4	*G. fasciculatum3*	2.8600 [bc] (0.0730)	38.81
T5	*G. macrocarpum*	2.9902 [bc] (0.2495)	41.48
T6	*G. mosseae1*	2.9530 [bc] (0.3589)	40.74
T7	*G. mosseae2*	3.4000 [c] (0.0584)	48.53
T8	*A. appendicula1*	2.8020 [bc] (0.2322)	37.50
T9	*A. appendicula2*	2.9800 [bc] (0.2979)	41.28
T10	*A. rehmii*	2.7520 [bc] (0.1890)	36.41
T11	*A. scorbiculata*	3.0880 [bc] (0.1889)	43.33
T12	*Gigaspora candida*	2.7940 [bc] (0.2114)	37.37
T13	*Gigaspora gigantea*	3.1360 [bc] (0.2483)	44.20
T14	*S. heterogama*	2.6460 [b] (0.1759)	33.64
T15	*S. erythropa*	2.9800 [bc] (0.3057)	41.28
T16	*A. appendicula1 +G. fasciculatum2*	2.9260 [bc] (0.0573)	40.19
T17	*G.fasciculatum 3+ G. mosseae2*	2.6940 [bc] (0.3208)	35.04
T18	*G. botryoides + G. fasciculatum2*	2.9680 [bc] (0.2125)	41.03
T19	*A. appendicula1 + G. mossease1*	3.0240 [bc] (0.1923)	42.13
T20	Control	1.7500 [a] (0.0537)	0
	Mean	**2.8725 (0.052)**	

*Figures given in parenthesis are SE; superscripts with same letters for means of seedling height and collar diameter in each treatment do not differ significantly

Table 5. ANOVA of data on collar diameter of plants in various treatments in the trial plots (9 months after planting)

	Sum of squares	df	Mean square	F	Sig.
Corrected model	8.753 [a]	21	0.417	6.333	< 0.001 **
Intercept	263.132	1	263.132	3998.050	< 0.001 **
Treatment	7.415	19	0.390	5.929	< 0.001 **
Replication	1.338	2	0.669	10.166	< 0.001 **
Error	2.501	38	6.582E-02		
Total	274.386	60			
Corrected total	11.254	59			

* R squared = 0.778 (Adjusted R squared = 0.655)

Table 6. ANOVA of terminal data on height of plants in various treatments in the trial plots

	Sum of squares	df	Mean square	F	Sig.
Corrected model	16731.028[a]	21	796.716	4.265	< 0.001 **
Intercept	544424.237	1	544424.237	2914.678	< 0.001 **
Treatment	15275.332	19	803.965	4.304	< 0.001 **
Replication	1455.697	2	727.848	3.897	0.029 **
Error	7097.909	38	186.787		
Total	568253.175	60			
Corrected total	23828.937	59			

* R squared = 0.702 (Adjusted R squared = 0.538)

Growth measurements recorded after 9 months of field planting showed significant differences among various treatments (Tables 5-7). Treatment No. 16 with *Acaulospora appendicula*1 + *G. fasciculatum*2 showed the maximum height growth of 122.76 cm followed by Treatment No. 7 with *G. mosseae*2. Among the 20 treatments including control, five treatments, *viz*., Treatment Nos. 1,3,7,16 and 18 showed better height growth than the other treatments (Table 7).

Collar diameter of plants also showed similar results. Highly significant difference among the treatment was observed (Table 7). Maximum collar diameter of 2.673 cm was recorded in Treatment No. 18 with *G. botryoides* + *G. fasciculatum*2 inoculum. Treatment Nos. 1 (*G. botryoides*), 3 (*G. fasciculatum*2), and 16 (*A. appendiculata*1 + *G. fasciculatum*2) exhibited almost same mean collar diameter and fall in the same group in DMRT. Treatment No. 7 (*G. mosseae*2) with mean collar diameter of 2.407 cm was also found one of the promising treatments. Another interesting observation recorded was on the occurrence of casualty during the draught period (February-March). Treatment No. 20 (control) recorded maximum percent of casualty (2%) among the treatments.

Many plants in the control blocks showed more or less complete defoliation during the draught period (February-March). However, plants in all the other treatments exhibited resistance against draught and defoliation registered was negligible. Even plants in treatments with lower height and collar diameter exhibited comparatively better resistance against draught and defoliation. The analyses of data on growth parameters and performance of plants in the field revealed that mycorrhization of seedlings has improved the growth of plants in the field and facilitated in reducing the casualty during the dry period.

Table 7. Height and collar diameter of plants 9 months after field planting

Treatment No.	AM Fungal inoculum	Mean height of plants (cm)*	Mean collar dia of plants (cm)*
T1	*G. botryoides*	116.723 [fgh] (7.891)	2.587 [gh] (0.148)
T2	*G. fasciculatum*1	84.040 [abcd] (7.891)	1.870 [abcd] (0.148)
T3	*G. fasciculatum*2	110.480 [defgh] (7.891)	2.533 [gh] (0.148)
T4	*G. fasciculatum*3	96.053 [bcdefg] (7.891)	2.347 [defgh] (0.148)
T5	*G. macrocarpum*	113.327 [efgh] (7.891)	2.373 [efgh] (0.148)
T6	*G. mosseae*1	101.370 [bcdefgh] (7.891)	2.250 [cdefgh] (0.148)
T7	*G. mosseae*2	119.443 [gh] (7.891)	2.407 [fgh] (0.148)
T8	*A. appendicula*1	104.457 [cdefgh] (7.891)	2.197 [cdefgh] (0.148)
T9	*A. appendicula*2	91.050 [abcde] (7.891)	1.910 [abcde] (0.148)
T10	*A. rehmii*	87.243 [abcd] (7.891)	1.937 [bcdef] (0.148)
T11	*A. scorbiculata*	81.133 [abc] (7.891)	1.757 [abc] (0.148)
T12	*Gigaspora candida*	76.510 [ab] (7.891)	1.857 [abcd] (0.148)
T13	*Gigaspora gigantea*	80.097 [abc] (7.891)	1.813 [abc] (0.148)
T14	*S. heterogama*	68.397 [a] (7.891)	1.603 [ab] (0.148)
T15	*S. erythropa*	84.810 [abcd] (7.891)	1.857 [abcd] (0.148)
T16	*A. appendicula*1 +*G. fasciculatum*2	122.763 [h] (7.891)	2.587 [gh] (0.148)
T17	*G.fasciculatum*3 + *G. mosseae*2	77.180 [ab] (7.891)	1.773 [abc] (0.148)
T18	*G. botryoides* + *G. fasciculatum*2	114.017 [efgh] (7.891)	2.673 [h] (0.148)
T19	*A. appendicula*1 + *G. mossease*1	89.717 [abcde] (7.891)	2.150 [cdefg] (0.148)
T20	Control	86.313 [abcd] (7.891)	1.433 [a] (0.148)

*Mean value of observations from 60 plants in three replications
*Figures given in parenthesis are SE; means of height and collar diameter in each column with superscripts of same letters do not differ significantly

Among various AM inocula tried, *G. fasciculatum* mixed with *A. appendicula* (Treatment No. 16) and *G. fasciculatum* mixed with *G. botryoides* (Treatment No. 18) gave maximum height growth and collar diameter in plants. Inoculum of *G. fasciculatum*2 (Treatment No. 3) and *G. botryoides* (Treatment No. 1) and *G. mosseae*2 (Treatment No. 7) applied singly also yielded better growth in treated plants than in control. Observations from the trial plantation was also recorded during the first week of June 2005 (wet period) and found that all the plants in AM fungi treated plots were performing better than the control plots in terms of plant height and vigour.

CONCLUSIONS

Teak rhizosphere soil and feeder root samples collected from 59 plantations situated in different eco-climatic zones in the Kerala, Karnataka and Andhra Pradesh States revealed moderately high percentage root colonization as well as AM fungal spore density. The intensity of colonization varied depending on the soil characteristics and age of the trees. Among 36 *Glomus* species recorded from the teak soils, *G. aggregatum, G. botryoides, G. fasciculatum, G. deserticola, and G. mosseae* were the most predominantly distributed ones. The results from nursery trial demonstrate the efficacy of artificial mycorrhization of 10 to 15-day-old seedlings raised in weed compost medium in root trainers. The results also substantiate the improvement of quality of teak seedlings within 90 days of their growth in root trainers by application of inoculum of *G. botryoides, G. fasciculatum, G. macrocarpum, G. mosseae, A. appendicula, A. scorbiculata, Gigaspora gigantea* and *Scutellospora erythropa* singly or in combinations.

Field trial carried out employing the mycorrhized and non-mycorrhized (control) teak seedlings selected from 20 treatments from the nursery trial, registered highly significant differences in growth performances of mycorrhized seedlings. In general, planting stock pre-colonized by efficient AM fungi in the nursery, exhibited better field performance than the control plants in terms of survival, increment in height and collar diameter of plants and also resistance to draught. This boost in growth and vigour of artificially mycorrhized teak plants in the early establishment phase of the plantation may also reflect in health and productivity of the stands in the ensuing years. For further validating the beneficial effect on improvement of planting stock by mycorrhizal manipulations and thereby boosting the stand growth and productivity, large-scale nursery screening and multi-location field trials with long term monitoring are warranted.

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Genetic Resources for Higher Productivity of Planted Teak Forests

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ABSTRACT

Results are summarized from two evaluations of five teak provenance trials aged 28 and 32 years located in Ghana and Cotës d'Ivoir. A total of 27 provenances/landraces are represented in field trials of Côte d'Ivoir and 13 in the field trials of Ghana. Provenances highlighted significant difference with regard to growth, stem straightness, stem axis persistence, frequency of epicormics and protuberant buds, height of fork, tendency to buttress and circularity of stems. The differences were especially pronounced in the case of growth, stem straightness and to some extent, presence of epicormics. Especially, provenance from Nilambur (India) showed both above average growth and stem straightness in the respective field trials they were tested. A significant genotype-environment interaction was found for growth mainly due to provenances from the dryer Indonesia with an above-average growth at a semi-deciduous dry site and below-average growth at two more moist sites. No genotype-environment interaction was present for stem straightness or epicormics. The correlation at provenance level between early (age 9 or 17) and late (age 28) epicormic scores was high. This was also the case for the basal area, while the age-age correlations as regards stem straightness were more uncertain. The studies stress the importance of choosing the right provenances for breeding programs of teak.

Keywords: *Tectona grandis*, provenance trials, growth factors, genotype-environment interaction.

INTRODUCTION

The demand for teak has long exceeded the growth of teak in natural forests and plantations. This has increased the prices for teak timber by more than 20% (deflated prices) from 1997 to 2007. Additionally, in the last decade the supply of high quality teak timber mainly from natural forests in Burma has almost stopped (Kjaer, 2005) and the present differences in price between low and high quality teak timber will probably enlarge in the future. Therefore, the economic incentive to improve growth, reduce rotation age, increase the percentage of heartwood, improve external quality characteristics (e.g. bole straightness, epicormics, circularity, etc.) and wood quality of teak timber from plantations is large. An important means to reach this is to explore the genetic variation and use the right genetic resources.

Earlier studies have found provenance variation concerning growth, several external quality characteristics and wood quality traits (Keiding *et al*., 1986; Madoffe and Maghembe, 1988; Kjaer *et al*., 1995; Kjaer and Lauridsen, 1996; Simatupang *et al*., 1996; Kjaer *et al*., 1999; Pedersen *et al*., 2007; Suhaendi, 1998). Additionally, significant genetic variation is found within provenances for growth, heartwood percentage and specific gravity (e.g. Persson, 1971a; Mandal and Chawhan, 2003). Some of these earlier evaluated provenance field trials are still valuable sources to estimate the possibilities of making early selection and to examine if the genetic variation is still present and to quantify to what extent it is present.

In this context the EU supported project West African Teak (WAFT) evaluated on a 28-year-old and a 32-year-old provenance field trial in Côte d'Ivoire and a 23-year-old and two 28-year-old field trials in Ghana. The field trials were measured growth and external quality characteristics and this paper will shortly summarise the results from two evaluations of these trials (Ofori *et al*., 2007; Koffi *et al*., 2007).

MATERIAL AND METHODS

Two of the above mentioned field trials are situated in Côte d'Ivoire. Both trials are in the semi-deciduous zone with a yearly estimated precipitation of 1300 and 1500 mm. In total 27 provenances/landraces from West Africa, Tanzania, India, Laos and Thailand are represented in the two trials. Three of the field trials are situated in Ghana in a moist evergreen zone, a moist semi-deciduous zone and a dry semi-deciduous zone with a yearly estimated precipitation of 1792, 1650 and 1140 mm, respectively. A total of 13 provenances/landraces from Ghana, Indonesia, India and Laos are represented in the three trials from Ghana.

Traits measured were height, basal area, volume, score of stem form (1 for crooked – 5 for straight trees), persistence of axis (height of unbroken axis, scored on a 1-9 scale where 1 denotes axis broken at the base of the tree and 9 denotes a continuous axis through to the top of the tree), height of first fork, score of epicomics (scored on a scale from 1 to 4 where 1 equals 75% or more of stem covered by epicormics and 4 equals a stem free of epicormics), score of buttress severity (scored on a scale from 1 to 4 where score 4 was for completely round trees and 1 for trees where the stem cross sectional area was 30% or less of an ideal round stem), score of protuberant buds (score similar to score of epicomics), circularity of bole (calculated as circumference/length of perimeter) and ovality (smallest diameter divided by largest diameter measured at 1.3 m with a calliper) of the bole. Besides this, we had data from older measurements from some of the field trials which we were able to correlate with the new measurements.

RESULTS

Provenances in the two field trials at Côte d'Ivoir were significantly different as regards growth, stem straightness, stem axis persistence (in one of the trials), frequency of epicormics, and frequency of protuberant buds (in one of the trials), height of fork (in one of the trials), tendency to buttress and circularity of stems. Provenances from Nilambur and one of the Tanzanian landraces showed both above average growth and stem straightness in the respective field trials where they were tested. The correlation at provenance level between 9 year of age in persistence of axis and stem straightness score at age 28 was close to one, while the correlation of stem straightness at 9 years and 28 years was only 0.36. Epicormics and the presence of protuberant buds were closely correlated. Epicormic scores at 9 years were highly correlated with epicormic scores at age 28 or 32 depending on the field trials.

Significant differences were found among the provenances for growth, stem straightness, fork height, and presence of epicormics, protuberant buds and buttress in the three provenance trials in Ghana. The provenance from Nilambur in moist India had above-average performance in all three trials as regards growth and was among the best concerning stem straightness and fork height. A significant genotype-environment interaction was found for growth mainly due to provenances from the dryer Indonesia with an above average growth at the semi-deciduous dry site in contrast to the other two sites. The genetic correlation between the two sites Pra Anum and Tain was high as regards stem straightness and epicormics. The study showed that stem straightness and fork height to some extent was influenced by early flowering (scored at age 9 years). Provenance basal areas at age 9 years were highly correlated with provenance basal areas at age 28 years in the field trial Pra Anum and this was also the case for between basal areas at age 17 and 28 in Tain. Provenances were significantly different across the three sites Pra Anum, Tain and Subiri concerning buttress scores and the site x provenance interaction non-significant.

Differences were particularly large for growth and stem straightness in the field trials. Growth differences were over 26% between the poorest and the best growing provenance and difference in stem straightness score were above 0.50. (Table 1)

DISCUSSION AND CONCLUSION

The two evaluations (Koffi *et al*., 2007; Ofori *et al.*, 2007) showed that provenance differences in growth and external qualities are also present at ages 23-32 and that differences between provenances in stem straightness, frequency of epicormics and presence of buttress are consistent across sites, while some genotype-environmental interaction is possible for growth. This confirms earlier results from several other field trials (Kjaer and Lauridsen, 1996). Additionally, it is possible to make early selection (age 9 years) to reduce frequency of epicormics, while it is more uncertain if it is possible as regards stem straightness. The results suggest that it is possible to make selections for growth as early as 9 years if provenance differences are present at that age, but it needs to be confirmed from more field trials of same age.

Overall, it seems that the provenances from Nilambur represent a favourable choice for sites in Ghana and Côte d'Ivoir, having fast growth and relatively good stem form. Provenances from this region are reported to perform generally well

Table 1. Basal area and stem straightness score from the five field trials in Ghana and Côtes d'Ivoir. Best linear unbiased predictors for provenances.

Field trial	Basal area		Stem straightnees	
	Highest %	Lowest %	Highest Score	Lowest Score
Tené (Côtes d'Ivoir)	16	-18	0.32	-0.19
Seguié (Côtes d'Ivoir)	21	-26	0.33	-0.33
Subiri (Ghana)	18	-22		
Pra Anum (Ghana)	16	-14	0.61	-0.68
Tain (Ghana)	12	-14	0.45	-0.36

Deviations from the mean in either percentage or score. Provenances were not significantly different as regards stem straightness in Subiri (Ghana).

(Keiding *et al.*, 1986; Kjaer *et al.*, 1995; Suhaendi, 1998; Pedersen *et al*., 2007). Additionally, it was found to have the highest percentage of heartwood compared with five other provenances (Kjaer *et al*., 1999). Nevertheless, the results pointed out that among other provenances Tanzanian landrace Bigwa is promising for West Africa. The local landraces generally had a poor form and average, or above average growth rate.

The large differences in growth and stem straightness stress the importance of choosing the right provenance for seed supply and for further breeding such as selection of plus trees for the establishment of either clonal seed orchards or for clonal propagation after clonal tests. However, these breeding programs should also consider important wood quality traits, in particular heartwood percentage.

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Performance and Yield of Teak (*Tectona grandis* L.f.) under Semi-Irrigated Conditions in Cauvery Delta of Tamil Nadu and Dry Belt of Bangalore Rural District in Karnataka

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ABSTRACT

Teak plantations in Tanjavur have demonstrated that good quality teak with very high heartwood content can be successfully grown within a short rotation of 20 to 30 years. As per the measurements and estimations made by Regional Centre, National Afforestation and Eco-Development Board for the standing teak trees in Tanjavur, Tiruvarur and Nagapattanam districts in the Cauvery delta of Tamil Nadu State, 50-year-old-trees are yielding nearly one m^3 (or 35 cft) of usable round timber and the trees have attained an average GBH of 143.75 cm and an average bole height of 10.75 m. Meanwhile, the 20-year-old teak trees have attained GBH of 81.00 cm and height of 5.80 m with 3 to 10 cft round wood volume. About 200 trees were maintained per ha or one km. The other case is of a privately raised teak plantation in Bangalore Rural district planted during 1990. The trees are planted both in rows (on contour bunds) and in blocks at an average spacing of 3.5 m in a row and 18 m between rows under the agroforestry system. In block plantations, 3.0 m x 6.5 m or 3.5 m x 4.5m spacing was given. There are about 400 trees of teak subjected to semi-irrigated treatment and about 1600 trees under rain-fed condition. The average GBH of teak trees grown under semi-irrigated conditions was 83.50 cm with a bole height of 4.5 m (7 cft per tree), while teak trees grown under rain-fed condition measured 55.30 cm with a bole height of 3.5 m (2 cft / tree). Trees in block plantations exhibited lower girth than trees grown in single rows. The study has shown that teak responds well to semi-irrigated condition and shows nearly 3 times faster growth in girth. Secondly, teak trees grown in rows wide apart have put on higher girth than trees in block plantations. Thirdly, teak trees grown under semi-irrigated conditions yield higher grade timber under much shorter rotation and accordingly fetch higher returns. However, while raising such plantations, use of known superior quality seed must be ensured to get good quality wood.

Keywords: Agroforestry, semi-irrigation, rainfed plantation, line planting, block planting, espacement.

INTRODUCTION

Teak (*Tectona grandis* L.f.) is one of the highly priced construction timber species in the world. It occurs in natural forests and is being grown in plantations in their traditional areas of occurrence. It is only during 1950s in Tamil Nadu and 1980 in Karnataka, Forest Department and the farmers resorted to introducing teak in non-traditional areas. There was a lot of criticism against its introduction in non-traditional areas and orthodox foresters believed that teak in non-traditional areas will not yield expected quantity and quality of timber. The present paper analyses the results obtained from a study of teak plantations raised by Tamil Nadu Forest Department along canal banks in Cauvery delta in Tamil Nadu and teak trees grown under agroforestry system by a farmer under semi-irrigated condition in Devanahally Taluk in Bangalore Rural District.

METHODOLOGY

The Regional Centre, National Afforestration and Ecodevelopment Board conducted this study at Cauvery delta of Tamil Nadu and dry belt of Bangalore Rural District, Karnataka to find out the performance of teak trees grown under semi-irrigated condition. Six ranges were selected in Tanjavur Division and one range from Villupuram Division in Tamil Nadu. In each range, a minimum of 10 to 20 plantations belonging to different years of plantation were randomly selected. The data on girth and height measurements of randomly selected trees from different size classes were recorded.

In the case of teak trees grown by a farmer at Bijwara, Devanahalli Taluk, Bangalore rural district, measurements of girth and height from randomly selected trees grown under different agroforestry systems in combination of different agricultural or horticultural crops were recorded.

The volume of trees in both the cases was estimated using standard formula:

$$\frac{\pi D^2}{4} \times Ht \times FF\ (0.7)$$

OBSERVATIONS

In Tamil Nadu, teak plantations were confined to the most preferred moist localities within forest tracts till 1956, when one research centre was opened in Tanjavur to study the possibility of raising teak along river and canal banks. Thus, teak cultivation under irrigated or semi-irrigated conditions turned out to be one of the most significant innovations in Tamil Nadu Forestry. A special Forest Division was formed in 1956 to implement the scheme of planting teak along the river and canal margins in Tanjavur, Nagapattanam and Thiruvarur Districts. Today, nearly 9400 km length of left bank and right bank of cauvery delta have been planted teak. In grand anicut canal, water flows throughout the year. But the flow of water in the tributaries is not maintained regularly. The tail ends of the cauvery delta remain dry during the summer season. Hence, the best growth, survival of teak plantation have been noticed along canals which had water flow almost throughout the year.

Teak stumps of thumb thickness with 15-20 cm length were used for planting during South-West monsoon on either side of canal banks. About 200 stumps were planted in one ha or one km length in 2m x 2m spacing. Usually, crowbar hole method of planting was practiced. After planting of stumps, a basin was made around each stump and watering was done during dry season for early sprouting and growth of plants. Replacement of casualties was taken up during second and third year of maintenance during July-August.

During first year, weeding and soil working operations were carried out before the onset of North-east monsoon. Tending operations such as pruning of lower dried branches was carried out. One watcher was provided for an area of 5 ha or 5 km stretch of teak plantation to protect the plantation from cattle grazing and to take up cultural operations. Illicit felling of trees was completely controlled as each and every tree was numbered.

In Tanjavur Range, the survival percentage ranged from 17.0 to 83.0 which was influenced mainly by wind or cyclonic storms, flooding of canal, desilting and widening of canals. The trees grown on the canal banks did not have a firm tap root system and as such there was no well established anchorage. The root system was more fibrous and shallow and the roots were concentrated on the shoulders of the canal bund and restricted to surface soil due to proximity to water source.

As per the enumeration and measurements made by Tamil Nadu Forest Department during 2000, a growing stock of nearly 7.27 lakh trees existed. The yield estimation done for plantations up to 1990 was nearly 80,000 m^3, which was valued at not less than Rs. 80 crores. As per the Department, mature trees above 30 years can be harvested.

As per the measurements and estimations made by RC, NAEB for the standing teak trees in Tanjavur, Tiruvarur and Nagapattanam districts in the Cauvery delta (Table 1), 50 years old trees were yielding more than 1 m^3 usable round timber. The trees had attained an average girth of 143.75 cm at breast height and an average bole height of 10.75 m, while, 20-year-old teak trees had attained GBH of 81 cm and height of 5.80 m with 3 to 10 cft round wood volume.

The trees above 30 years are expected to give logs of varying classes from C-I to C-III including unclassified logs. The average rate expected per m^3 with the current timber schedule of rates comes to Rs. 10,000.

Among the plantations sampled, Kalyana Odai Vaikal plantation (1959) in Pattukotai Range, recorded highest girth of 211 cm GBH, 10 m height, 1.81 m^3 volume and the expected revenue to be generated from 179 trees was Rs. 32.32 lakhs.

Teak plantations along canal banks in Tanjavur have demonstrated that a good quality teak can be successfully grown with very little proportion of sapwood and maximum heartwood with dark shade and distinct growth rings within a short rotation of 20 to 30 years. Interestingly, trees which had attained 60 to 70 cm GBH in the age class of 10 to 15 years had developed nearly 75 percent heart wood. The seed origin of most of the teak plantations in this area is said to be from Top Slip which is known for best quality teak trees.

In Karnataka, Sri. Ramakrishnappa, a farmer, in Devanahally taluk of Bangalore Rural district is maintaining about 2000 teak trees which were planted during 1990 and were 15 years of age as on 2005. These trees were planted both in rows (on contour bunds) and blocks at an average spacing of 3.5 m between trees in a row and 18 m between rows under agroforestry system. In block

Table 1. Yield of teak trees raised along canal banks in cauvery delta of Tamil Nadu

Year of raising plantation	Age as on 2000 (yrs)	Average GBH (cm)	Average bole height(m)	Average timber volume (m^3)/tree
1956	50	143.75	10.75	1.28
1961	45	131.25	8.75	0.98
1966	40	120.40	9.60	0.82
1971	35	100.00	8.40	0.47
1976	30	97.00	8.80	0.47
1981	25	96.60	6.90	0.40
1986	20	81.00	5.80	0.28

plantations, 3.0 m x 6.5 m or 3.5 m x 4.5m spacing was given. Main agricultural / horticultural crops grown were grape, sapota, ragi, brinjal, mulberry and maize. Brinjal, grape, sapota crops were semi-irrigated, while ragi, redgram and maize were grown under rainfed condition. Furrow irrigation was given to brinjal and mulberry while grape was drip irrigated. There are about 400 trees of teak subjected to semi-irrigated treatment and about 1600 trees under rainfed condition.

The average girth at breast height of teak trees grown under semi-irrigated conditions was 83.50 cm with a bole height of 4.5 m while teak trees grown under rainfed condition measured 55.30 cm girth with a bole height of 3.5 m (2 cft per tree). Trees in block plantations exhibited lowest girth than trees grown in single row (Table 2). The heartwood development in both the systems was not as much as it had in Tanjavur teak for the same age.

DISCUSSION

Although the reports on the effect of irrigation on teak growth are meagre (Bhaskar, 1995), the present studies have indicated that protective or semi-irrigated conditions boost the growth of teak and hence partial irrigation is recommended in non-traditional areas. Irrigation by percolation from shallow trenches or furrows which run between the rows of teak trees was recommended by Bhaskar (1995). Bhandran (1959) and Kadambi (1972) did not recommend irrigation by flooding.

Table 2 . Comparison of teak based agroforestry models on growth, development and economics

Sl. No.	System / Model	Spacing (m) between teak trees	Semi-irrigated (400 trees)		Rainfed (1600 trees)	
			GBH (cm)	Height (m)	Girth (cm)	Height (m)
1	Teak – Coconut – Ragi	- 7.0 - (T – C – T)	-		73	3.5
2	Teak – Brinjal	3.5	79	4.5		
3	Teak – Grapes (Plot – I)	3.5	-		35	3.5
4	Teak – Grapes (Plot – II)	3.5	94*	4.5		
5	Teak – Redgram	2.5	-		54	3.5
6	Teak - Sapota	3.5	94**	4.5		
7	Teak – Maize	6.5 x 4.5	-		68	3.5
8	Teak – Sapota - Mulberry	3	94*	4.5		
9	Block plantation	4.5 x 3.5	-		43	6.0
		6.5 x 3.0	-		59	6.0
	Average		**83.50 cm**	**4.5**	**55.30**	**3.5**
	Volume		**0.21 m³/tree**		**0.05 m³/tree**	
Approximate value of standing crop			Rs. 21.56 Lakhs for 83.16 m³ @ Rs. 25926 / m³		Rs.16.00 Lakhs for 86.4 m³ @ Rs. 18518.5 / m³	

T = Teak, C = Coconut

* There is less soil moisture evaporation due to coverage by grape canopy as compared to open lands.

** Both in red soil and black soil closer to a nallah.

Under semi-irrigated condition teak is found to yield about 10 cft of usable round wood in about 15-20 years. However, the heartwood content appears to be not correlated with girth of the tree but depend upon the genetic resource. From one of the studies conducted by the author (unpublished data), it is seen that the content of heartwood in an even-aged teak plantation varied greatly among trees. (Table 3). This indicates that early development or proportion of heart-wood in relation to the age or girth of trees is a genetic trait which may be exploited by selecting seed from known elite trees identified for highest and earliest heartwood development. Hence, the effect of fast growth under irrigated condition on heartwood development in teak needs further research as the grade of timber usability and monetary returns ultimately depend upon the heartwood quality and quantity. However, recent studies conducted by Bhat and Indira (1997) have indicated that faster grown dominant teak trees had relatively little effect on the strength of timber in 13, 21, 55 and 65 years-old plantations. According to them, teak seems to have potential for producing timber of optimum strength with relatively short rotations of 21 years in suitable plantation sites. Their findings showed that wood density, maximum bending and longitudinal compressive stresses of 5 year-old teak grown in farm land were not inferior to those of mature teak of forest plantations although stiffness of wood was only 82 percent of the average value of mature teak (Bhat *et al.*, 2001).

Table 3. Heartwood content in teak in relation to girth of trees grown in Bangalore (Age : 18 years)

Tree no.	Diameter (o.b.) of tree (cm)	Diameter of heartwood (cm)	Heart wood percentage
1	15.6	7.6	48.7
2	18.15	10.15	55.92
3	16.87	9.87	58.60
4	22.92	14.92	65.09 *
5	19.52	9.42	48.25
6	15.76	10.76	68.30 *
7	14.6	7.64	52.32
8	12.42	5.42	43.65
9	18.78	12.78	68.05 *
10	19.74	11.74	59.47
11	12.42	6.42	51.70
12	10.82	4.82	44.55
13	10.50	4.50	42.85
14	10.66	5.66	53.09
15	11.46	5.46	47.68
Mean	**15.35**	**8.47**	**53.88**

* Trees with highest heartwood content

The farmer, Sri. Ramakrishnappa, is using the thinned poles of teak measuring about 50 cm gbh for door and window frames after giving a treatment with diesel. Its durability is yet to be checked.

CONCLUSION

The present study has shown that teak responds well to semi-irrigation and shows nearly 3 times faster growth in girth. Secondly, teak trees grown in rows wide apart have put on higher girth than trees in block plantations. Thirdly, teak trees grown under semi-irrigated conditions yield higher grade timber under much shorter rotation and accordingly fetch higher returns. However, while raising such plantations the seed source from known superior quality seed stands must be ensured to get good quality heart wood.

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Wood Quality of Planted Teak Outside Forests

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ABSTRACT

With the changing pattern of industrial round wood supply, trees grown outside forests, especially in homesteads and farmlands, play a significant role in India, Indonesia and many other tropical countries. Home garden forestry with teak is a common practice of growing trees outside forests (ToF) in Kerala, India, which accounts for more than 50% of industrial round wood supply. Comparative timber property investigations showed that wet home garden sites produced larger diameter logs with an average dbh of 39.6 cm (at 35 years of age) qualifying for Site Quality I of All India Yield Table. In contrast, the dry sites produced smaller diameter logs (average dbh 24 cm) at the same age reaching only Site Quality II/III with more frequent pole sizes. However, trees in drier homesteads produced timber of more attractive figure with black streaks and darker golden brown colour. Although yield was higher, the paler wood colour and lesser decay resistance (to brown-rot fungi) lowered the timber value of teak grown in wet home gardens. No significant differences were noticed in wood basic density, dimensional stability and strength properties. Due to lack of standard espacement / thinning and pruning regimes, the logs of home garden teak were often defective with eccentric growth, bends and knots leading to lower market value. The study concludes that teakwood grown in homesteads differs from that produced in forest plantations in certain properties such as log form, extent of natural defects, appearance/wood colour and grain as well as natural durability depending on the type of locality of growth. However, wood density and strength properties were almost similar. These differences in timber quality may influence the price factor of teakwood coming from trees outside the forests (ToF). However, timber quality of teak grown in farmlands is not necessarily inferior if adequate silvicultural techniques are adopted by tree growers.

Keywords: Trees outside forests (ToF), home garden forestry, wood quality, brown-rot fungi, durability, wood colour.

INTRODUCTION

With the changing pattern of industrial round wood supply, trees grown outside forests especially in homesteads and farmlands play a significant role in terms of timber production. In Kerala State, India, of the total annual production of 11.7 million m^3 of wood for the year 2000-01, State forests including plantations accounted for only 9.5% of industrial wood supply, in contrast to 75% of the supply coming from home gardens including estates (Krishnankutty *et al.*, 2005). There is, however, a prevailing notion that farm-grown teak is inferior in decorative value, durability and strength properties to that grown in forest plantations and hence fetches much lower price. Many teak growers often express serious concern about the timber quality before making further investments on growing high quality teak timber. The recent investigations (Bhat 2000; Bhat *et al.*, 2001), however, indicate that:

- Fast grown teak timber is not necessarily weaker and less durable than the traditional plantation timber though slightly different in grain and texture.
- Faster growth in relatively young plantations with judicious fertilizer application / genetic inputs can be advantageous in terms of heartwood volume and strength.
- The specific objectives of this study were: i. to assess the teak timber value from homesteads in terms of log size and grade / recovery of sawn wood. ii. To determine timber property differences particularly with regard to figure (colour, grain, texture), dimensional stability, strength, heartwood-sapwood proportions and durability of teak grown in homesteads as compared to that from forest plantations. Thus the present study envisaged to evaluate the timber quality of 35-year-old teak grown in homesteads chosen from both wet and dry localities of Kerala and to compare the same with teakwood grown in forest plantation of Nilambur, which is reputed in timber trade as Malabar teak.

MATERIALS AND METHODS

Log characterization and grading of home garden teak was done in the field in the wet and dry localities as per the Indian Standard IS: 4895 (1985). The study material comprised five defect-free dominant teak trees each (age 35 years) sampled from the wet and dry locality home gardens as well as forest plantation. The data on three site conditions and tree characteristics are given in Table 1.

Table 1. Site and tree characteristics of sampled homesteads and forest plantation

Factor	Wet (Muvattupuzha)	Dry (Nemmara)	Forest plantation (Nilambur)
Altitude (m.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	Loamy sand	Loamy sand
Annual rainfall range (mm)	2500 - 3500	1500 – 2300	2500 – 3000
Temperature range (°C)	17 – 34	26 – 37	17 – 37
Relative humidity %	Above 80	70	70
Tree age (years)	35	35	35
Mean tree height (m)	17.0	14.0	21.0
Mean, dbh (cm)	39.6	24.0	31.0

For estimating the percent sawn timber recovery, the basal billet above the stump level was sawn in a mill. The wood discs from BH level were utilized for studying wood colour variation, heartwood-sapwood proportion, physical properties and durability. Sawn timber output (in m^3) and recovery percentage (ratio of sawn timber output over log volume) were calculated based on the commercial quarter girth formula. For mechanical properties, scantlings prepared from the basal billets as per Indian Standard (1986) were used.

RESULTS AND DISCUSSION

Grading and Log characterization

Grading of 96 logs (of 35-year-old trees) from wet and dry localities revealed that teak timber from homesteads qualified only for Grade II or III as specified in Indian Standard (IS 4895). Out of the logs, 59% belonged to timber class and the rest were of pole size. Export quality Grade I timber was not available from either of the two homesteads (Table 2). Home garden trees from wet site produced timber of average dbh 39.6 cm, indicating their 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 produced smaller dimensional timber of 24 cm average dbh, which qualifies only to SQ II/III and major proportion of the logs belonging to pole classes. Pole sized logs were less frequent in wet sites (Table 3). The log form/quality was poor due to defects such as bends, frequent knots and eccentric radial growth, probably due to lack of standard silvicultural management practices in home garden forestry.

Sawn timber recovery

Details of the sawn timber recovery rate are presented in Table 4. The sawn timber recovery was significantly lower for logs from dry site (66.8%) (P<0.05) than wet home-garden and plantation teak (76.5 and 77.8%, respectively). Even though wet site teak had slightly larger diameter logs (39.6 cm), the recovery percentage was not significantly different from that of the plantation teak (diameter

Table 2. Classification and grading of teak timber from homesteads.

Teak timber classes	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						**12**	**38**

**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 3. Classification and grading of teak poles from home gardens.

Pole classes	Girth limits (cm)	Length (m)				Number of poles in each Grade*				Number 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										**5**	**33**

**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 & D - Cumulative value of permissible visual defects 7.5 units and above

Table 4. Mean sawn timber volume and recovery from homesteads and forest plantation.

Location	Log length (m)	Log mid girth (m)	Log volume - Quarter girth (m^3)	Sawn timber output (m^3)	Sawn timber recovery (%)
Wet	1	1.33[a]	0.111[b]	0.084[c]	76.5[d]
		(9.4)	(18.0)	(10.1)	(10.9)
Dry	1	0.81[e]	0.041[f]	0.028[g]	66.8[h]
		(8.0)	(15.8)	(23.8)	(8.2)
Forest plantation	1	1.05[i]	0.069[j]	0.054[k]	77.8[d]
		(2.8)	(5.6)	(3.4)	(2.7)

Note: Cell values differing by a letter in the superscript within each column are significantly different at P<0.001

31.0 cm) (P>0.05). This reflects that large diameter logs with higher sawn wood volume equaled the silviculturally managed plantation teak in percentage recovery (Table 3). The major structural factors that determined sawn wood grade and recovery were size and frequency of unsound hollow knots, deep flutes in the log, stem size, bole shape and heartwood-sapwood proportion. In spite of the low sawn timber recovery recorded for the dry site, its remarkable decorative features were preferred for manufacture of specialty products like decorative veneer, joinery and furniture and such logs fetched higher price despite small log dimensions (Bhat, 2005; Thulasidas and Bhat, 2005). Table 4. Mean sawn timber volume and recovery from homesteads and forest plantation.

Wood colour

Typical samples of wood obtained from wet and dry sites and also forest plantation are shown in Figure 1. The colour of wood has a crucial importance in fixing the price of teak timber and generally visual colour perception often varies from person to person. Two standard methods of colour determination, viz., Munsell system (1905) and CIE L* a* b* system (1976) were used to precisely interpret the colour variation. As per the Munsell hue system, heartwood colour from wet locality was comparable to that of dry locality and plantation specimens. However, the chroma value indicated less saturation of colour in the former

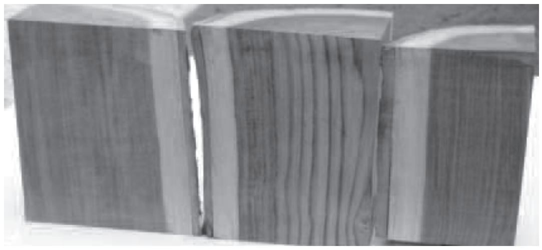

Fig. 1. Heartwood colour difference between homestead and plantation teakwood. Note the paler heartwood in sample from wet site (left), golden brown colour with black streaks in dry site (middle), and uniform golden brown colour of forest plantation teak (right).

making it paler. The chromaticness index b* (yellowness) of wet site sample with less yellowness, as determined by L* a* b* system, differed significantly from that of dry site and plantation specimens (Figures. 2a-c). No significant difference was observed between samples of different localities with regard to L* brightness and a* redness. The results suggested that the paler colour (less yellowness) of wet site teakwood was one of the factors for lower price of home garden teak.

Heartwood proportion

Heartwood proportion of stem volume also determines the timber value in the market as it is the durable part of the timber for which teak has worldwide reputation. The heartwood proportion,

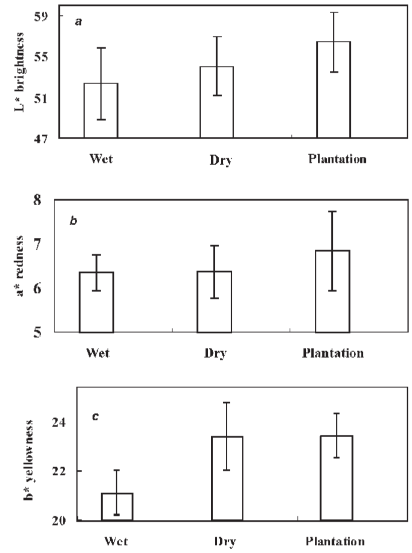

Fig. 2a – c. Lightness index (L*) and chromaticness a* and b* (CIE L* a* b* system) in relation to wet, dry sites of home garden teak and forest plantation.

as measured at breast height level (1.37 m), was 71%, 64% and 73% from wet, dry and forest plantation site, respectively. Although stem diameter of the trees differed significantly, the heartwood percentage did not show significant variation with tree size and locality of the planted site as it was reported to vary more with tree age (Bhat, 2000). This means that homesteads of wet localities produce larger diameter logs without adversely affecting the heartwood yield compared to dry localities and plantation sites (Figure 3).

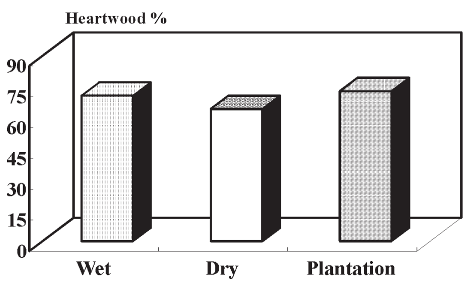

Fig. 3. Mean heartwood percentage at BH level of home garden teak (wet and dry sites)

Physical and mechanical properties of wood

No significant differences were noticed in wood basic density and volumetric shrinkage values except for the slightly higher shrinkage recorded for the plantation teak (Table 5). This implies that teak wood grown in homesteads has almost the same dimensional stability as the plantation grown teak of forest sites.

Table 5. Physical property differences of teakwood between different sources

Property	Wet	Dry	Plantation
Basic density, kg / m^3	600^{ns}	645^{ns}	597^{ns}
Volumetric shrinkage %	9.2^{ns}	8.3^{ns}	11.3*

** Significant at 0.05 level*

Except for slightly higher longitudinal compressive stress of dry site teak due to higher air-dry density, no significant variation was encountered in timber stiffness (modulus of elasticity- MOE), air-dry density and bending strength (modulus of rupture-MOR) among the samples (Figures 4-7). As expected, the above values increased from inner to outer part of the wood cylinder in all the three sites. The study reveals that the mechanical properties of home garden teak are not inferior to mature plantation teak as reported earlier (Bhat, 2000; Bhat *et al.*, 2001).

Natural durability

Accelerated laboratory test (ASTM, 1981) conducted on 1800 wood blocks (600 each from wet, dry and plantation) with five major decay fungi (two brown-rot and three white-rot) revealed that significant differences existed in natural decay resistance between wet and dry localities (Table 6). While the two brown-rot fungi caused severe weight loss in wet site samples than in dry and plantations sites, the three white-rot fungi

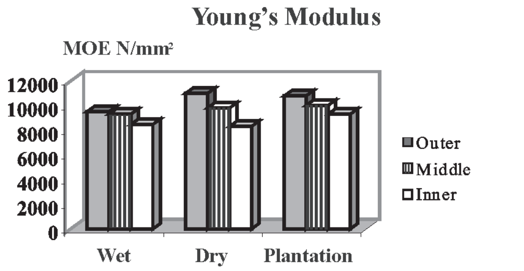

Fig. 4. Mean MOE (stiffness) of home garden and plantation teak

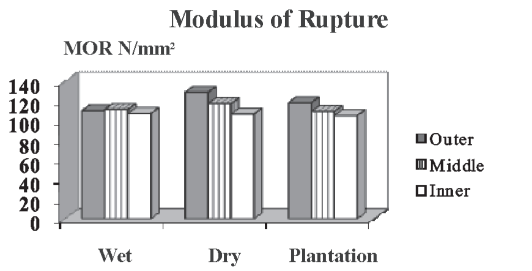

Fig. 5. Mean MOR (bending strength) of home garden and plantation teak

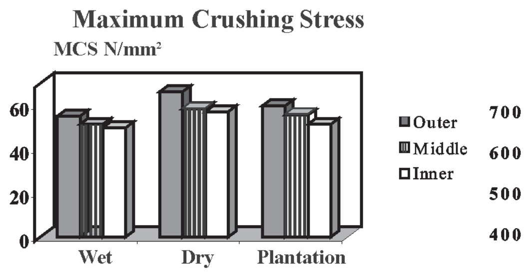

Fig. 6. Mean ultimate compressive stress (MCS) of home garden and plantation teak

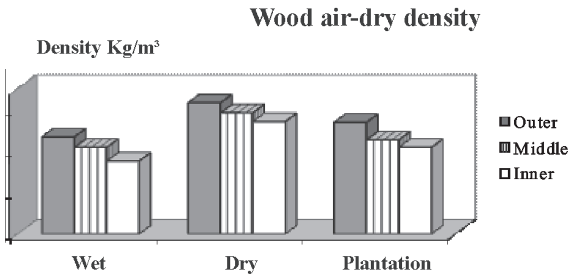

Fig. 7. Mean air-dry density of home garden and plantation grown teak

(*Pycnoporus sanguineus* , *Trametes hirsuta* and *T. versicolor*) did not show significant differences between the sites. In general, *Polyporus palustris* was the most aggressive fungus (weight loss 43.3%) followed by *Gloeophyllum trabeum* (7.05%), both belonging to brown rot. This was in agreement with earlier report of Balasundaran *et al.* (1985) that *P. palustris* is the most aggressive fungus causing severe damage to teak timber in service. White-rot fungi did not cause any damage to the timber as the mean weight loss due to infection was in the range of 1.65-3.02% which is less than the threshold value of 10% for the durability class I. The present findings of high susceptibility of wet site home garden teak may be attributed to lower extractive content (12%) compared to dry and plantation sites (Table 6). The test results of durability imply that the wet site samples are more susceptible to brown-

Table 6. Weight loss due to different fungi and extractive contents of teak from different sources (n = 5 each)

Location	Weight loss (%)					Total extractive content %	Tecto-quinone %	Naphtho-quinone %
	Brown-rot		White-rot					
	Polyporus palustris	*Gloeophyllum trabeum*	*Pycnoporus sanguineus*	*Trametes hirsuta*	*T. versicolor*			
Wet	43.30^{a}	7.05^{b}	1.86^{c}	2.76^{c}	1.94^{c}	12.44^{a}	0.23^{a}	0.62^{a}
Dry	18.41^{d}	4.28^{e}	1.70^{cf}	3.02^{cf}	1.73^{cf}	15.98^{b}	0.34^{b}	1.26^{b}
Plantation	26.88^{g}	2.34^{cfh}	2.06^{cfh}	2.16^{cfh}	1.65^{cfh}	13.31^{a}	0.32^{b}	0.97^{c}

Note: Cell values differing by a letter in the superscript within each column are significantly different at P<0.05 rot fungi and one must be cautious when the timber is put to exterior use for structural applications.

Extractive content and chemical factors determining durability

Extractive content (EC) of wood is known to determine the natural durability and dimensional stability of teak wood (Sandermann and Simatupang 1966; Simatupang *et al.*, 1996; Yamamoto *et al.*, 1998). The total extractive content as determined by ethanol-benzene solubility of wood was significantly different between wet and dry sites and the lowest extractive content was observed in samples of wet site. In contrast, dry site showed higher values for total extractive content (Table 6). The paler colour of wet site samples was attributable to lower extractive content of 12%. Whereas the decorative black streaks of dry site sample were probably due to the presence of higher and denser distribution of extractives. The heartwood of plantation grown timber also often displayed a similar pattern of black streaks with uniform golden brown colour.
Tectoquinone (2-methyl anthraquinone) and Naphthoquinone (1, 4-naphthoquinone) are the two main components responsible for the durability of teak heartwood. Tectoquinone is known to be responsible for the insect resistance, especially termite resistance and naphthoquinone is anti-fungal. The chemical characterization of extractive content by HPTLC showed that total EC, tectoquinone and naphthoquinone were significantly lower in wet site wood which experienced severe weight loss due to the brown-rot fungi bringing down teak timber to class III durability, even though teak is known to be very durable (Table 6). It is evident that Naphthoquinone is the single most important chemical compound that determines the durability of teak timber rather than the total extractive content. This supports the view that individual chemical composition, even if present in small amounts, is more vital than the total quantity of extractives in determining the durability of teakwood (Haupt *et al.*, 2003).

CONCLUSIONS

Based on the results, the study draws the following conclusions:

1. Teak grown in homesteads of wet sites has generally larger diameter logs and that from dry localities has smaller logs with more pole sizes than forest plantation of similar age group. Obviously sawn wood outturn from the logs of wet sites is significantly higher. However, due to lack of standard silvicultural practices, home garden teak has more defects like bends and knots which lower the timber value.
2. While the darker colour with black streaks of dry site heartwood from homesteads is more attractive and often similar to that of forest plantation sample, wood from wet site displays paler colour, which may adversely affect the price of the timber.
3. Timber from homesteads of wet sites is more susceptible to brown-rot fungi although no significant differences exist with respect to white-rot fungi among the home garden and plantation grown timbers.
4. Higher natural durability of teak wood from drier home gardens and forest plantations is reflected in higher extractive contents with darker colour than wet site teak, which has faster growth.
5. It is the Naphthoquinone, the single major compound that offers high decay resistance to teakwood. This supports the view that individual chemical composition, even if present in small amounts, is more vital than total extractives in determining the durability of teakwood.
6. Teak wood of home garden forestry is not inferior to that of forest plantation in its

strength properties and heartwood proportion.

7. Finally, the farmers at farm level should be oriented towards the market for quality production of teak wood by adopting appropriate management practices.

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Rapid Prediction of Teak Wood Natural Durability Using Near-Infrared Spectroscopy

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ABSTRACT

Near Infrared Spectroscopy (NIRS) is widely used to identify compounds and to assess wood properties based on information drawn from reference methods. Unlike most conventional analytical methods, NIRS is a non-destructive method, requires little or no sample preparation or chemicals and does not produce any chemical waste, requiring disposal. The ability of NIRS to predict teak natural durability using solid wood spectra was assessed on a total of 250 wood samples collected from approximately 80 African (Ivory Coast, Ghana, Togo) and 30 Malaysian trees. Natural durability tests on heartwood were performed in controlled conditions using the fungi *Antrodia* sp. and *Coniophora puteana* with beech (*Fagus sativa*) and pine sapwood (*Pinus sylvestris* L.) as references. The relative resistance to decay (x -value) expressed as mass loss after four months of biodegradation by the two fungal strains was calculated and durability classes were estimated according to European standard EN 350-1. It was found that NIR spectroscopy can be used for accurate and fast determination of natural durability of a large number of samples.

Keywords: Teakwood durability, near infrared spectroscopy, durability tests, biodegradation.

INTRODUCTION

Teak wood obtained from natural forest is known to be highly durable while that from plantation is less durable. Near-infrared (NIR) spectroscopy is useful for estimating wood chemistry parameters (cellulose, lignin and extractives contents). NIR data can also be used for quick assessment of physico-mechanical properties and decay resistance of a large number of samples when data are correlated with these properties. In this study, the natural durability of commercial teak wood was determined and correlated with NIR data. The major goals of the study were to develop calibration models to validate and optimize the experimental conditions, and to address conditions for future applications.

MATERIALS AND METHODS

Teak wood samples representing 52 trees for the present study originated from Togo, Ghana and Malaysia reflecting a wide range of growth, ecology and age. Natural durability tests were performed using the fungi *Antrodia* sp. and *Corolus diversicolor* for 16 weeks according to European standard EN 350-1. The durability classes were based on 'x-value' obtained by relative mass loss of the wood samples as compared to reference samples. NIR spectra were recorded on a Bruker FT-IR spectrometer to measure diffuse reflected light from 12,500 to 4100 cm^{-1}. Three spectra taken from every cross-section were used in the calibration modeling. After preprocessing the spectra and outlier detections, calibrations were developed using partial least squares (PLS) regression (with Unscrambler 9.6 software) based on NIR spectra and x -value. These were used to determine predicted durability classes which were compared to measured durability classes.

RESULTS

The natural durability classes (derived from x - value measured and predicted) of the samples are shown in Figure 1. The predicted values more or less conformed to the extent of natural durability measured from the samples.

Figure 2 summarizes the calibration model which refers to durability results obtained with respect to *Antrodia* sp. and spectral values; the selected wave number range and derived values. A factor of four was chosen for the prediction.

It was found that in 70% of instances, the durability classes based on measurement matched with the durability classes derived by prediction (Table 1) and no mismatch among samples from high and low classes was observed. Partial least squares regressions between the x -values and the NIR spectra with second derivative correction were calculated. *Antrodia* sp. gave rise to higher coefficients of regression and lower root mean

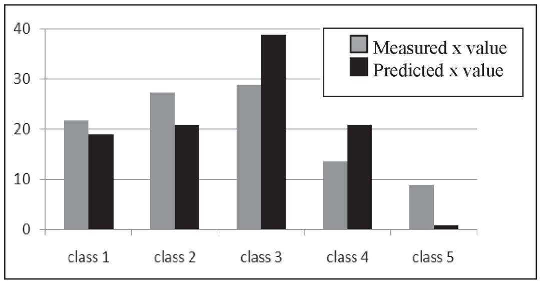

Fig. 1. Durability class distribution

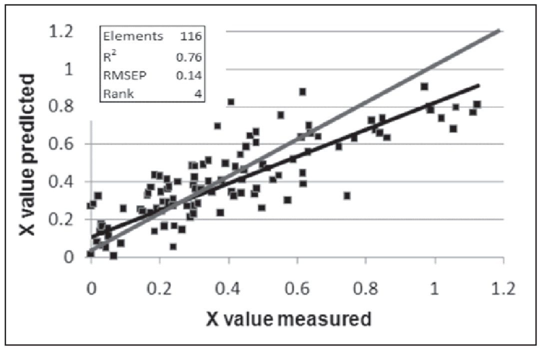

Fig. 2. Natural durability x value cross validation of calibration model

Table 1. Contingence table of durability classes measured *vs.* predicted

		Predicted classes						Bad classified		Well classified	
		1	2	3	4	5	Total	Nb	%	Nb	%
Measured classes	1	20	5	1	0	0	26	6	23	20	77
	2	1	18	12	0	0	31	13	42	18	58
	3	0	3	27	5	0	35	8	23	27	77
	4	0	0	3	13	0	16	3	19	13	81
	5	0	0	0	7	1	8	7	88	1	13
Total		21	26	43	25	1	116	37	32	79	68

square errors of cross validation than those obtained with *Coniophora puteana*. An error of only 30% was found between the durability classes established from the natural durability tests and the classes determined by NIRS predicted values.

CONCLUSION

PLS regression calibration models based on FT-NIR spectra and reference data can be applied to predict decay resistance of teak wood. The technique can be successfully employed to determine natural durability of a large number of samples in a short time as required in breeding programmes. Detailed work is needed for developing prediction models based on a larger sampling so as to cover the variability of growth and site conditions and age especially for short rotation timber.

Productivity and Wood Quality of Planted Teak in Central India

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ABSTRACT

In India, the natural occurrence of teak is confined to the peninsular region and most important teak forests are found in Central and South India. Teak is planted widely, both within and outside its range of natural distribution, throughout the country because of its high commercial value, desirable wood properties and amenability to plantation establishment. Teak has come a long way from being a product of forest to a dynamic plantation crop including in agro forestry systems since the raising of first successful plantation in 1846 at Nilambur, Kerala. Silvicultural techniques have been standardized, yet the productivity of plantations is low and is declining steadily in successive rotations. In many cases plantations have been raised without due consideration for site quality, planting material and appropriate silvicultural management. In many cases, plantations have been raised by heavy application of growth promoting inputs to induce fast growth. Concerns have been expressed on the quality of wood produced from such fast grown short rotation plantations. In this paper, the effect of improved planting stock on growth, yield and quality of wood from three different plantations raised in three different situations is reported.

Keywords: Teak plantations, plantation productivity, growth, productivity, wood quality, faster growth.

INTRODUCTION

Teak (*Tectona grandis* L.f.) yields highly durable and attractive wood and hence extensively planted even outside its natural distribution. Teak constitutes about 8% of the plantations in countries with climatic regimes suitable for teak growth (Pandey and Brown, 2001). The estimated global production of tropical hardwood logs, including teak, in 1998 was around 123 million m^3 (ITTO, 1998). However, demand for high quality wood is growing despite gains made in engineered timber and other low cost substitutes (Earhart, 1999). There has been a steep rise in the total area under teak plantations from 2.2 million ha in 1995 to 3 million ha in 1997 (Centeno, 1997). Growing global demand of teak wood and reduced output from natural forests have necessitated substantial establishment of large areas of quality hardwood plantations (Katwal, 2005). The productivity of teak plantations varies according to site conditions, environmental factors and management. One study has shown the productivity to vary from 0.97 to 5.64 m^3 ha^{-1} $year^{-1}$ with average productivity of 2.85 m^3 $ha^{-1}year^{-1}$ in 53 years rotation period (George, 1961). Productivity from forest plantations can be increased with the use of quality planting material which has been aptly proved by the highly successful eucalypt plantations (White, 1993). Using quality planting material, it is possible to gain similar high yields from plantations of other tropical forest trees, including teak. Impact of improved planting material on growth performance and productivity of teak plantations has not been studied so far. In view of the above, a study has been made to compare the productivity, in terms of growth and yield, from trial plantations of teak raised using quality planting material.

MATERIALS AND METHODS

For the above study, two experimental teak plantation trials raised at Lohara and Mohogata (Maharashtra state), were selected. The Lohara trial plantation was 29-years-old and Mohogata 19-year-old. Both the trials were established by Maharashtra State Forest Department using open pollinated seeds collected from phenotypically superior trees (plus trees) of Allapalli region of Maharashtra. The plus trees were selected based on superior phenotypic traits (e.g., straight, round and tall stem free from insect and disease damage, less basal buttresses, few knots, few lateral branches). For the present study, fifty trees were randomly selected from each experimental plantation and measurements were taken on total tree height and girth at 130 cm above ground level. Increment cores (6 mm dia) were extracted from individual trees at 130 cm above the ground and wood specific gravity was determined by oven drying(Otegbeye and Kellison, 1980). Measurements on height and girth were used to compute individual tree volume and thereby productivity using the regression equation method of Chaturvedi (1973). Similarly, in the above two trials, observations were also made on the growth traits and wood specimens collected from trees in the control plot, which were raised through unimproved seeds collected from local sources. Volume of total wood was computed following the regression method referred above.

RESULTS AND DISCUSSION

Planting material had significant impact on growth and wood parameters and productivity of wood in teak in the two trial sites (Table 1). At both the sites, the teak trees raised through seeds from plus trees exhibited better height, girth and specific gravity. Specifically, at Lohara, teak trees raised through seeds from plus trees showed 1.26 times more girth and 2.63 times more volume than control. Similarly at Mohogata, there was 1.04 times more girth and 4 times more volume when improved planting material was used. With reference to specific gravity, trees raised through selected planting material at Lohara showed 1.09 times more specific gravity than the control. However, at Mohogata, specific gravity was not significantly different among the treatments.

Table 1. Performance of teak at two locations in Maharashtra.

Sl. No.	Type of planting material	Height (m)*	Girth (m)*	Specific gravity*	Volume (m^3)*
1	Lohara (Improved seed source)	16.62 (0.55)	0.67 (0.02)	0.69 (0.04)	0.116 (0.02)
2	Lohara (Unimproved seed source)	16.10 (0.81)	0.53 (0.01)	0.63 (0.02)	0.044 (0.01)
3	Mohogata (Improved seed source)	11.75 (0.34)	0.51 (0.01)	0.68 (0.01)	0.008 (0.01)
4	Mohogata (Unimproved seed source)	11.70 (0.67)	0.49 (0.04)	0.67 (0.01)	0.002 (0.002)

*Mean of observations from fifty individual trees; values in parentheses indicate SE.

Chawhaan and Mandal (2003) compared growth and productivity of 15-year-old teak trees which were raised using planting material obtained from clonal seed orchard and local seed sources. The teak trees raised through improved seeds exhibited significantly higher growth (height and DBH) and thereby productivity (standing volume per ha and mean annual increment per ha) than those which were raised through unimproved local seed sources. Specifically, Chawhaan and Mandal (2003) demonstrated that teak trees raised through improved seed sources exhibited almost two times more standing volume and mean annual increment per hectare when compared to unimproved seed sources.

Regarding genetic gain, Mandal and Chawhaan (2001) estimated 2.83 to 34.46% and 3.42 to 25.64% gain with an average of 13.68 and 11.12% for height and DBH, based on data from various teak breeding programme. In such breeding programmes based on selection and recombination through open pollination mating, genetic gain is influenced by the individuals with higher general combining ability. Hence, raising plantation through seeds from parents with comparatively higher general combining ability can result in higher genetic gain in terms of growth and productivity parameters. Nevertheless, increased selection differential coupled with judicial silvicultural management practices can also influence growth performance and thereby productivity in teak (Mandal and Chawhaan, 2001).

Based on earlier studies in teak and other tropical as well as temperate forest trees and the observations from the present investigation, it can be inferred that improved planting material can have significant impact on growth and productivity in teak. The present study, and the earlier investigations are however limited to few experimental plantations. It is essential to conduct several such comparative studies in teak raised under different eco-climatic conditions in the country, under different rotation ages, in order to obtain accurate estimates of genetic gain in wood and growth traits using improved planting stock.

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Natural Decay Resistance and Hysteresis of Juvenile Teak Thinning Trees from Southern Mato Grosso, Brazil

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ABSTRACT

Natural decay resistance, shrinkage and swelling properties of young teak, grown under agroforestry management systems in southern part of the Mato Grosso State in Brazil, were determined in comparison with commercial teak obtained from South-East Asian region. Accelerated laboratory tests were conducted on sample material obtained from 13 teak poles harvested at the age of seven and eight years from two planted sites. Samples were tested against fungal decay caused by *Coniophora puteana, Gloeophyllum trabeum, Stereum hirsutum*, and *Coriolus versicolor*. Decay resistance increased from the pith to periphery of the heartwood. Samples from the same trees were also tested for physical properties, equilibrium moisture content and shrinkage and swelling to determine the hysteresis. The shrinkage and swelling of the sapwood was found to be slightly higher as compared to the heartwood. At moisture content relevant to practice (at 65 percent relative humidity) only slight differences in shrinkage values were found between sapwood and heartwood in this juvenile material.

Keywords: Juvenile wood, plantation-grown timber, natural durability, decay resistance, physical properties, shrinkage, hysteresis, 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. As the trend is towards much shorter rotations (15-25 years) than originally adopted (50-80 years), this question is even more crucial for economic and financial reasons (Baillères and Durand, 2000). Technical information and research data on naturally grown and plantation grown teak are relatively abundant. But very different is the availability of such data on teak managed in short rotation plantations. Therefore it is very important to generate data on technical qualities of short rotation teak. It is also equally vital to evaluate the wood quality when teak is raised in plantations outside its natural range. In this regard, some data on decay resistance of 22- and 14-year-old trees from Mato Grosso growth area (Brazil) have already been collected (Laming and Sierra-Alvarez, 2000; 2001). In addition, the wood anatomical, chemical and physical characteristics have also been investigated (Polato *et al.*, 2003). Currently a large quantity of wood obtained from thinning operation is being used for low-value applications such as firewood, small timber for agricultural implements, etc. in the State. In this context it is necessary to determine if the large quantity of wood resulting from thinning is suitable for better uses. Thus, the present study aims to provide some technical data of wood from thinning trees with a view to facilitate their utilization in high value applications. The study attempts to do some practice-orientated research into the basic technological properties of the raw material, namely the natural durability of the sapwood and the heartwood, and some aspects of dimensional stability, shrinkage and swelling. Knowledge of these basic properties is required for any attempt to make industrial production profitable and optimization of resource use.

These analyses were performed, according to the standard methods on heartwood and sapwood samples by selecting from the same orientation in the investigated trees. In this way it was possible to assess the variation of these characteristics from pith to bark.

MATERIALS AND METHODS

All the wood samples tested were obtained from thirteen thinned trees of teak (*Tectona grandis* L.f.). Six 7-year-old and seven 8-year-old trees were cut from two different planted sites (Pimental and K8), managed by Floresteca Agroflorestal Ltd. in Várzea Grande, Brazil. The trees were provided with plastic tag numbers corresponding to plot data during growth and harvesting. The trees were cut 1000 mm above ground level, and the next 1500 mm length was selected for the tests. Based on cross-diameter measurements under bark on both ends, the average diameter of the 7-year-old trees was 155mm and that of the 8-year-old trees was 158mm. Thus there was no appreciable difference in diameter between the trees.

Decay resistance

Of the log material received, 10 logs were used for the determination of the durability of the sapwood (code A), and 4 logs were used for the determination of the durability over the radius of the stems (codes A to E), as shown in Figure 1. The durability test followed the EN 305-1 and EN 113, in which sterilized samples were placed on mono cultured fungi growing on malt agar. The weight loss after 16 weeks exposure was calculated and compared with that of European beech (*Fagus sylvatica* L.) reference samples. Two test samples and one reference sample were placed together in a test container. *Coniophora puteana*, *Gloeophyllum trabeum*, and *Coriolus versicolor* were use as test fungi. For the determination of the sapwood durability two samples of each stem were exposed to each of the three fungi.

Following EN 350-1, the mass loss of the samples is related in the EN 113 test to the mass loss of the reference samples (beech) in an x-value (equation 1).

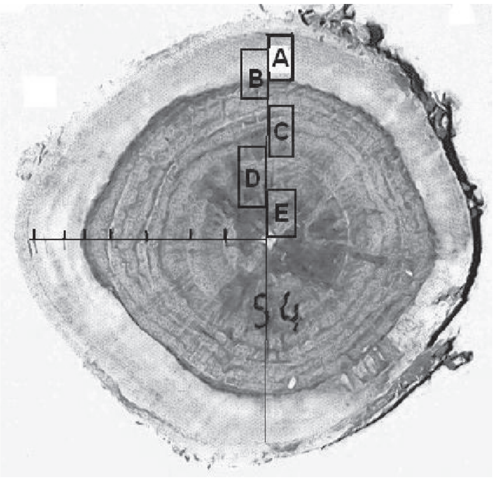

Fig. 1. Schematic diagram of the sample orientation over the cross-section of the logs.

$$x - value = \frac{ML_{test\ sample}}{ML_{reference\ sample}}$$ where, ML = mass loss **(%)**

The classification into durability classes was based on the x-value found. The criteria of the durability classes as defined in EN 350-1, are given in Table 1.

Table 1. Durability classification according to EN 350-1 for laboratory tests

Durability class	Grade	x-value			
1	Very durable			x	0.15
2	Durable	0.15	<	x	0.30
3	Moderately durable	0.30	<	x	0.60
4	Slightly durable	0.60	<	x	0.90
5	Not durable	0.90	<	x	

Shrinkage and swelling

Sample material from the logs was cut in dimensions measuring 20 x 20mm and 40 x 40mm sticks. Separate sticks for heartwood and sapwood were used. These were cross-cut in thickness between 5mm and 10mm. The pieces were defect-free and accurately sawn in the radial and tangential direction. Matching samples were used, one series for adsorption and one series for desorption. The methodology was adapted from Rijsdijk and Laming (1994). The sample material was conditioned at different relative humidity (RH) values and constant temperature (23°C), from the oven-dry state till water saturation. The equilibrium moisture content (EMC) and the related shrinkage and swelling were determined at different climate conditions.

The samples were subsequently conditioned in increasing or decreasing RH. Water saturation and oven-drying were the last steps as both processes can influence the physical properties of the wood. Shrinkage was calculated at fibre-saturation-point (FSP) conditions (after the 95% RH air at 23°C conditioning) and expressed in percent of those dimensions. Swelling was calculated at dry conditions (after the 35% RH air conditioning), and was expressed as percentage of the dimensions determined under those conditions.

Besides the radial and tangential swelling, the longitudinal shrinkage was determined on 200mm long samples. The shrinkage from water-saturated to 90%, 65% and 35% RH, was determined. EMC values were calculated using the formula:

$$EMC_i = \frac{(m_{ci} - m_{od})}{m_{od}}$$

where,

EMC_i equilibrium moisture content at relative humidity [%]

m_{ci} mass of the wood after conditioning at RH [g]

m_{od} mass of oven-dry [g]

The swelling was determined by the formula:

$$S_{swell,j} = \frac{(d_j - d_{od})}{d_{od}}$$

Where,

$S_{swell,j}$ swelling of the wood at the moisture content at RH j [%]

d_j dimensions of wood at EMC at RH j (in radial or tangential direction) [mm]

d_{od} dimensions of oven-dry wood (in radial or tangential direction) [mm]

The shrinkage was determined by:

$$S_{shrink,j} = \frac{(d_{sat} - d_j)}{d_{sat}}$$

Where,

$S_{shrink,j}$ swelling of the wood at the moisture content at RHj (%)

d_j	dimensions of wood at EMC at RHj (in radial or tangential direction) [mm]
d_{sat}	dimensions of water saturated wood (in radial or tangential direction) [mm]

All the values of radial, tangential and longitudinal shrinkage and swelling, reported in this paper are averages of the 10 (heartwood) or 13 (sapwood) samples tested for each zone investigated with the respective standard deviation.

Hysteresis curve

The hysteresis curves for the sapwood and the heartwood were drawn based on methodology adapted from Rijsdijk and Laming (1994). EMC was plotted against relative moisture content for increasing and decreasing relative humidity. The shrinkage and swelling related to the EMC was plotted in the corresponding graph.

RESULTS AND DISCUSSION

Natural Durability

The EN 113 test requires the determination of the virulence of the fungi before the durability class can be determined. At the end of the test, three of the four fungi appeared to be sufficiently virulent to attack the reference samples (beech). The virulence of the *Stereum hirsutum* strain was found to be insufficient to be used in the analysis and its test results are omitted from this work. Table 2 shows the virulence of the fungi. The median value of the virulence control samples is given together with the requirements as stated in EN 113. The virulence was determined as the percentage mass loss of the reference samples after 16 weeks of inoculation.

Sapwood durability

The average mass loss of the sapwood samples due to the three fungi is given in Table 3, in comparison with the calculated x-value of the reference samples. The durability class was calculated using the x-values according to EN 350-1. Following this standard, durability class 1 was found for the brown rotting fungi, class 3 was found for the white rot fungus.

Heartwood durability

The results of the durability test on the juvenile teak heartwood are shown in Table 4. The median values of the logs involved, are given. The locations A and B (Figure 1) were fully or partly from sapwood. From the results the following inferences may be made:

- In agreement with the classification criteria in EN 350-1, the durability of the heartwood was found to be class 2.
- The durability of the heartwood was highest adjacent to the sapwood. Samples taken from this location could be classified in durability class 1. However, closer to the pith of the stems the heartwood was found to be less durable (class 2).

Table 2. Virulence of the fungi on beech (% mass loss after 16 weeks)

Fungus	Type	Required virulence (acc. EN 113) (%)	Found virulence (%)
Coniophora puteana	Brown rot	20	39.4
Gloeophyllum trabeum	Brown rot	20	22.4
Coriolus versicolor	White rot	20	27.4

Table 3. Mass loss and X-value of juvenile teak sapwood samples.

Fungus	7-year-old teak		8-year-old teak	
	Moisture content (%)	Weight loss (%)	Moisture content (%)	Weight loss (%)
Coniophora puteana	50.5 ±4,3	4.5 ±2,6	49.1±15,6	3.0 ±3.3
Gloeophyllum trabeum	76.2 ±7,6	3.3 ±1,8	53.9 ±9,6	0.6 ±0.4
Coriolus versicolor	62.3 ±6,7	12.7 ±4.0	55.9 ±8,3	14.3 ±3.2

Table 4. Durability of teak wood on different locations of stem cross section.

	7-year-old teak		8-year-old teak	
	Moisture content (%)	Weight loss (%)	Moisture content (%)	Weight loss (%)
		Coniophora puteana		
A sapwood	50.0 ±5.2	6.2 ±3.3	37.5 ±14.8	4.4 ±3.7
B	51.1 ±5.9	0.9 ±0.8	46.9 ±8.8	2.7 ±2.4
C	49.3 ±11.6	15.7 ±19.0	45.8 ±5.5	-0.2 ±0.7
D	46.5 ±4.2	4.9 ±5.3	39.7 ±3.7	0.6 ±1.4
E heartwood	54.2 ±14.8	8.3 ±8.9	41.3 ±3.0	2.1 ±1.9
		Coriolus versicolor		
A sapwood	66.4 ±8.7	14.10 ±3.4	58.3 ±12.2	12.4 ±3.4
B	56.1 ±5.3	4.02 ±0.9	55.6 ±6.6	8.5 ±4.0
C	52.4 ±4.1	9.53 ±9.7	55.8 ±1.9	3.4 ±2.1
D	53.5 ±3.9	12.64 ±7.9	59.9 ±7.7	6.8 ±1.4
E heartwood	57.5 ±5.8	10.19 ±6.8	51.1 ±11.8	12.3 ±9.4

- In one log the heartwood was found to be less durable compared to the heartwood of the other stems. Located adjacent to the sapwood area, an average mass loss of the samples in this log was found to be 32% and 18% for *Coniophora* and *Coriolus*, respectively. As median values were used, these numbers did not influence the classification of the heartwood.

Generally, it may be expected that the durability of mature heartwood may reach durability class 1, although a slight variation is possible. Broadly speaking, the results seem to be more or less similar to results obtained from recent experiments performed by Bhat and Florence (2003) with 5-year-old teak from high input plantations in Kerala (India). Their study proved that the juvenile material is comparable in natural durability to the inner heartwood of even mature teak trees: class 2 for the juvenile wood compared to the very resistant (class 1) of the outer heartwood of mature trees. Similar observations were made by Laming and Sierra-Alvarez (2001) from their study of Brazilian teak.

Hygroscopicity

Hygroscopicity is an important property because it affects most of the other moisture sensitive characteristics of wood, dimensional stability and mechanical properties. Knowledge of the measure of hygroscopicity of juvenile wood is a rather unexplored aspect of the wood - moisture relationship. In order to assess the hygroscopic behavior, the equilibrium moisture content (EMC) at eight different relative humidity (RH) conditions, was determined. Test specimens were conditioned is in such a way that for each RH value (35-95%), 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 curves shown in Figure 2 and Figure 3. The magnitude of the hysteresis is expressed by the adsorption/desorption ratio at equal RH.

Generally, for wood this ratio constantly varies from 0.74 to 0.88, depending on the species (Tsoumis, 1991). The juvenile teak investigated in this study presents the average ratio of 0.87, both for heartwood and sapwood. In the heartwood of some 22-year-old trees from the Brazilian origin an average ratio of 0.93 or 0.94 was obtained (Polato *et al.*, 2003).

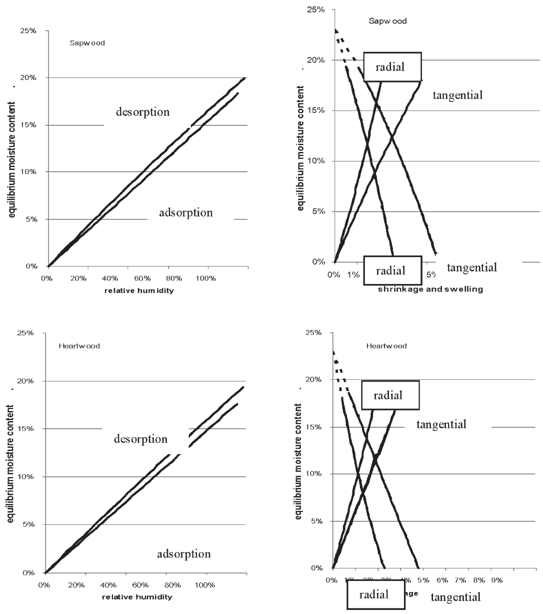

Fig. 3. Shrinkage and swelling of sapwood and heartwood in 8-year-old teak trees

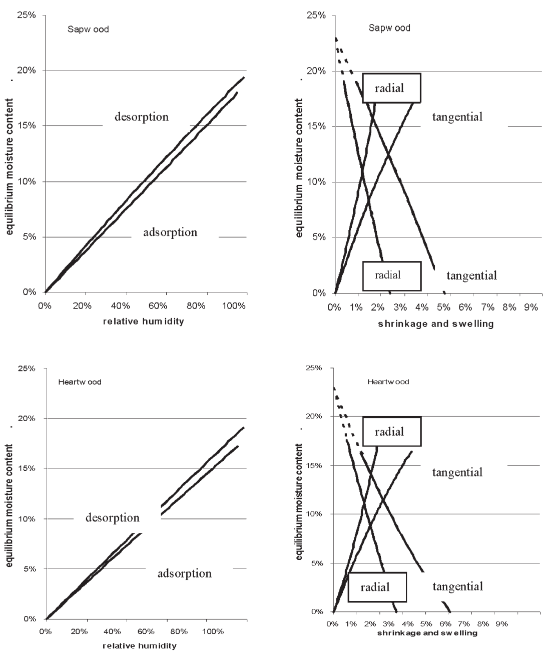

Fig. 2. Shrinkage and swelling of sapwood and heartwood in 7-year-old teak trees.

The results show that the average FSP is at about 23% moisture content, higher than the values of 18% and 19.7% obtained by Haygreen and Boyer (1996) and Polato *et al.* (2003) respectively, but about equal to Rijsdijk and Laming (1994). This relatively high FSP for teak should be primarily ascribed to lower extractive content in young trees. Specimens with relatively high extractive content, like the heartwood of adult teak trees, show a relatively low FSP. For practical purposes, a higher FSP means that the effect of shrinkage in juvenile wood under desorption conditions, starts much earlier while drying. Investigation on the variation in EMC at FSP showed no substantial differences between the trees.

Shrinkage and swelling

The Malaysian plantation teak wood is reported to shrink by 2.5 to 3.0% in the radial direction, and 3.4 to 5.8% in the tangential direction from the green state to oven-dry condition (Trockenbrodt and Josue, 1998). In Brazilian (non-plantation) teak the average radial and tangential shrinkage values of the outer heartwood zone (14- to 17-year-old)were 0.7% and 1.5% respectively from green to 10-12% moisture content (Polato *et al.*, 2003). These observations are similar to those obtained by Trockenbrodt and Josue (1998) for the Malaysian material for similar shrinkage conditions. The results of the present juvenile material from Brazil, reveal slightly different shrinkage values, as presented in Table 5.

The results reveal a general phenomenon that the shrinkage appears to be related to the age of the trees. The shrinkage ratio of the 8-year-old / 7-year-old material seems to be fairly homogeneous, namely 0.83. This might indicate at a more elementary transversal shrinkage behavior between the two age categories studied. However, the question that arises is whether the difference is caused by mere age difference or other factors are also involved in controlling the shrinkage behavior, which requires further studies.

The longitudinal shrinkage of the heartwood is larger compared to that of the sapwood. This is mainly due to the usual larger fibril angle in the initial growth rings at the core of the log than in the outer growth zones (Megraw *et al.*, 1998)

These results obtained in the juvenile material do not seem to vary substantially with respect to mature commercial teak from Asia as observed by Rijsdijk and Laming (1994), for the shrinkage to oven-dry condition.

CONCLUSIONS

The study shows that juvenile teak sapwood could be classified in durability class 3. Juvenile heartwood could be classified in durability class 2. Wood nearest to sapwood boundary, was more durable compared to the wood close to the pith. The shrinkage and swelling properties of the sapwood of juvenile trees were slightly higher compared to the heartwood zone. At 65%relative humidity, only a slight difference was found in

Table 5. Transverse shrinkage of 7- and 8-year-old Brazilian teak from green to 65 and 35 relative humidity.

			Green – 65% RH	Green – 35% RH	Green - oven dry
Radial	7-year- old teak	Sapwood	0.94 ±0.19	1.62 ±0.35	2.34 ±0.39
		Heartwood	1.21 ±0.22	1.89 ±0.27	2.70 ±0.35
	8-year-old teak	Sapwood	1.21 ±0.22	1.92 ±1.92	2.77 ±0.41
		Heartwood	0.96 ±0.16	1.58 ±0.28	2.29 ±0.38
Tangential	7-year-old teak	Sapwood	2.21 ±0.43	3.28 ±1.04	4.82 ±0.61
		Heartwood	2.08 ±0.67	3.27 ±0.86	4.32 ±1.03
	8-year-old teak	Sapwood	2.47 ±0.35	3.24 ±0.77	5.03 ±0.75
		Heartwood	1.83 ±0.41	2.71 ±0.54	3.79 ±0.72
Longitudinal	7-year-old teak	Sapwood	0.17 ±0.08	0.22 ±0.03	0.33 ±0.06
		Heartwood	0.19 ±0.05	0.26 ±0.06	0.39 ±0.06
	8-year-old teak	Sapwood	0.17 ±0.05	0.21 ±0.11	0.34 ±0.10
		Heartwood	0.28 ±0.07	0.38 ±0.09	0.51 ±0.11

shrinkage values in the sapwood and the heartwood. The longitudinal shrinkage from green to 65% relative humidity was found to be 0.22% for the heartwood and 0.17% for the sapwood. The observed differences between the heartwood and the sapwood need to be bridged by applying appropriate processing techniques.

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Processing, Marketing and Price Trends

Processing, Marketing and Price Trends

Industrial Processing of Plantation Teak for Innovative Products

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ABSTRACT

Over-exploitation of teak timber from natural forests of teak growing countries has depleted the resource so much that these countries have to depend on plantations for their internal requirements and export. In the global scenario, the demand for teak wood is much higher than the supply. The rare combination of favourable qualities makes teak very useful wood for furniture and other products. The timber and its products fetch high price in the global market. Since the raw material being in short supply, every effort has to be made to enhance productivity of the plantations. Besides, attempts should be made to practice prudent use of the raw material to produce innovative products by value addition. The waste generated at the extraction point as well as in the sawmills should be minimized and attention should be devoted to utilize such residues for some useful products.

Keywords: Raw material, innovative products, value addition.

INTRODUCTION

Teak (*Tectona grandis* L.f.) the most versatile timber species that grows naturally as a dominant species among its associates in the tropical forests of Myanmar, Thailand, Indian Peninsula, Laos, Cambodia and Indonesia. The total extent of natural forests is estimated to be about 22 million ha. India and Myanmar are the two leading teak-producing countries with approximately 9 million ha each of teak forests. In India teak forests are distributed in Kerala, Madhya Pradesh, Maharashtra, Karnataka and Tamil Nadu.

The importance of teak for its multiple uses was made known to the world by the British during the colonial period. Vast tracts of natural teak forests were over-exploited during the period totally disregarding the forest structure and environmental considerations. To start with, the exploitation of teak forests was a selective extraction of the large sized trees for ship building, railway sleepers, coach building, bridge construction, etc. Gradually the system changed to clear felling of the teak-bearing forests in the name of artificial regeneration of teak for future uses. The exploitation of teak was so intensive that there was very heavy deterioration and degradation of natural forests. Large diameter teak trees are rare to find now-a-days except a few preserved ones here and there. Two such giant trees exist in Kerala (India); one at Parambikulam and the other at Malayattoor.

PLANTATION ACTIVITY

When the teak resource started dwindling in the natural forests, the need for raising it in plantations was realized in view of the superior quality of the timber for diverse end-uses. The plantation activity started at Nilambur (Kerala, India) in the year 1844, and subsequently at Tennesserim (Myanmar) in 1856. Though started on a smaller scale the activity was stepped up in the later years by clearing larger extents of natural teak forests. The other teak growing countries started their plantation activities as well. Though commenced on an experimental scale during early period, large scale plantation activity started in Thailand and Laos only as late as in 1942.

Teak plantation raising started as early as 1800 in Malaysia. Bangladesh commenced planting teak in 1871 and Philippines in 1910. Plantation activity in Sri Lanka dates back to as early as 17th century. The oldest plantation in Sri Lanka dates back to 1876. In the Solomon Islands teak was introduced in 1950s. Teak was introduced to African countries like Seirra Leon in the year 1920, Tanzania in 1898, Togoland in 1905. Many other countries like Ivory Coast, Dahomay, Nepal, West Indies, Vietnam, Australia, Papua New Guinea, Central America, Caribbean Islands, Cuba, Jamaica, Trinidad, El Salvador, Venezuela and Columbia introduced teak on a smaller scale. It is estimated that the total teak plantations in the world is approximately 2.254 million ha. India tops the list with about 1.4 million ha of teak plantations.

TEAK WOOD QUALITY AND UTILIZATION

The unique qualities of teak include its durability, aesthetic quality and workability. Teak exhibits medium hardness and possesses outstanding dimensional stability, a low thermal conductance and a highly favorable strength to weight ratio. These qualities make teak timber the most valuable and most preferred one for diverse end-uses. Compared to species like *Shorea robusta* (sal), *Mesua ferrea* (iron wood), *Vitex altissima* (myla), etc., teak exhibits a lesser strength, still it has adequate strength and durability to be used for small span trusses. Teak is adopted as a standard for deciding the suitability index of other timbers used in varied uses. If the timber is seasoned properly, there will not be any kind of degrade like splitting, warping or cracking.

The major uses for which teak timber is put to include ship building, railway carriages and cabins, railway sleepers, bridges, cart and carriages, various types of furniture, construction works, electric and telegraph transmission posts, marine props, fence posts, decorative face veneers for plywood, wood paneling, agricultural implements, carvings and turnery works, particle boards, lamin boards and wood wool cement boards, musical instruments, parquet flooring, and an array of handicraft items. Of the above uses, particle boards and wood wool cement boards are made from sawmill residues. None of the other species of timbers can be put to such multifarious uses.

DEMAND AND SUPPLY

Due to over exploitation the availability of teak wood has dwindled. Currently almost all teak growing countries having natural teak forests depend mainly on plantations for their wood requirements. Thailand once used to produce large quantity of teak timber which was exported mostly in the log form and partly in the semi-processed form. The production of timber was to the tune of 2, 64,000 m^3 during 1976 which dropped to 26,000 m^3 in 1989. The multifarious uses and easy availability of teak as a raw material made Thailand develop a large number of woodworking units for producing furniture and allied products mainly for export. During 1989 the import from Indonesia and Myanmar was to the extent of 1, 56,000 m^3 in order to meet the industrial demand. Thailand stands as the pioneer in the field of furniture industry that provides employment to a large proportion of the population.

Myanmar gets its teak timber supply mainly from plantations. Most of the timber is exported to other countries in the log form. Thailand is the main buyer. As far as Indonesia is concerned, the teak timber produced is mostly processed within the Country. It exports teak in the processed and semi-processed form to the US and other countries. Thailand is the main importer of lndonesian teak in log form. Most of the timber produced in India comes from plantations and much of it is consumed within the Country. The production is not even sufficient to meet the internal requirement though some portion is exported both in the log form and processed form.

INNOVATIVE PRODUCTS FROM TEAK

Furniture is the most promising industry as far as teak wood is concerned. Similarly, handicrafts production is another equally promising area. There are immense possibilities for developing a wide array of handicraft items from the residues generated at furniture industry, sawmills and extraction sites. Sawmill residues account to about 33% of the timber volume which goes mainly for fuel. As an alternative utilization, this waste can be used in the production of particle board and wood wool cement boards.

Inside the forest plantation areas all the extraction operations are carried out through traditional logging. This operation is not only labor intensive but also generates considerable logging waste in the place of operation. In some places mechanical logging operations are now resorted to, in order to reduce wastage. According to an estimate, about 45 - 50% tree volume harvested is left in the extraction site as logging waste. The waste in the form of stumps, branch wood, cut chips, etc. are better utilizable as raw material for fiber board, particle board and chipboard. The branch wood accounts for about 25 - 40% of the tree volume. The material thus left in the forest plantations either gets decayed, or is burnt while preparing the site for next generation planting or collected by the local people as fuelwood.

Reducing the wastage in the conversion points by adopting some modern methods like engaging mobile units and/or establishing some suitable machinery near the plantation extraction sites will help in collection and semi-processing of the left - over residues. The residues from thinning, intermediate felling and final felling will give very many articles of attraction and of higher value.

Many of the major woodworking units are striving hard to produce articles of new design as well as of varied new uses by devoting much attention in research activities. More than the conventional furniture and other common articles, there is lot of scope for the new innovative articles of better value. Therefore, the production field does require sufficient research backing by establishing research units attached to the manufacturing establishments. The Forest Research Institutes located in the different countries should also enter into this field and take sufficient interest.

The Western India Plywood Industry located in Kerala has a unit for the manufacture of furniture and other articles. A full- fledged R & D Division is functioning all the time in the factory for the development of innovative products not only of teak but also other timbers and plywood. The price addition is much more for the new products compared to the conventional products.

CONCLUSION

Teak timber being in short supply every effort is to be made to enhance its production by adopting intensive management practices. Besides attempts to boost the production, it is also necessary to concentrate on wastage-free utilization of the available teak wood. Possibilities of utilization of logging/mill residues and value addition should be intensively explored to develop innovative products.

Preliminary Attempts to Season *Tectona grandis* Wood Using Vacuum Press Drying – Possibility of Faster Seasoning

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ABSTRACT

Studies were conducted on drying behaviour of 25mm thick samples of *Tectona grandis* wood under vacuum press drying. The experiment was conducted under three different vacuum level-temperature combinations. The results showed that the samples could be dried faster by employing a combination of 90°C and 873 mbars of pressure. Thus faster drying rates could be achieved as compared to conventional seasoning methods, by the use of this drying technology.

Keywords: Vacuum press drying, *Tectona grandis*, wood seasoning.

INTRODUCTION

The need for faster drying of refractory and moderately refractory woods without much drying degrades is being increasingly felt by the wood processing industry. To achieve this, various methods like vacuum drying, radio frequency drying, microwave drying, etc. are being attempted round the world with varying extents of success. Among these, vacuum drying appears to be a promising technique and different vacuum drying methods have been developed for wood. The technique is based on the principle that water boils at lower temperatures when the atmospheric pressure over it is lowered. The vacuum creation gives an added advantage of causing a pressure gradient inside the wood which would also assist in moisture movement from the core to the surface. This is expected to significantly enhance the drying rate. However, in India the technique is yet to gain popularity. Though a few industries are using this technique mainly on 'easy-to-dry' woods, systematic research is required on feasibility of this technique for a wide variety of timbers.

Teak is the major timber used by wood industry for various end products from furniture to export quality handicrafts. It is a moderately refractory wood (classified under group B) as far as its kiln seasoning characteristics are concerned (BIS 1993). It has been assigned schedule V in this standard. It is found that for drying 25 mm (1 inch) thick planks of teak wood, 13 and 15 days required. In this context an experiment was conducted to study the drying behaviour of teak wood samples under vacuum press drying.

MATERIALS AND METHODS

The experiment was carried out in a MASPELL vacuum press dryer. Seven teak wood samples of 60 cm length, 15 cm width and 25 mm thickness were prepared from plain sawn logs of mid-girth 91-120 cm. The drying experiment was conducted by placing the samples between the top two platens. The spaces between the other platens were filled with one-inch thick false material. The machine allowed heating up of the samples using hot water circulating through the platens at atmospheric conditions. The vacuum was applied in a discontinuous mode manually by switching on the vacuum pump. The maximum vacuum level that could be achieved was 373 mbars which is nearly 640 mbars below the atmospheric pressure.

In the experiment conducted, three different temperature-pressure combinations were used which are designated as treatments T1 (70^{o} C, 373 mbars), T2 (80^{o} C, 913 mbars) and T3 (90^{o} C, 873 mbars). Before applying the treatment, the samples were preheated for 6 hours up to a temperature 10 degrees below the treatment temperature. This was to soften the wood tissue so that moisture movement in the subsequent drying period would be easier.

The initial moisture content of each sample was calculated using the standard method of sub sampling. From the calculated initial MC (IMC) of the samples, their oven dry weights were calculated. These values were used to calculate the MC achieved after application of the treatment. The effectiveness of a particular treatment was assessed by the MC reduction (MCR) percentage with respect to its IMC. This was calculated as

(IMC-Final MC) x100 / IMC

As the IMC of the samples varied widely and the experiment was carried out progressively, the experiment resulted in unequal replications in different IMC ranges. For the analysis purpose, the data on samples with at least three replications in a particular IMC range for any given treatment only was considered. The MC reduction percentages were analysed for the below and above 30% levels of the IMC ranges. No samples were available in the below FSP level of 19% (Jain *et al*., 2000) during this preliminary investigation.

The analysis was done on the actual MCR% for a given IMC interval range. For this, one-way ANOVA was adopted. Suitable transformations were adopted for these percentage data for analysis. Wherever more than two treatments could be analysed, the method of least significant differences was employed to distinguish the differences between the effects of the treatments (Gupta and Kapoor, 1976).

RESULTS AND DISCUSSION

Table 1 presents the IMC and percentage MC reduction data of the seven samples used in the study. It can be seen that the IMC of the samples varied between 20 and 41%. Under each treatment, reduction in MC varied from a minimum of 2.6% to 6.61%.

Table 1. Percentage MC reduction values under different treatments

T1		T2		T3	
IMC	**MCR**	**IMC**	**MCR**	**IMC**	**MCR**
25.37	4.56	22.42	2.82	20.09	4.65
26.74	3.89	25.79	3.98	20.41	5.88
27.29	3.08	26.31	2.60	22.02	6.61
27.76	3.70	28.81	4.81	23.18	5.15
31.19	4.53	32.39	2.70	24.97	5.42
38.80	5.13	35.12	5.66	26.85	5.43
41.16	3.71	37.63	4.57	27.51	3.47
Mean	**4.08**	**Mean**	**3.88**	**Mean**	**5.23**

Figures 1 to 3 indicate the trends of MCR % values observed under the three treatments for different IMC values of samples under each treatment. Figure 1 shows a fairly constant trend for MC reduction percentage throughout the IMC range and the value hovers around 4%. Figure 2 suggests a possible upward trend for MC reduction

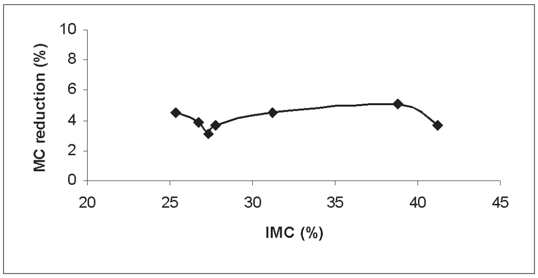

Fig. 1. Percentage MC reduction under T1

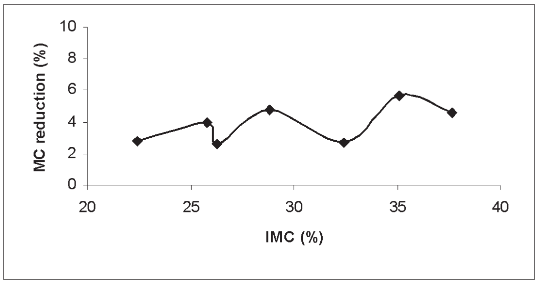

Fig. 2. Percentage MC Reduction under T2

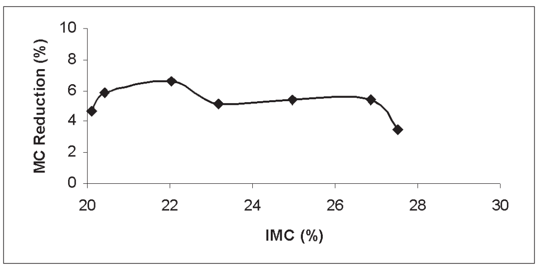

Fig. 3. Percentage MC Reduction under T3

The observed values were analysed for the above and below 30% IMC ranges using one-way ANOVA. As all these percentage values were below 10%, square root transformation was applied before performing the analysis.

For above 30% IMC range, a minimum of three replications could be obtained only for T1 and T2. The results of ANOVA on the transformed values are given in Table 2. It is seen that T1 and T2 do not show any significant differences between them as far as bringing down the MC is concerned in the above 30% IMC levels. This is despite the fact that T1 used a much higher vacuum level but along with a lower temperature level for drying the samples. For the below 30% IMC range, four values for each treatments were available. The results of ANOVA on the transformed values of these are given in Table 3.

It is seen that there is a significant difference between the MC reduction percentages in the below 30 % IMC samples. To understand the exact difference between each treatment, the method of least significant differences (LSD) was employed. For this purpose, the critical difference (CD) was calculated for this treatment at 0.05 significant

Table 2. ANOVA table for above 30 % IMC range

Source of Variation	SS	df	MS	F	P-value	F crit
Between Treatments	0.004155	1	0.004155	0.048987	0.835676	7.70865
Within Treatments	0.339295	4	0.084824			
Total	**0.343451**	**5**				

percentage as the values of IMC increases. These values seem to increase from about 2% to around 4%. Figure 3 is again indicative of a fairly constant trend for MC reduction throughout the IMC range and the values lie between 4 and 6%. As such, these values seem to be higher than those obtained for the other two treatments.

levels to be 0.30. The differences between the mean values of each treatment are given in Table 4. The table shows that T3 is capable of drying the samples much faster than the other two. Here T3 actually does not use a higher vacuum like T1; but it uses a higher temperature. Hence it may be possible that a combination of higher temperature and higher

Table 3. ANOVA table for below 30% IMC range

Source of Variation	SS	df	MS	F	P-value	F crit
Between Treatments	0.651219	2	0.32561	8.411692	0.00871	4.256492
Within Treatments	0.348383	9	0.038709			
Total	**0.999602**	**11**				

Table 4. LSD values for MC reduction below 30% IMC level

	Mean	T1	T2	T3
T1	1.95	0	-0.08	0.45
T2	1.87	0.08	0	0.53
T3	2.40	-0.45	-0.53	0

vacuum level might bring down the MCs much faster.

The drying rates obtained might seem to be much low compared to those reported for European hardwoods. For example, drying rate in the range of 20% per hour has been reported through vacuum press drying technique in beech samples (Cividini *et al.*, 2003). It may be noted that these experiments under each treatments lasted for about 7 hours. This included a preheating period of 6 hours and the vacuum application and subsequent vacuum releasing period of roughly one hour. Thus the actual drying rate for T3 works out to 0.75% per hour for the whole range of 20-27% of IMC. In the normal seasoning of teak by conventional methods, it takes about 13-15 days as recorded in the BIS for bringing down the MC from 45% to 15%. This accounts for an overall MC reduction percentage of about 66.7% in roughly 360 hours. The drying rate in such a case works out to 0.18% per hour. The present value obtained is about four times higher than this. This is in agreement with the reports on vacuum drying of rubber wood which indicated a 50% time saving and 24.33% energy saving compared to other conventional seasoning methods (Jain and Pandey, 1993). The only reservation is that the present study does not have values for drying below the Fibre Saturation Point. But the results are encouraging in that there is a good chance of drying teak wood much faster than the conventional methods by using the vacuum press drying.

CONCLUSIONS

Moisture contents could be brought down by about 2-6% from various initial values in the 20-40 range in about seven hours using three different temperature-pressure combinations. A combination of 90°C and 873 mbars of pressure resulted in significantly higher MC reductions in the below 30% IMC range. Overall, this treatment gave drying rates of 0.75% per hour compared to the 0.18% per hour that is usually observed in conventional methods. The results are indicative of the possibility of vacuum press drying being effective in faster drying of this moderately refractory species.

ACKNOWLEDGEMENTS

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Marketing Efficiency of Planted Teak in Madhya Pradesh: A Case Study of Jabalpur Circle

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ABSTRACT

In the recent study, it was found that teak from natural forests fetches higher price than that from planted woodlots. This is because teak from natural forests managed by Forest Department (SFD)yields large diameter logs while the Forest Development Corporation(FDC) follows a shorter rotation yielding smaller diameter logs. It is presumed that timber from natural forest is stronger and durable as compared to plantation timber produced by FDC. Therefore, sawmills get higher profit from teak coming from FDC as they buy teak at low price and sell it at par with existing rate of timber price, after processing. More recently, teak price has increased at the rate of 15% per year due to the tremendous increase in demand and shortage in supply. Thus, in order to meet the growing demand of teakwood, large scale plantation of teak should be taken up under the proposed public- private partnership.

Keywords: Marketing efficiency, marketing cost, market margin, price spread, State Forest Department, Forest Development Corporation.

INTRODUCTION

Marketing efficiency is concerned with the allocation of resources among alternative use. It is crucial to success of sustainable forest management (SFM) which focuses on equitable distribution of benefits to producer, consumer and society. Marketing efficiency often measures the degree to which the minimum possible input is used to capture a given output called input orientation or where the maximum possible output is acquired from a given input called output orientation. Pricing is the one of the aspects of marketing efficiency. Pricing efficiency implies that price should reflect actual cost incurred. With this background the present study was conducted with the specific objectives to calculate marketing cost, market margin and prices spread of channel in timber marketing and also to evaluate marketing efficiency by taking chair- making as case in consideration.

Based upon objectives, selection of species, channels, circles and market was done. Madhya Pradesh (M.P) has got two sources of timber supply channels, i.e., the State Forest Department (SFD) and the Forest Development Corporation (FDC). SFD supply timber from natural forest and FDC from plantations to wood-based industries.

METHODOLOGY

Multistage sampling was used for identifying respondents for the study. The highest producing Divisions were chosen. Final selection of the respondents was based on simple random sampling (SRS). Snowball sampling was used for timber consuming industries. For the analysis of market price variation of all grades of teak in M.P., auction result data pertaining to Jabalpur circle has been taken into account. The present Jabalpur circle includes three districts viz., Jabalpur, Mandla and Dindori. The SFD depots of Sijora , Kalpi and Mandla and FDC depot at Mohgaon were selected for study. Average price for teak at auction was taken into consideration and average annual price for the year 2003 to 2006 was calculated by taking species- wise average for major timber depots of Jabalpur circle. The data gathered were classified as wood (means all timber coming from the division including teak and non teak), teak timber (including logs, poles, dengri and fuel-wood) and finally logs and poles.

RESULTS AND DISCUSSION

Timber production (m^3)

Madhya Pradesh Forest Department is divided into 18 circles. The main function of the circle is to regulate Forest Divisions under them. Conservators of Forests decide upset price of timber for auction in the Division. As shown in Figure 1 Jabalpur circle has the highest timber production in Madhya Pradesh from 1990 to 2005 period. The functioning of the Division is in accordance with the Working Plan prepared and approved for the Division. It gives proposed guidelines of task in the form of working circle for territorial and production divisions. Basically working circle is divided into conversion, improvement and plantation for timber marketing.

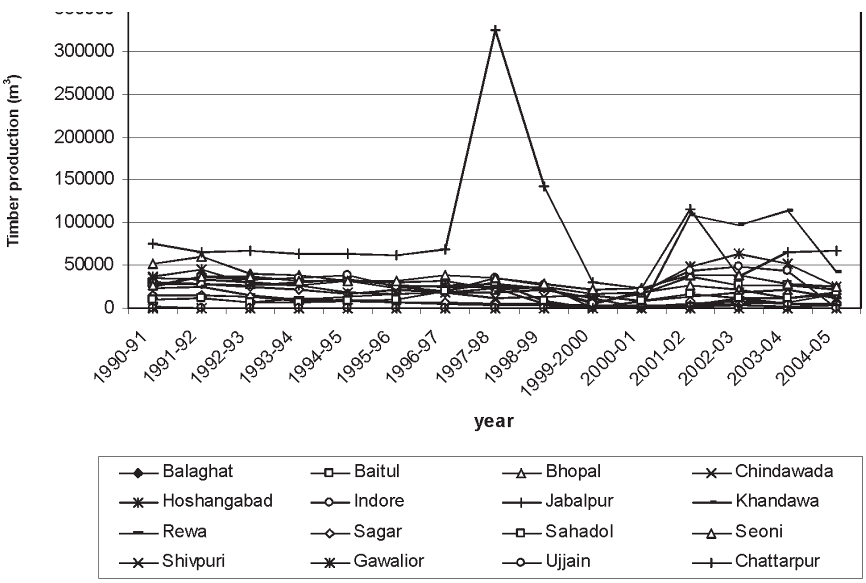

Fig. 1. Timber production of Madhya Pradesh State

East Mandla Division

According to Working Plan, East Mandla Division has 118204.08 ha of reserved forest and 36.80 ha of protected forest area. Jagmandal and Mohgaon area has teak forests producing one of the best quality teak in India. Mandla Division has Kalpi, Sijhora and Mandla depots for disposal of timber. Generating revenue by grading and auctioning of timber are the primary functions of these depots. Quantity of wood sold and the price during different years are shown in Tables 1 and 2.

On an average, there were more than 10 auctions in a year and hundreds of buyers participated in each auction. Selling was done as per Department's selling procedure at all the three depots. Average operation cost of timber including logs, pole, dengri (pieces of teak) and fuelwood was Rs. 1148.39 per m^3 in East Mandla Division as shown in Table 3. The average selling price was Rs. 6795.17 per m^3 and average quantity sold was 47215.66 m^3 per year. The Table shows that timber prices increased from year 2003 to year 2006. Price of teak was Rs. 13623.36 per m^3 and average quantity sold was 13702.18 m^3 per year which shows increasing trend from previous four years indicating high demand of teak logs. Teak logs fetched average selling price of Rs. 22990.15 per m^3 and average quantity sold 11830.69 m^3 per year. Quantity of teak logs sold decreased and selling price increased during the period. Table 3 further shows that selling price of teak poles increased between years 2003 and 2006.

Table 1. Quantity (m^3) of wood sold at East Mandla Division

Year	Teak Logs	Non Teak Logs	Teak Pole	Non Teak Pole	Dengri (Pieces of Teak)	Fuel wood
2001-2002	11428.58	18992.60	2273.60	149.41	1254.49	9352.00
2002-2003	10222.24	12336.27	1196.64	227.82	1019.62	15732.00
2003-2004	12156.40	28022.23	3731.91	191.16	1296.26	11098.00
2004-2005	12000.20	18080.17	3887.70	119.58	1796.60	20435.00
2005-2006	11335.48	17531.72	278.15	59.10	905.45	8968.00

Table 2. Price of wood (per m^3) sold at East Mandla Division

Year	Teak Logs	Non Teak	Teak Pole Logs	Non Teak Pole	Dengri	Fuel wood
2001-2002	22573.25	7074.05	3943.32	888.33	3989.36	250.69
2002-2003	21385.37	5038.06	2596.51	611.52	3473.36	300.75
2003-2004	20394.49	6890.62	3993.00	1042.86	2928.60	490.87
2004-2005	22203.99	7845.91	4269.88	1020.02	3855.69	400.68
2005-2006	26371.96	8003.88	4506.80	1189.18	6354.27	550.35

Forest Development Corporation

Madhya Pradesh Rajya Van Vikas Nigam limited (MPRVVN) is State Government public sector undertaking registered under Companies Act, 1956 on 24 July 1975 with authorized capital of Rs. 40 crore and is responsible for raising and managing plantations of timber and bamboo. Main objective of the MPRVVNL are as follows.

- To accelerate and increase forestry production by creating plantation of species. These should be fast growing, higher economic value and diversified use for industrial and commercial purposes.

Table 3. Wood sale record of East Mandla Division

Items	Year	Quantity of wood sold (m^3)	Expenses (Rs.)	Operation Cost/m^3	Selling price/m^3
Wood	2001-2002	43450.665	39527214.75	909.70	6453.17
	2002-2003	40734.577	32184011.00	790.09	5567.60
	2003-2004	56495.950	45150531.00	998.82	5956.74
	2004-2005	56319.240	45659816.00	1279.50	6599.36
	2005-2006	39077.893	35114501.00	1166.85	7829.40
	Average of 2003-06	*47215.665*	*41974949.33*	*1148.39*	*6795.17*
Teak timber	2001-2002	13702.18	12464915.4	909.70	13258.29
	2002-2003	11418.88	9021946.73	790.09	11990.94
	2003-2004	15888.31	12697649.42	998.82	12193.75
	2004-2005	15887.90	12880826.21	1279.50	13236.94
	2005-2006	11613.62	10435735.96	1166.85	15439.38
	Average of 2003-06	*13702.18*	*12004737.20*	*1148.39*	*13623.36*
Teak logs	2001-2002	11428.58	10396614.61	909.70	22573.26
	2002-2003	10222.24	8076494.53	790.09	21385.37
	2003-2004	12156.40	9715168.93	998.82	20394.49
	2004-2005	12000.20	9728946.58	1279.50	22203.99
	2005-2006	11335.48	10185800.33	1166.85	26371.96
	Average of 2003-06	*11830.69*	*9876638.61*	*1148.39*	*22990.15*
Teak poles	2001-2002	2273.60	2068300.78	909.70	3943.33
	2002-2003	1196.64	945452.20	790.09	2596.51
	2003-2004	3731.92	2982480.49	998.82	3993.00
	2004-2005	3887.70	3151879.63	1279.50	4269.88
	2005-2006	278.15	249935.63	1166.85	4506.80
	Average of 2003-06	*2632.59*	*2128098.58*	*1148.39*	*4256.56*

- To enhance the productivity and quality of forest by imposing intensive forest management practices.

The Nigam has headquarters at Bhopal and having 11 Project Divisions covering 2,70,538 ha land area.

Mohgaon Project Division

Mohgaon is highly productive area of Jabalpur region. It has an area of 53,368 ha, highest among the project divisions of MPVVN. Geographical conditions and loamy soil favor large production of teak. Details of wood selling quantity and price received in Mohgaon Project Division are shown in Tables 4 and 5 respectively.

Details of actual revenue generated, cost incurred in Mohgaon Project Division in the year 2003 to 2006 are given in Table 6. The average operating cost for timber was Rs.5293.61 per m^3 and average selling price was Rs.4562.52 per m^3. It is seen that selling price of timber increased every year. The average quantity of teak timber sold was 4429.72 m^3 per year and average revenue generated from it was Rs.9306.57 per m^3 per year. The Table further shows that average volume of teak logs sold was 2131.79 m^3 per year and average revenue generated for the Division was Rs.16626.69 per m^3 per year. Operating cost on teak logs has decreased showing higher margin for MPVVN. For teak poles average selling volume is 2297.93 m^3 per year and average revenue generated is Rs.1986.45 per m^3 per year in Mohgaon project division. Finally it can be concluded that Mohgaon project division of MPFDC is having trade average Rs.9306.57 per m^3. while East Mandala Division of MPSFD trade average Rs. 13623.36 per m^3 for teak. It shows

Table 4. Volume of wood sold (m^3) in Mohgaon Project Division during 2003-06

Year	Teak logs	Non teak logs	Teak pole	Non teak pole	Fuel wood
2003-2004	2501.97	5275.97	2163.46	890.71	5470.00
2004-2005	1638.08	2088.24	2454.33	403.58	958.00
2005-2006	2255.33	2526.58	2276.01	276.10	4228.00

Table 5. Selling price of wood at Mohgaon Project Division during 2003-06

Year	Teak logs	Non teak logs	Teak pole	Non teak pole	Fuel wood
2003-2004	32883520.00	7917360.00	2838500.00	789965.00	1887885.00
2004-2005	27643125.00	4272630.00	4456150.00	374650.00	582935.00
2005-2006	44794600.00	8863270.00	6444960.00	587590.00	2734225.00

approximately Rs. 4316.79 per m^3 difference from last three years average.

The efficiency of the marketing system is crucial to producer welfare, consumer welfare as well as government budgets and economic development. This study examines the timber marketing and its efficiency and focuses on the State Forest Department channel and Forest Development Corporation channel. The study finds that state Forest Department is highly efficient in timber marketing. It is not only fulfilling the requirement of timber but also manages the forest in systematic manner.

It was found that selling price of FDC teak timber was lower than that of SFD teak timber. It is presumed that timber from natural forests is of better quality and durability as compared to FDC timber. Because Forest Department which manages natural teak resorts to longer rotation while FDC follows a shorter rotation for planted teak. Therefore the sawmiller gets high profit from teak obtained from FDC as they buy teak in low price

Table 6. Wood sale record of Mohgaon Project Division

Items	Year	Quantity of wood sold (m^3)	Expenses (in Rs)	Operation Cost/m^3	Wood sell price/m^3
Wood	2003-04	16302.11	61758000.00	1200.51	3437.55
	2004-05	7542.22	56995000.00	1586.78	4454.77
	2005-06	11562.02	52442000.00	2054.02	5795.24
	Average of 2003-06	*11802.12*	*57065000.00*	*1613.77*	*4562.52*
Teak Timber	2003-04	4665.42	1149990.00	1200.51	7227.55
	2004-05	4092.40	3092942.00	1586.78	9345.50
	2005-06	4531.34	20552869.00	2054.02	11346.66
	Average of 2003-06	*4429.72*	*8265267.00*	*1613.77*	*9306.57*
Teak Logs	2003-04	2501.96	9478306.21	1200.51	13143.08
	2004-05	1638.08	12378590.12	1586.78	16875.37
	2005-06	2255.33	10229546.35	2054.02	19861.62
	Average of 2003-06	*2131.79*	*10695480.89*	*1613.77*	*16626.70*
Teak Poles	2003-04	2163.46	8195930.26	1200.51	1312.01
	2004-05	2454.33	18546851.61	1586.78	1815.62
	2005-06	2276.01	10323322.20	2054.02	2831.69
	Average of 2003-06	*2297.93*	*12355368.03*	*1613.77*	*1986.44*

and sell it at par with existing price after processing.

The study found that marketing efficiency of State Forest Department is higher than that of Forest Development Corporation. This is because of expenditure incurred by Forest Development Corporation is higher than that by the State Forest Department. The estimated marketing cost of SFD teak timber is found to be Rs. 79,083.18 per m^3, while the FDC has marketing cost at Rs. 79,548.56 per m^3. Similarly, SFD has market margin of Rs. 1,76,616.03 per m^3 and FDC has at Rs. 1,76,616.02 m^3, showing efficient marketing but there is still some scope for improvement. The data show that demand for teak is very high. Therefore, teak price has increased at the rate of 15% per year. The probable reason is the growing demand and shortage of supply. Thus, in order to meet the growing demand of teak wood, large scale plantation of teak should be taken up under proposed public private partnership.

CONCLUSIONS

The study shows that state Forest Department is more efficient in timber marketing than the Forest Development Corporation. The expenditure incurred for plantation management by Forest Development Corporation is higher than that by the State Forest Department which is one of the factors for difference in market margin. The main reason for increasing price of teak wood is the growing demand and shortage of supply. To meet this demand. it is necessary to establish large scale plantation of teak under public and private partnership.

Teak wood Market in Kerala: Production, Consumption and Trade

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ABSTRACT

Teak plantations occupy nearly 780 km^2 in Kerala, which is about half of the area under forest plantations in the State. Teak is also grown in areas outside forests, particularly in home gardens. Thus teak wood used for various purposes in different sectors within the State comes from forest plantations, areas outside forests and that imported from elsewhere. The wood-balance study in Kerala for the year 2001 highlighted that the demand for teak wood in the State during 2001 was 96,000 m^3 of which households sector for constructions accounted for 77%; industries sector, 7% and other wood-using sectors, 2%. Teak wood export to other states within the country was 14,000 m^3, which is about 14% of the demand. However, actual export outside India was negligible. Nearly half of the export comprised teak poles from thinning of forest plantations and the market was the neighboring State of Tamil Nadu. In the total teak wood production, contribution of forest plantations was substantial (52%), import accounted for 15% and areas outside forests, the remaining 33%. Production and consumption of teak wood was more or less matched, with only a small deficit of 667 m^3. Teak wood from home gardens was mostly used for construction in the households sector. Out of 37,000 m^3 of teak wood from forests, about 7,500 m^3 was exported to other states. At the same time 14,000 m^3 of teak wood was imported mainly from Myanmar and 500 m^3 from the neighboring State of Karnataka, resulting in a net import of 7,000 m^3 logs of larger girth. The import and export were also more or less balanced, but the constituents were different. While larger girth teak logs were imported to Kerala from abroad, teak poles were exported to other states within the Country. The trend in teak wood export from Kerala to other states declined mainly due to the increased import from abroad. There is hardly any international market for Kerala teak wood due to non-availability of logs in larger girth classes. It is important to note that Kerala, which was once an exporter of teak wood, has become a net importer. The shortening of rotation age of forest teak plantations to 50 years has reduced the production of high value, larger girth logs. A policy favoring production of large girth logs must be adopted by increasing the rotation age of teak plantations.

Keywords: Teak wood, market, production, consumption, import and export.

INTRODUCTION

Kerala has certain unique features different from other states in the Indian Union. It has a very high population density of 819 persons per km^2 (Census of India, 2001), low per capita annual income of Rs.18,000 (during 2000) and a very high literacy rate of 91% (Government of Kerala, 2001). The notified area under forests in Kerala is 10,815 km^2 which comes to about 29% of the State's geographical area (Government of Kerala, 2001). Timber production from forests comes exclusively from 1960 km^2 of forest plantations. To conserve the remaining forests, harvesting of timber from natural forests was stopped in Kerala even before it became a national policy. The current area under teak plantations is 780 km². Pulpwood plantations of eucalypts occupy nearly 380 km². Other species such as acacia, albizia and cashew account for smaller areas. Extensive estates of rubber trees including small holdings (4,700 km²) provide an abundant quantity of rubber wood during each cycle of replanting. Home gardens in Kerala occupy 17,870 km² which is about 46% of the geographical area (Government of Kerala, 2001). The home gardens are dominated by coconut palms which is a source of cheap timber. The area under coconut palms alone is 8,800 km². Along with other trees, teak is an important component of the home garden system which contributes to a high volume of timber production. Trees are planted mainly along the boundaries or in intimate mixtures with agricultural crops. Jack (*Artocarpus heterophyllus*), mango (*Mangifera indica*), cashew (*Anacardium occidentale*), tamarind (*Tamarindus indica*), anjily (*Artocarpus hirsutus*), matty (*Ailanthus triphysa*) and vatta (*Macaranga peltala*) are other commonly found trees. The home gardens supply substantial volume of teak wood and other timbers to the Kerala market.

There has been an interesting transformation of the timber sector in Kerala, whereby, currently forests are no longer the main timber supplier; areas outside forests, particularly home gardens and rubber estates, supply almost all industrial wood requirements and a major share of the construction timber in Kerala. Based on the wood-balance study in Kerala for the reference year 2001 (Krishnankutty *et al.*, 2005), the production-consumption situation and trade-balance of teak wood in comparison with other timbers is presented in this paper. The trends in the teak wood trade are also examined.

METHODOLOGY AND DATABASE

Concepts and definitions

Timber refers to teak wood and all other timbers, industrial wood and poles. In this paper, volume of timber is presented in m³ roundwood. In the case of sawn timber, its round wood equivalent in m³ was calculated using appropriate conversion factors for different timbers. The relationship between consumption, production and trade (import and export) of timber during a year can be shown as *Consumption = Production + Import - Export*. In this study, *Consumption + Export* is taken as the effective *Demand* and *Production + Import*, as the *Supply*. In any particular year, a portion of the accumulated inventory of timber enters the market as supply, while at the same time part of the production in the same year is added to the inventory. In this study, inventory of timber is ignored as it is assumed to be in a dynamic equilibrium over time. Demand for timber in a year is defined as the effective demand, which is considered identical with the supply in the same year. In this study, the reference year was taken as the financial year 2000-01. As this study is confined to Kerala State, import and export refer to the trade with other states in India and other countries. The total demand for timber during 2000-01 has been estimated under four sectors: timber industry, housing sector, institutions sectors and export. Similarly the contribution of different sources of timber supply during 2000-01 was assessed under three components: import, forests and agricultural lands (home gardens and private estates).

Estimation of demand

Demand for teak wood and other timbers in a year is the sum of consumption of teak wood and other timbers in the timber industry, housing sector, institutions (all other timber-using) sectors and export, in the same year. All timber-using entities have been classified into one of these four classes. The sawn timber from the sawmilling industry either reaches the housing sector, institutions sector and certain industries like furniture or exported to other states in India or abroad. As the output from the sawmilling was accounted as being used in any of the four sectors, timber consumption in the sawmilling industry is not shown separately to avoid double counting. All houses in the residential category were included under the housing sector; all other buildings including commercial, government and other constructions, under the institutions sector. The method of estimation of teak wood and other timber consumption in different sectors is explained below.

Consumption in the housing sector

In the housing sector, timber is used for house construction, repair, alteration of existing houses and making furniture, fixtures and implements. A stratified two-stage sampling design was adopted for the estimation of the total quantity of timber used in the housing sector of Kerala. The housing sector was divided into rural and urban sectors. Houses in all the *grama panchayats* in Kerala constitute the rural housing sector and those in municipalities/corporations constitute the urban housing sector. *Grama panchayats* in Kerala were stratified according to natural regions– lowland, midland, highland and high range regions. The *panchayats* coming in lowland, midland and highland regions were further divided into those in southern and northern Kerala. Thus altogether, seven strata were formed in the rural sector. *Grama panchayats* in each stratum were treated as the first-stage units of sampling. Of the total number of *grama panchayats* in Kerala, 2% were allocated in the seven strata approximately in proportion to the total number of *panchayats* in each stratum, ensuring at least two in a stratum. *Panchayats* within a stratum were selected at random. Altogether, 23 *panchayats* were selected in all the seven strata comprising the rural sector of Kerala. All the municipalities and corporations in Kerala were grouped together to form the eighth stratum representing the urban households sector. In the urban stratum, all the municipalities and corporations were treated as the first-stage units of sampling and 6 such units were selected at random. The wards in the *grama panchayats*/ municipalities/corporations were treated as the second-stage units of sampling. Two wards each were randomly selected from the chosen 23 *grama panchayats* and 6 municipalities/corporations. All the houses in the selected wards were visited to collect information such as year of house construction, whether timber was utilised during the reference year 2000-01 for (i) new house construction, (ii) repair or alterations to the existing houses built before the reference year and (iii) furniture, fixtures and other uses. Actual measurements on all types of timber-use during 2000-01 were made in the selected wards. Any timber work done during the reference year but not fixed before the cut-off date was also included. The same procedure was adopted in the case of fixtures and furniture. Only those which were actually processed during the reference year were considered. Each item was measured and dimensions (length, breadth and thickness) of its individual members were recorded. Allowance for wastage of each member was also made to find out the actual sawn timber used in an item. After measuring the volume of timber used in all types of work in the selected ward, the total volume of timber used in the ward in each of the categories of (i) new house construction, (ii) repair or alterations and (iii) furniture, fixtures and other uses, was separately worked out. Based on the ward totals in the sample first-stage units, the total quantity of timber used during 2000-01 in a particular category of use was estimated using the formula for two-stage sampling design given in Murthy (1967). The three quantities, corresponding to the above three categories estimated for the rural and urban sectors, were added together to arrive at the total quantity of timber used in the housing sector of Kerala.

Consumption in the industry sector

Timber industry sector consists of all industries which consume timber as raw-material. Industries producing packing cases, pulp and paper, plywood, match splints and veneers, furniture and fixtures, boat making, handicrafts, etc. utilise timber. Industry sector is comprised of two broad groups: organised and unorganised sectors. All industrial units registered under Sections 2 (m) and 85 of the Factories Act were included in the organised sector. The unorganised sector consisted of units registered as small-scale and other unregistered industrial units. Stratified random sampling design was used for estimating the total quantity of timber consumed in industries in the organised sector. Adopting the same classification of the NSSO for stratification, five classes were identified: workers ranging from 5 and below, 5-9, 10-19, 20-49 and 50 or above. In each type of industry, the units were stratified on the basis of average number of workers as above. Of the total number of units, 5% were selected at random from each stratum of each type of industry for detailed survey. The quantity of timber used in different industries in Kerala during the year 2000-01 was estimated using data collected through the surveys of different timber using industries in Kerala. Along with the housing sector survey, data on timber consumption during 2000-01 in all industrial units in the unorganised sector in the selected wards in the sample first-stage units were collected and ward totals were computed. Based on the ward totals, the quantities of timber used in different industries in the unorganised sector were estimated using the formula for stratified two-stage sampling design given in Murthy (1967).

Consumption in the institutions sector

Institutions sector consists of all timber-using agencies other than housing and industries sectors. Business establishments, educational and other institutions came in the institutions sector. Timber-use in this sector was mostly in construction. Along with the housing survey, all non-residential establishments in the selected wards in the sample first-stage units were visited. There was 100% coverage of establishments in the selected ward and actual measurements on all types of timber-use for (i) new building construction (ii) repair or alterations to the existing buildings constructed before the reference year and (iii) furniture, fixtures and other uses during 2000-01, were made. Using the ward total consumption of timber in the sample first-stage units, consumption of timber in the institutions sector during 2000-01 was estimated using the formula for stratified two-stage sampling plan given in Murthy (1967).

Export

Export refers to the quantity of teak wood and other timbers moved out of Kerala to other states in India and that actually exported to other countries. For estimating the quantity exported, the quantity of timber moved out of Kerala by road was compiled from the registers maintained at all the inter-state border forest check-posts. Where there were no forest check-posts at the inter-state boundaries, the registers maintained at the sales tax check-posts were also perused. The data collected included species and quantity of timber moving through each route. Besides, data from records available at railway stations as well as Kochi and Kozhikode Chambers of Commerce and Industries for ports were taken to estimate the total volume of export of timber.

Assessment of supply

Timber supply during the year 2000-01 is defined as the production in Kerala plus the import during the same year. The sources of production in Kerala are forests and agricultural lands (home gardens and private estates of rubber, cardamom, coffee, and tea). Production refers to the actual quantity of teak wood and other timbers extracted and used in the reference year 2000-01. The method of assessing production and import is given below.

Import

Import includes the quantity of teak wood and other timbers coming to Kerala from other states in India and from other countries. Quantity of teak wood and other timbers imported to Kerala was estimated from data available in the registers maintained at the ports, railway stations and all inter-state border forest and sales tax check-posts.

Production from forests

For estimating the recorded production of timber from forests, data available in the Annual Administration Report of the Kerala Forest Department were used. The recorded timber production from forests, shown in the Report, is the timber reaching the government timber depots during the reporting year. The current year's sale includes part of the current year's receipt and also the leftover stock of the previous year. So, the production of teak wood and other timbers from forests was the average of the production during 1999-2000 and 2000-01.

Production from agricultural lands

Area under agricultural lands includes area under home gardens, farmlands and estates of cardamom, coffee and tea. Total production of teak wood and other timbers from agricultural lands was estimated in an indirect way. The total rubber wood production in India during 2000-01 was estimated as 16,02,000 m^3 by the Rubber Board of India (George and Joseph, 2002). Out of the total rubber wood production, the quantity available in Kerala was assessed as 85%. The distribution of commercial timber has been reported as 60% of total wood. Based on the rubber wood production in Kerala during 2000-01 and the timber proportion, production of timber from rubber plantations was estimated. Teak wood and other timber production from all other sources within Kerala, i.e., from forests and rubber plantations, were reliably assessed and the quantity of import was fully accounted. The remaining quantity of the total demand for teak wood and other timbers, which can only come from home gardens and estates of cardamom, coffee and tea, was determined as the production from agricultural lands.

Trends in trade

To understand the market for timber in Kerala, it is necessary to have a background on the trends in the import and export. To observe the short-term trends, data on import and export during the period from 1996-97 to 2000-01 covering all the check-posts, were compiled. For the long-term trend covering the period from 1981 to 2001, data from six major check-posts were used. Consistency and continuity of data availability determined the selection of the six major check-posts for the long-term trends. These data are intended to indicate the relative changes over time.

PRODUCTION, CONSUMPTION AND MARKET

Demand (consumption and export) for timber in Kerala is presented in Table 1. The estimated total demand for timber is 20,65,173 m^3 roundwood of

Table 1. Demand for teak wood and other timbers in Kerala during 2000-01

Sectors	Teak wood		Other timbers		Total	
	Volume in m^3 round wood	% to total	Volume in m^3 round wood	% to total	Volume in m^3 round wood	% to total
Timber industry	6,481	6.7	13,54,307	68.8	13,60,788	65.9
Housing	73,855	76.7	5,41,963	27.5	6,15,818	29.8
Institutions	2,033	2.1	8,437	0.4	10,470	0.5
Export	13,925	14.5	64,172	3.3	78,097	3.8
Total demand	**96,294 (4.7%)**	**100.0**	**19,68,879 (95.3%)**	**100.0**	**20,65,173 (100.0)**	**100.0**

Table 2. Supply of teak wood and other timbers in Kerala during 2000-01

Sources	Teak wood		Other timbers		Total timber	
	Volume in m^3 round wood	%	Volume in m^3 round wood	%	Volume in m^3 round wood	%
Forests	50,265	52.2	37,246	1.9	87,511	4.2
Agricultural lands*	31,437	32.6	16,35,687	83.0	16,67,124	80.8
Import	14,592	15.2	2,95,946	15.1	3,10,538	15.0
Total supply	**96,294**	**100.0**	**19,68,879**	**100.0**	**20,65,173**	**100.0**

which teak wood accounted for only 4.7%. Of the total demand, industry sector accounted for the major share (66%), housing sector ranked next (30%), followed by export (3.8%). Institutions sector accounted for a negligible quantity (0.5%). Timber demand in the institutions sector is in the form of construction timber for non-residential and commercial buildings. The actual timber export was 78,097 m^3. The total demand for teak wood is estimated as 96,000 m^3 of which housing sector accounted for 76.7%. Teak wood used in the industries and service sectors was 6.7 and 2.1% respectively. Teak wood export accounted for 14.5% of the total demand for teak wood. Supply (production and import) of timber in Kerala is shown in Table 2. The figure on timber production from agricultural lands includes timber production from home gardens, farmlands and private estates of cardamom, coffee and tea. Agricultural lands contributed 80.8% of the total timber supply, rubber estates alone contributed 11% and forests produced only 4.2%. Timber imported from other states and countries was 15% of the total timber supply. When teak wood production is considered, contribution of forests was substantial (52.2%). Import accounted for 15.2% of the total teak wood production and the remaining 32.6% was contributed by home gardens and estates.

The market supply-demand situation is shown in Table 3. Consumption and production of teak wood were 82,369 and 81,702 m^3 respectively. The difference of 667 m^3 was the net import, whereas import and export of teak wood were 14,592 m^3 and 13,925 m^3 respectively. That is, production and consumption of teak wood matched with only a small deficit of 667 m^3. Consumption and production of other timbers in Kerala during 2000-01 were 19,04,707 and 16,72,933 m^3 roundwood respectively. The difference of 2,31,774 m^3 was the net import, where import and export of other timbers were 2,95,946 m^3 and 64,172 m^3 respectively. The analysis revealed that

Table 3. Market for teak wood and other timbers (in m^3 round wood) in Kerala

Timber	Supply		Demand		Net import
	Production	Import	Consumption	Export	
(0)	(1)	(2)	(3)	(4)	(5) = (2) – (4)
Teak wood	81,702	14,592	82,369	13,925	667
Other timbers	16,72,933	2,95,946	19,04,707	64,172	2,31,774
Total timber	**17,54,635**	**3,10,538**	**19,87,076**	**78,097**	**2,32,441**

consumption exceeded production showing a deficit of 2,31,774 m^3 which was met by import.

TRENDS IN TRADE OF TEAK WOOD AND OTHER TIMBERS

Organised trade in timber has a long history in Kerala which was famous for timbers such as teak, sandal, rosewood, ebony and venga. Most of these timbers came from the natural forests where they were abundant. The expansion of agriculture and plantations at the cost of natural forests has reduced the supply of such timbers from the natural forests. Timber production from forests is currently teak and eucalypts from plantations. Out of the total production of 13,000 m^3 roundwood equivalent of teak poles from forest plantations, 6,000 m^3 was exported to Tamil Nadu. Out of the total production of 37,000 m^3 logs including billets, about 7,500 m^3 was exported to the neighbouring states. At the same time 14,000 m^3 of teak wood was imported from other countries and 500 m^3 from the neighbouring State of Karnataka, resulting in a net import of 7,000 m^3 of larger girth teak wood. Of the total timber consumed in Kerala, 21% was imported from other countries and rest of India.

The short-term trends in import of teak wood and other timbers are presented in Table 4. Teak import has increased more than three-fold during this period, although there is a slight decline during 2000-01. Larger girth natural teak from Myanmar is coming to Kerala market which currently has shortage of large diameter logs due to the lowering of rotation age in teak plantations. The five year data on import of other timbers from overseas reveal a steady rising trend. The short-term trends in the export of teak wood and other timbers are shown in Table 5. Teak is a major export item from Kerala with a volume between 11,000 and 18,000 m^3. But this is deceptive when the volume of import of teak wood is recalled. The actual net export of teak wood has reversed during the five-year period and became net import since 1998-99. This is a combined effect of increase in consumption and decline in production.

Table 4. Short-term trends in import of teak wood and other timbers from Kerala

Year	From rest of India		From other countries		Total import	
	Teak wood	**Others**	**Teak wood**	**Others**	**Teak wood**	**Others**
1996-97	208	57,627	5,546	94,771	5,754	1,52,398
1997-98	72	81,370	10,101	1,17,495	10,173	1,98,865
1998-99	152	2,09,139	16,593	1,20,082	16,745	3,29,221
1999-00	173	75,660	16,692	1,39,486	16,865	2,15,146
2000-01	521	1,51,103	14,071	1,44,843	14,592	2,95,946

Table 5. Short-term trends in export from Kerala to rest of India

Year	Teak wood in m^3	Other timbers in m^3	Total export in m^3
1996-97	17,680	87,830	1,05,510
1997-98	13,534	79,525	93,059
1998-99	13,319	55,568	68,887
1999-00	10,999	58,526	69,525
2000-01	13,812	61,779	75,591

The long-term trend in the timber market in Kerala can be seen from Table 6, which gives the trends in import and export of timber to and from Kerala during the last 20 years. The average volume per annum during successive 5-year periods is shown in the Table. The annual export of teak which stood at around 33,000 m^3 during the period from 1981-82 to 1985-86 fell sharply to just 4,000 m^3 during the period from 1995-96 to 2000-01. On the other hand, the annual import of teak wood has grown spectacularly from around 600 m^3 to 12,000 m^3 during the above period. When the international export of teak wood from Kerala is considered, the decline in the volume of export is more profound (Table 7). While the annual export of teak was of the order of 900 m^3 in the 1970's, it was only 93 m^3 during 2001. Non-availability of logs in larger girth classes is the primary reason for the poor performance in the international market. The shortening of rotation of teak plantations to 50 years has reduced the production of high value larger girth logs. It is important to note that Kerala which was once a supplier of teak wood has become a net importer of teak wood since 1996.

Table 6. Long-term trends in import and export of teak wood and other timbers

5-Year periods	Import (m^3 per annum)			Export(m^3 per annum)		
	Teak	Others	Total	Teak	Others	Total
1981-82 to 1985-86	594	46,732	47,326	33,109	3,63,662	3,96,771
1986-87 to 1990-91	935	1,58,645	1,59,580	24,298	1,35,701	1,59,999
1991-92 to 1995-96	1,873	1,33,737	1,35,610	18,507	1,03,441	1,21,948
1996-97 to 2000-01	11,583	1,81,265	1,92,848	4,392	90,137	94,529

Table 7. Trends in international export of timber

5-Year periods	Teak (m^3 per annum)	Rosewood (m^3 per annum)	Other timbers (m^3 per annum)	Total (m^3 per annum)
1971-72 to 1975-76	899	17,197	603	18,699
1976-77 to 1980-81	517	7,730	955	9,202
1981-82 to 1985-86	112	1,641	453	2,206
1986-87 to 1990-91	39	1,396	277	1,712
1991-92 to 1995-96	21	1,128	94	1,243
1996-97 to 2000-01	93	1,408	1	1,502

CONCLUSIONS

The import and export of teak is more or less balanced, but the constituents are different. While larger girth teak logs are imported to Kerala from other countries, poles from forest teak plantations are exported to other States in India. There is a clear declining trend in the export of teak wood from Kerala. The export of teak wood from Kerala declined to around one eighth during the period 1996-2001 from the level prevailed in 1981-86 period. When the international export of teak wood from Kerala is considered, the decline in the volume of export is more profound for which non-availability of logs in larger girth classes is the primary reason. The shortening of rotation of teak plantations to 50 years has reduced the production of high value larger girth logs. A policy favouring the production of large girth timber must be adopted by the Kerala Forest Department and the rotation age of forest teak plantations must be increased.

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Projection of Future Availability of Teak Wood from Forest Plantations and Its Prices in Kerala State, India

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ABSTRACT

Kerala is the first state to raise teak plantations in India. Teak plantations form the major source of teak wood supply in the State. The area under forest plantations in Kerala is 16% of the total forest area of 11,271 km^2 which comes to about 70,000 ha, constituting 40% of the total area under forest plantations. Based on the latest data available in the database on forest resources of Kerala developed by the author at the Kerala Forest Research Institute, the following two major analyses with respect to teak were carried out. i. Projection of availability of teak wood from forest plantations under different scenarios, taking into account factors such as species-mix, age structure, rotation age, productivity and planting rates. The comparison of projected availability of teak wood with the projected demand revealed that the existing level of teak plantations has enough potential to meet the future demand up to the year 2030. However, the past trends in the actual production of teak wood have been promising. Therefore, the promotion of growth of teak outside the forests such as home gardens and farmlands would help to bridge the gap between future demand and supply. ii. The trends in the real prices of teak wood were analyzed. The real prices were almost same during the period 1993 to 2004. Based on current prices of teak wood from the year 1942 to 2006, the short term price forecasts were made using artificial neural network and auto-regressive integrated moving average models. The price forecasts are discussed in this paper.

Keywords: Teak plantations, teak wood availability, demand and supply, actual production, prices.

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. The beginning for the establishment of teak plantations was first made at Nilambur in Kerala State, which dates back to 1842. At present the total plantation area in Kerala is 17% of the total forest area of 11,271 km^2. The teak plantation area available for commercial exploitation is about 70,000 ha, which constitutes 41% of the total forest plantation area (Sivaram, 2008). The teak plantations in the State are managed by the Government machinery mainly the Kerala Forest Department and Kerala Forest Development Corporation. The long-term revenue and expenditure in plantation sectors of the Forest Department in Kerala have been centered on teak plantations, which form the major source of teak wood supply. Apart from teak plantations, home gardens are also major source for the teak wood supply in Kerala. Most of the teak wood produced is consumed within the State mainly for building construction and furniture-making. Of the total timber consumption, about 12% is teak (Krishnankutty *et al.*, 2005). Other important timber species consumed in the State are anjily, jack, mango, coconut and rosewood and imported timbers such as pynkado. The rubber wood has been used heavily in industries sector as Kerala has large tracts of rubber plantations which do not come under the purview of forest plantations.

Future projection of supply, demand and prices is an important aspect in any business enterprise to plan the required activities ahead for addressing the future demand-surplus situation and for optimal investment. As far as forest products are concerned, such exercise will aid developing forest policies for the sustainable forest management.

The major objectives of this study are:

i) to project the future trends in the availability of teak wood from forest plantations based on its age structure under different scenarios
ii) to analyze the trends in the real prices of teak wood and to make short-term forecasts of current prices of teak wood

The paper is presented in two parts. Part I deals with the first objective and Part II presents the details with respect to second objective.

Database used for the study

The kind of tasks involved in this study require a good database containing all relevant details on forest plantations, forest products and their prices. The database software developed on the forest resources of Kerala by the author at the Kerala Forest Research Institute contains such details which has enabled the present study (Sivaram, 2008). The database was developed referring a number of 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 through communication with the officers of the Kerala Forest Department and the Kerala Forest Development Corporation.

The data set used with respect to first objective is time series data on status of forest plantations including details such as year of planting, volume estimates (productivity), thinning and rotation age and actual teak wood production and demand. The data set used for the analysis of price trends is related to current prices of teak wood belonging to different girth classes for the period 1943-2006. The current prices were collected from different timber sales divisions/sales depots of the Kerala Forest Department. The data relating to 1943-1994 was originally collected by Krishnankutty (1997) and data for the period 1994-98 was from Krishnankutty *et al.* (2003). Data for the period 1998-2006 was collected and compiled during the development of the database software (Sivaram, 2008). The specific methodology for the projection of availability of teak wood from forest plantations and forecasting of timber prices are presented under respective sections.

I. Projection of availability of teak wood from forest plantations

Age structure of teak plantations

The age structure of presently available plantations determines the future outturn of timber. The teak plantations as on year 2005 from all the territorial forest divisions was classified according to different age groups and presented in Figure 1. Nearly 60% of them were found in the age group of 25-44 years. The forest plantations from wildlife divisions were not included in the analysis as thinning and felling operations are banned in those plantations.

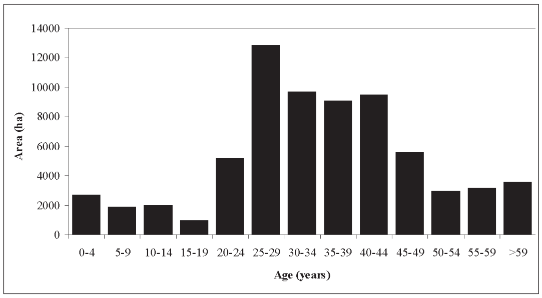

Fig. 1. Age structure of teak plantations in Kerala -2005

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 and the extent of pest and disease problems. An assessment made by Jayaraman and Chacko (1997) shows that only 5% of the area under teak belongs to site quality class I and 86% of the area belongs to moderate site quality classes either II or III. In terms of stocking, the understocked and overstocked plantations are 74% based on basal area per ha and 81% 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 plantation and clear felling of the 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, aspect, 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 that indicated in the yield table. Expected yield in India is 4 to 6 m^3 per ha per annum over the likely rotation length (Leech, 1998). Mean Annual Increment (MAI) obtained from government-owned plantations ranges from 2 to 5 m^3 per ha and is often below the potential yield of the site (Enters, 2000). The actual yield obtained from thinning and final felling in Konni forest was reported to be 2.5 m^3 per ha per annum 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 per ha in Kozhikode Forest Division to 2.2 m^3 per ha in Kothamangalam Division at 60 years. The State level MAI was 3.1 m^3 per ha. Chundamannil (1998) reported actual yield realized from teak plantations in Nilambur Forest Division during the period 1967 to 1994 based on the data available in the records of Forest Department. The MAI ranged from 0.97 to 5.64 m^3 per ha with the overall mean of 2.85 m^3 per ha at 53 years.

Modeling the future availability of teak wood from forest plantations

The mathematical formulation of the idea of projection is as follows:

a_i be the area of the i^{th} individual plantation in ha (i=1,2, …N). c_i be the year of planting of the i^{th} plantation. The projected availability of teak wood or projected total yield (P_{tr}) in a given projection year t is the sum of the quantum of yield that is obtained from thinning (T_{tr}) and felling (F_{tr}) for the given rotation age r.

$$P_{tr} = T_{tr} + F_{tr}$$

$$T_{tr} = \sum_{j=1}^{k} A_{tj} \times t_j$$

$$F_{tr} = A_{tr} \times y_r$$

where,

$A_{tj} = \sum_{i=1}^{N} a_i$ for all i satisfying the condition $c_i + j = t$ (j =1,2, ... k)

D_t

$A_{tr} = \sum_{i=1}^{N} a_i$ for all i satisfying the condition $c_i + r = t$

t_j = thinning yield (cum per ha) for the given thinning year j.

y_r = felling yield (cum per ha) for the given rotation age r.

Formula used for projecting the future demand

$$D_t = D_0 (1 + r)^n$$

where,

= teak wood demand in the projection year t

D_0 = teak wood demand in the beginning year (base year)

n = number of years between base year and intended projection year t

r = compound growth rate for teak wood

Options and assumptions involved in projections

Options: 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 felling yield used for projection, the yield as per the All India Yield Table (FRI, 1970) against site quality III was used because majority of teak plantations in Kerala were of site quality II or site quality III (Jayaraman and Chacko, 1997). Two possible variations with respect to yield due to thinning could be thought of:

i) thinning years *viz*., 4, 8, 12, 18, 28 and 40 years as per the All India Yield Table, and
ii) thinning years *viz*., 7, 10, 16, 24, 31 and 35 years as worked out by Jayaraman and Chacko (1997) based on the records of the Kerala Forest Department.

The sum of the thinning yield and felling yield as per the All India Yield Table was termed as potential yield. The sum of the thinning yield as per Jayaraman and Chacko (1997) and felling yield as per the All India Yield Table was termed as estimated yield.

With respect to projection of future demand for teak wood, the studies conducted by Krishnankutty, 1997 and Krishnankutty *et al*., 2005 were relied upon. According to these studies the total demand for teak wood was 64,000 m^3 in 1987-88 and 96,000 m^3 in 2000-2001 showing the annual compound growth rate of nearly 3.2 % over the period of 13 years. On this basis the future trends in the demand for teak wood was projected by considering differential annual growth rate with the demand estimated in 2000-01 as base (Figures 4-6). The different annual growth rates considered were 2%, 3% and 4% respectively.

Assumptions: One of the important assumptions made in the projection of future availability of teak wood is that plantations that are felled during the year 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.

II. Price analysis

Trends in current and real prices of teak wood

Teak wood is classified into as many as 50 classes based on mid girth, length and quality. In this study, for the purpose of analysis, 5 girth classes *viz*., Export class (185 cm and above), Girth Class I (150-184 cm), Girth Class II (100-149 cm), Girth Class III (75-99 cm) and Girth Class IV (60-74 cm) were considered for analysis. The weighted average prices were used for analysis after duly accounting for the quantity of timber sold.

The changes in current prices may be due to inflation (general price increase) in the economy of the Country. Therefore, the real prices of teak wood were calculated after taking into account the inflation using the formula

Real Price = Current Price / Wholesale Price

The base year for the calculation of real prices is 1993-94 (=100).

Forecasting of teak wood prices

A time series is a sequence of observations taken sequentially in time. The succession of price values in a time series is usually influenced by number of external factors. If the information on influencing factors is not known, only the past price values of the time series itself can be used to build a mathematical model for forecasting future values. In this study, two different forecasting modeling approaches were used.

1. ARIMA (Autoregressive Integrated Moving Average) model which is a traditional statistical technique.
2. Artificial network (ANN) model which is a non-traditional modeling technique.
   The details of the models used are given in Sivaram (2007).

RESULTS AND DISCUSSION

I. Projection of availability of teak wood from forest plantations

When the projected demand are compared with the projected 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 period 2030-2040 even at the maximum assumed annual growth rate of 4% demand (Figures 2-4). However, the past trends in the annual production of teak wood from forest plantations have been far less when compared to the projected demand scenario (Figure 5). For example, the production of teak wood from forests during the last five years was only about half of the demand. Therefore, activities in promoting teak outside the forests such as home gardens, farmlands should be continued. This would help filling up the gap between future demand and supply from forest plantations.

II. Price analysis

Trends in current and real prices

The trends in the annual percentage increase in the current prices are given in Figure 6. It shows that the increase was relatively very less during 1991-2001 as compared to the periods 1981-90 and 2001-2005. Figure 7 shows the trends in the real prices for the period 1993-2005. Though there is an increasing trend in the current prices, the real prices remained more or less same. This indicates that the demand for teak has not been increasing, might be due to substitute materials available in the market. However, there is an increasing tendency in the year 2005.

Forecasting of timber prices

Among the ARIMA and ANN models, ARIMA model was chosen for forecasting because forecasting by ANN model was not sensible from

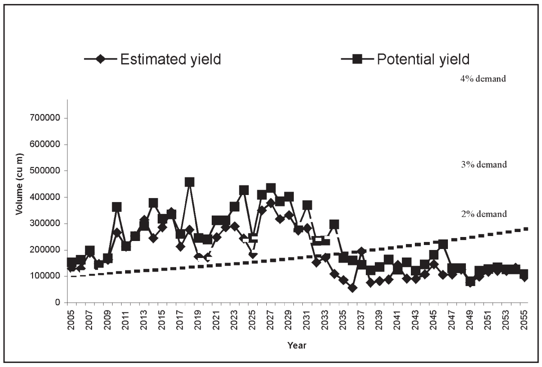

Fig. 2. Future trends in the gap between demand and availability of teak wood from forest plantations (rotation: 50 years)

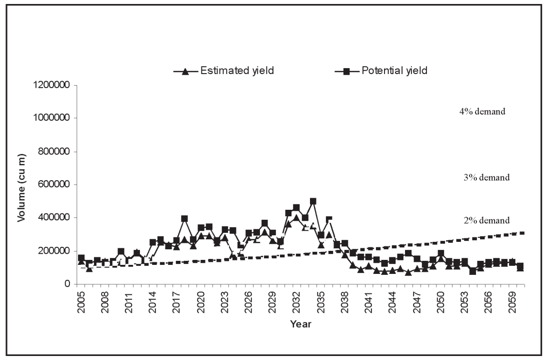

Fig. 3. Future trends in the gap between demand and availability of teak wood from forest plantations (rotation: 55 years)

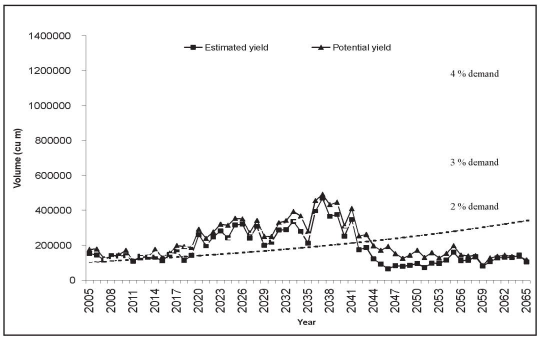

Fig. 4. Future trends in the gap between demand and availability of teak wood from forest plantations (rotation: 60 years)

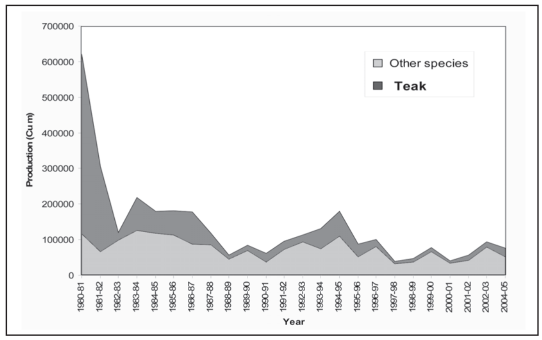

Fig. 5. Trends in the production of teak wood (round wood equivalent) and other species from the forests of Kerala (1980 -2005)

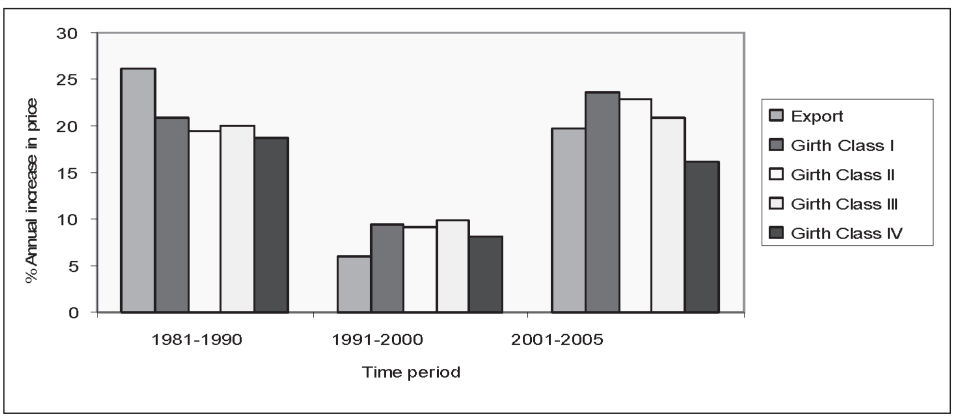

Fig. 6. Percentage annual increase in current prices of teak wood in Kerala (1981-2005)

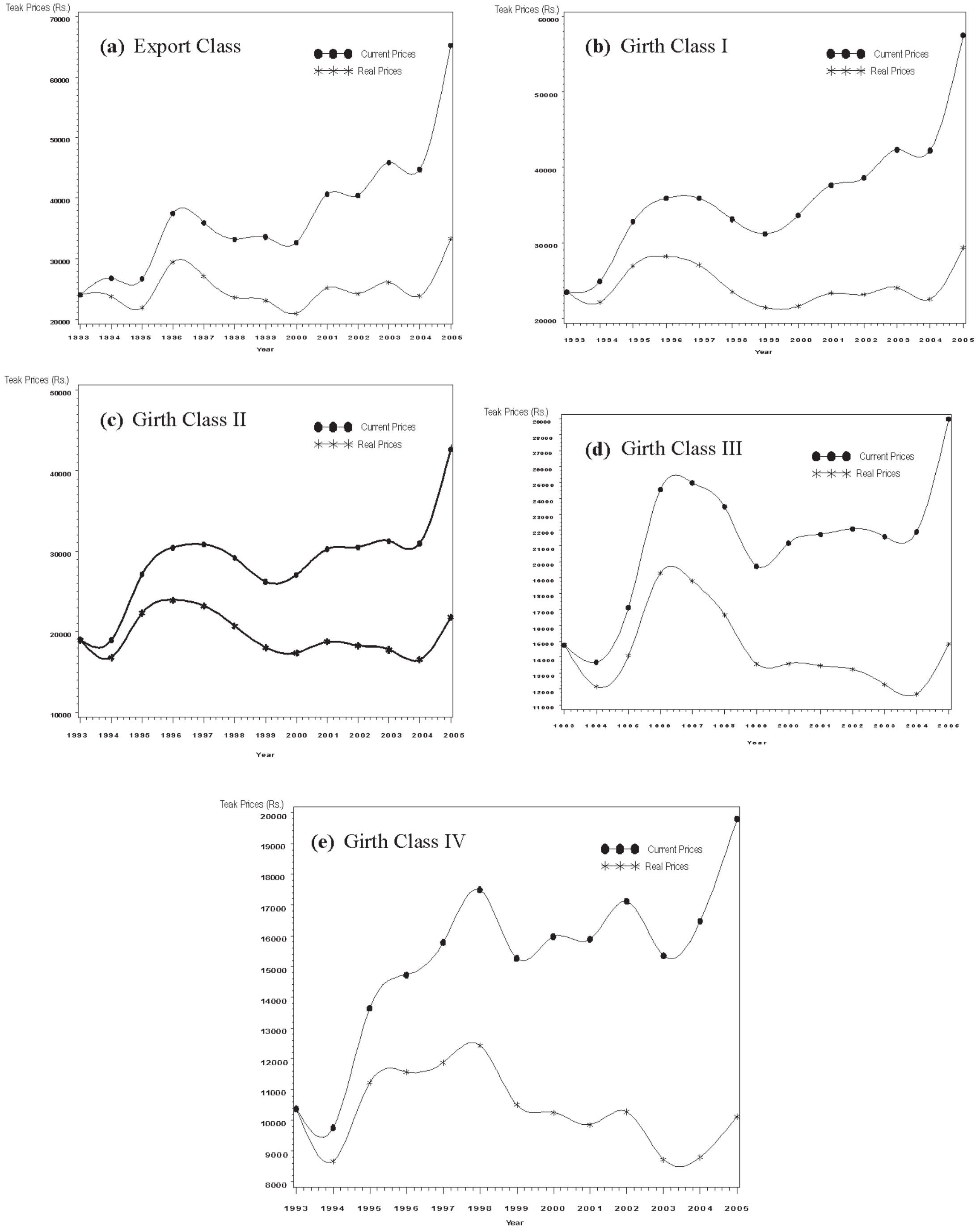

Fig. 7. Trends in real prices of teak wood per m^3

Table 1. Forecasted percentage increase in Teak wood prices in Kerala using ARIMA model

Girth Class	Current Price (Rs/cum) -2006	Forecasted Current Price (Rs/ cu m) -2007	Percentage increase
Export	57,270 (1437)	69,830 (1753)	21.9
Girth Class I	48,937 (1228)	56,834 (1426)	16.1
Girth Class II	44,295 (1112)	46,231 (1160)	4.4
Girth Class III	33,174 (833)	34,783 (873)	4.9
Girth Class IV	24,638 (618)	25,949 (651)	5.3

US dollar equivalent is provided in parentheses (1 US$ = 39.845 INR)

the practical point of view. The exact forecasting of current prices for the year 2007 for five broad girth classes is given in Sivaram (2007). The forecasts indicate that the higher girth classes, *viz*., Export class (185 cm and above), Girth class I (150-184 cm) would fetch high prices than the lower girth classes might be due to higher demand for quality teak wood (Table 1).

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Processing and Marketing of Teak Wood Products of Planted Forests pp 312 - 317

Processing and Marketing of Wood Products from Fast-Grown Teak Plantations in Costa Rica

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ABSTRACT

Between 1940 and 1980, the extension of teak plantations in Costa Rica was quite small. However, between 1980 and 1996, the government promoted forest plantations of native and exotic tree species with monetary and fiscal incentives. Thus about 20,000 ha of area was planted with teak. In the last 10 years several foreign enterprises have invested in teak plantations and this has led to establishment of over 35,000 ha of teak plantations. With regard to teak wood markets, initially a very limited local market was the only option, as the wood properties of teak were quiet unknown in the Country. During 1960-1990 teak trees were sold to luxury boat (yacht) factories, which regulated the buying price and conditions. In general, logs with diameter >30 cm and with very few defects were accepted. After 1990 several companies decided to develop new products such as parquet, interior and exterior furniture, decks, etc. from teak wood coming from thinning, for local as well as for international consumers. However, prices were still very low and consequently many factories discontinued their production. In the last decade the market for teak products has widened. Solid wood articles and blockboards have been produced for the local market in addition to furniture-making. In the international market, Indian and Vietnam buyers have started importing wood from Costa Rican teak plantations. There is still room for improvement, as most of the wood production is being sold as logs or squares with no added value. In addition, no regulations have been established to generate a fair trade between small plantation owners and buyers.

Keywords: wood quality, wood trade, wood properties, small producers, wood price.

INTRODUCTION

Teak (*Tectona grandis*) was introduced in Costa Rica and other countries in Central America between 1927 and 1929. Until the year 2000, approximately 223,000 ha of teak plantations were established in this region (Pandey and Brown, 2000). In the past 10 years, Costa Rica has steadily increased the annual plantation rate of several species to an approximate total of 11,000 ha per year. In 2000, the total area of plantations reached 178,000 ha of which 30,300 ha (17.0%) of the area was represented by teak (FAO, 2000).

WOOD QUALITY

Teak is suitable for multiple end-uses, including construction, furniture and cabinets, railway sleeper cars, decorative veneer, joinery, ship and vehicle body building, mining, reconstituted products, etc. The quality of teak timber, which could be improved by high input management, depends partly on tree form and partly on basic wood structure and strength properties. The major structural factors that should receive attention, among others, are stem size, bole shape, knot size and frequency, and heartwood-sapwood proportions (Bhat, 2000). Evidence of similarity in wood mechanical properties between young (21 years) and old (65 years) teak trees offers scope for reducing the rotation age of fast-grown wood without affecting timber strength.

In timber with clearly demarcated sapwood and heartwood, trees with higher percentages of heartwood will yield more saleable timber; conversely, a high proportion of sapwood is not a problem in treated poles because it is easily penetrated by preservatives. Once treated, the sapwood may be even more resistant to pests and fungal infections than the heartwood (Oteng-Amoako, 2004). In Costa Rica and other Central American countries, grading rules are based mostly on visual assessment, i.e., on quality characteristics such as wood defects and heartwood color. Heartwood color and content determine, in most cases, whether the log will fetch high or low price, with a corresponding gain/loss of up to 50% of its potential value.

The important property requirements in fast-grown teak are straight, least-tapered boles with reduced flutes/buttresses and knots, low proportions of juvenile and tension wood, high proportion of heartwood, and optimum wood density and strength. The two major factors that influence sawn wood grade and recovery are unsound/ hollow knots and deep flutes in the logs (Bhat, 1998).

LOCAL USES FOR TEAK WOOD IN COSTA RICA

The first report about end uses of teak in the Country from 1970, mentioning the utilization of trees with diameter greater than 23.0 cm for the construction of luxury sailing boats for the Canadian market. Nearly 100 m^3 of wood was obtained per year from plantations in the Central Pacific region (dry region of the Country) established in 1940-1950 (Moya, 1990). It was not until the beginning of this century that teak planting was taken up on a massive scale in the country and the advantages of teak wood for outdoor and structural construction were recognized whereby teak wood was accepted as prime material for housing and furniture-making. Other important use for teak coming from thinning for production of panels or blockboards, which are used locally for the constructions of low cost furniture and floors. These floors are exported after lamination with high quality wood (for example mahogany or red cedar) coming from native forests. The older the teak plantations get, the more

Table 1. Main products of *Tectona grandis* wood coming from fast-growing plantations in Costa Rica.

Construction	Furniture	Other uses
Gluelams	Filers	Sailboats
Frame and molding wood	Benches	Wood craft
Solid beams 5 x 15 y 2 x 10 cm	Beds	Preserved fence poles
Floorings 2.5 x 7.5 cm	Drawers	Non-preserved fence poles
Tongue and groove 1.2 x 7.5 cm.	Dinning room furniture	Wood Urns
Boards of 2.5 x 5.0 cm	Living room furniture	
Boards of 5.0 x 7.5 cm	Tables	
Steps	Chairs	
Doors	Arm chairs	
Windows	Desks	
Deck near swing pool	Office furniture	

uses and added value they will receive. A summary of the main products exported from Costa Rica is presented in Table 1.

PROCESSING OF TEAK WOOD

Primary sawing process

Different end-uses are identified for teak wood produced in the Country for different stem sections and for different plantation qualities. Wood from 2nd and 3rd thinning (ages between 6 and 12 years) or the intermediate upper sections of dominant trees are selected mainly for export, as logs or square blocks to the Asian market. The central core of the lower stem sections is usually converted into laminated boards of 'gluelam' or into structural handcrafted blocks for the international market.

Logs with diameter lower than 15.0 cm and coming usually from the first thinning (age 4-5 years) or from upper sections of large trees are used for fence posts, usually after preservative treatment, due to their high sapwood content. Nevertheless, logs with a heartwood diameter of 8-10 cm, are sold to the small producers. Wood coming from the oldest plantations (usually 15-20 years and occasionally 25-30 years) is being used for production of high quality furniture, decorative flooring, and handicraft which are exported to North America and Europe. Thus, the use of logs coming from fast-growing teak plantations in Costa Rica is governed by age and log size.

The processing technology in Costa Rica is suited for logs from natural forest. Thus, the equipment used for processing large diameter logs (> 35 cm) is not appropriate for the processing of fast-growing teak plantations (Carrillo, 2001). This situation has led to changes in processing techniques and development of specific sawing patterns for plantation teak (Moya, 2004). The following are some constraints for the limitations in processing technology:

- The extension of teak plantations is usually less than 1000 ha per project.
- The reforestation rate by medium to large owners does not exceed 200 ha / year.
- Limited wood volume availability per year.
- Plantations are located on areas or regions with qualified manpower.
- Difficult accessibility for high-technology equipment.

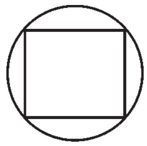
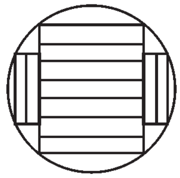
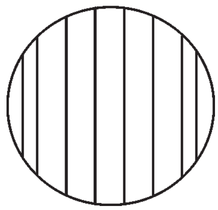
Thus, for processing, chainsaws placed parallel with adjustable distance are commonly used for the primary process (on site) of small diameter logs (<22cm). The chainsaws are powered by two 15 hp motors and having a sawing capacity of 20 m^3 / day and a cost of 25 US$ per m^3, for obtaining square, sapwood-free blocks. These squares are meant for export to India, Vietnam, and China. Additional primary processing machinery is listed on Table 2.

Reports of the wood industry suggest an average yield of 30-60% of main products, 10-30% of firewood, and 10-20% of sawdust for teak plantations in Costa Rica. Further wood processing (drying, preservation, planing and molding) has been included in order to elaborate more added-value products, such as glue lams and block board panels.

Drying

Both kiln drying as well as conventional air drying are followed in processing of plantation teak wood in Costa Rica. Three different kiln drying schedules have given good results for teak wood, under drying periods of 120-150 hours for 25 mm timber thick (Berrocal *et al.*, 2007). These schedules are more popular for drying timber under moderate or slow speed.

Table 2. Machinery and sawing patterns used for primary processing of teak plantations in Costa Rica.

Diameter (cm)	Machinery	Sawing pattern	Products
12-15	Parallel chainsaws		Square blocks
15-22	Main saw: Parallel chainsaws Twin circular saw Horizontal band saw Multiple circular re-saw Edger Trimmer		Square blocks Blockboards Panels
>22 cm	Band saw Multiple circular re-saw Edger Trimmer		Wood for furniture Exportation products

Air drying is also followed by the teak wood industry due to its ease, low requirement of expertise and cost, and relatively short drying periods (particularly in the dry region of the Country with 6 dry months). The time required for drying 2.5 to 5.0 cm thick boards is 15 to 25 days for reaching 18.0% of moisture content, costing approximately 4.83 US$/m^3 (Gómez, 2007).

Preservative treatment

In Costa Rica the preservation by vacuum pressure method is applied only to log poles coming from the upper stem sections or from young plantations (first thinning) mainly due to the high sapwood content and consequent easy penetration of preservatives under pressure. Additional techniques consist of preservation through diffusion of boron compounds, which allows a full penetration of preservatives in 20-25 days for different board thicknesses and costing approximately 23.47 US$/m^3.

MARKETING

Recently, with opening of the trade market with Asia (basically after the strong regulations for native teak trade), the export of teak wood from Costa Rica has increased significantly (Figure 1). In 2005 the teak wood exports doubled as

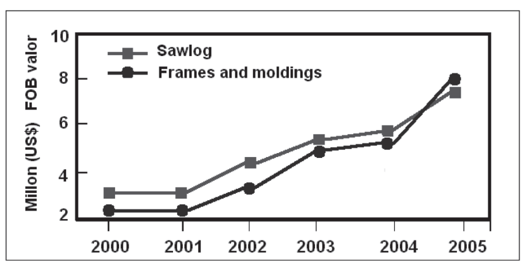


Fig. 1. Export trends for sawlogs, frames, and moldings between 2000 and 2005 in Costa Rica.
Source: Barrantes & Salazar (2006).

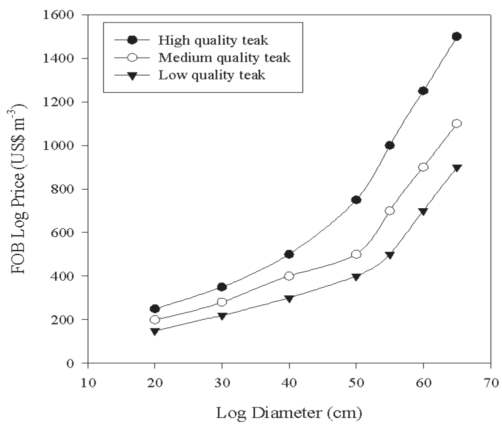
compared to 2004, reaching US$ 7.7 million for a total volume of 38.500 m^3 at a price of 200 US$/$m^3$. In addition, since 2001 a noticeable increase in the exports of frames and molded products has occurred, reaching US$ 6.9 million in 2005.

Wood price

It is difficult to get accurate and regular wholesale and export prices for teak wood. This is also applicable to teak production as it stands today. There is no organized market and the majority of the products come from unregulated or illegal sources, which have no interest in giving details of their dealings. A study by FAO in 2001 on the market of forest products in Costa Rica revealed that teak prices vary between 400 and 1300 US$/$m^3$, depending on size and quality.

Mundo Forestal (www.mundoforestal.com), an electronic bulletin for business opportunities in the Forestry sector, posts offers from teak wood traders from Central and South America. For November of 2002, the highest price of teak logs (15-25 years, diameters up to 45.0 cm) from the posted offers was 330 US$/$m^3$ and for board feet 770 US$/$m^3$. An initiative of the CCF (Costa Rican Forest Chamber) and the CACH (Regional Agriculture Center Hojancha) achieved the export of teak lumber at a price of 655 US$/$m^3$ with the following specifications: sound knots, healthy, free of the fungi and insects attacks, free of sapwood, with up to 50% white color and 50% golden brown color, without cracks and sawn four sides.

Teak wood prices are presently determined based on visual assessment and case-to-case basis; there are no systematic or consistent grading rules with corresponding price values. However, some quality and size requirements such as age (related to would quality) and log diameter (relative to size and yield) are being standardized. Average teak wood prices for different log quality and size were defined using the available information for Costa Rican teak wood (Figure 2). The quality was assumed to be related to log shape, defects such as pith eccentricity, knots and sapwood content.



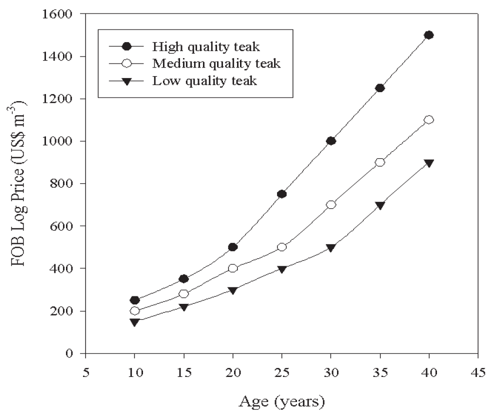


Fig. 2. Estimated average prices for plantation teak wood in relation to (a) age and (b) log diameter.

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Teak Wood Prices 2000-2005: An Overview

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ABSTRACT

Teak wood prices are still set up based on visual assessment and on a case-to-case basis due to the lack of systematic grading rules with corresponding values. The current teak price review indicated that the highest prices (upto 2000 US$ m^{-3}) were achieved by naturally grown logs from Myanmar, which could be processed into veneers, while thinned logs (from rapidly expanding plantations) such as those so far exported from central America are placed in the lowest price category and yield prices of about 200 US$ m^{-3}. The apparent cumulative difference in various wood properties between natural and plantation grown teak, coupled with the much smaller dimensions offered by the latter, seems to have established the fact that plantation teakwood is no match for mature-aged natural teak in the market place. New market avenues need to be explored and developed for plantation grown teak products, which produce less mature wood but with less defects due to intensive management practices with the ecological and sustainable production label.

Keywords: Prices, investments, plantation grown teak.

INTRODUCTION

Possible investors currently looking at different options for international “green investments” usually consider teak (*Tectona grandis*) plantations as a feasible investment option. However, information on reforestation costs and market prices for teakwood are meager and fragmentary, particularly for plantation teak. The present report aims at presenting and analyzing part of the information currently available for teak trading, in order to generate criteria for developing potential and realistic price growth trajectories that guarantee high returns on investment.

METHODOLOGY

The review of teak pricing was focused on three main topics:

a. Historical teak prices
b. Current teak prices
c. Potential new prices

For this, different sources were consulted, as follows:

a. Forest companies, wood traders, NGO’s, and other organizations involved in the teak trading network in different countries and world regions. The channel of information used for this search was the internet.
b. Information from visits carried out to reforestation companies, sawmills, and furniture factories in Costa Rica, as part of a thesis research for Ph.D. studies.
c. Information from a visit carried out to Perum Perhutani, the governmental institution in charge of all the teak plantations in Indonesia.

d. The official price list used in the auctioning of teak logs in Indonesia by Perum Perhutani.

The information obtained from the different sources was used for creating possible scenarios of the near-future trend of the international teak wood prices (very optimistic, optimistic, likely, without increment?).

RESULTS

Historical teak prices

Few reports on historical teak prices are available, as teak is relatively new in many regions of the world and thus the grading and pricing for this species in particular has not being well developed and documented. In countries with a large history on teak culture, such as India and Indonesia, reports of teakwood prices can be found from the year 1970 and on. In the last 10 years, the teak market has been more unstable than ever, therefore documented historical reports for the period 1990 to 2005 are scarce and confused as well.

Figure 1 shows the price history for Indian teak between 1970 and 1990, provided by the Department of Commercial Intelligence and Statistics of India.

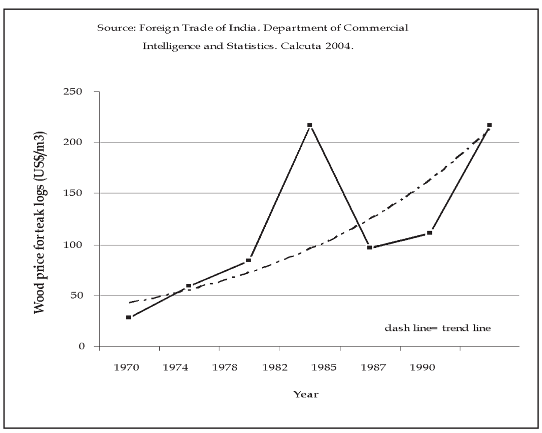

Fig. 1. Historical teak prices for Indian teak between 1970-1990.

Another source (Bebarta, 1999) reports a similar trend for Indian teak in the same period (Figure 2), with slightly higher prices in the last 10 years (1980-1990) and a more exponential yearly growth.

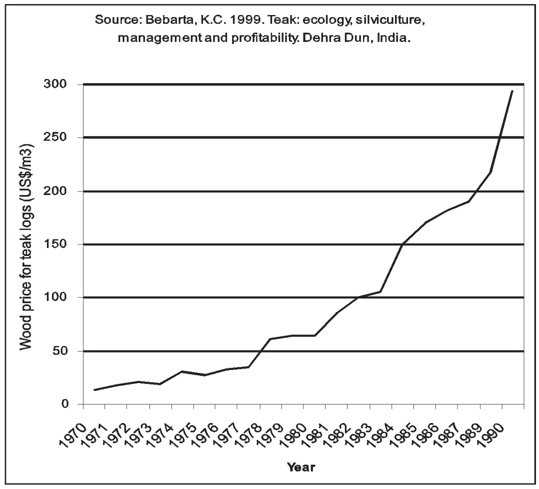

Fig. 2. Historical teak price for Indian teak for the period 1970-1990.

ITTO (International Tropical Timber Organization) publishes the monthly changes in Asian teak in their public e-bulletin, from which a report on teak prices for the period 1990-2005 extracted (Figure 3) presents the price trend of Asian teak logs for the period 1997-2001. Bold lines show FOB prices, normal lines show nominal FOB prices. Grades are according to ITTO official quality grading, i.e., veneer quality (4^{th} grade) and Sawing Grade (SG) quality.

The average value of all forms of raw teak imported to North America during 1997, including high quality veneer logs and teakwood derived from thinnings was US$ 830 m^{-3}. As of today,the price has risen to approximately US$ 1900 m^{-3} (Panacea Growth Limited, www. panaceagrowth.com).

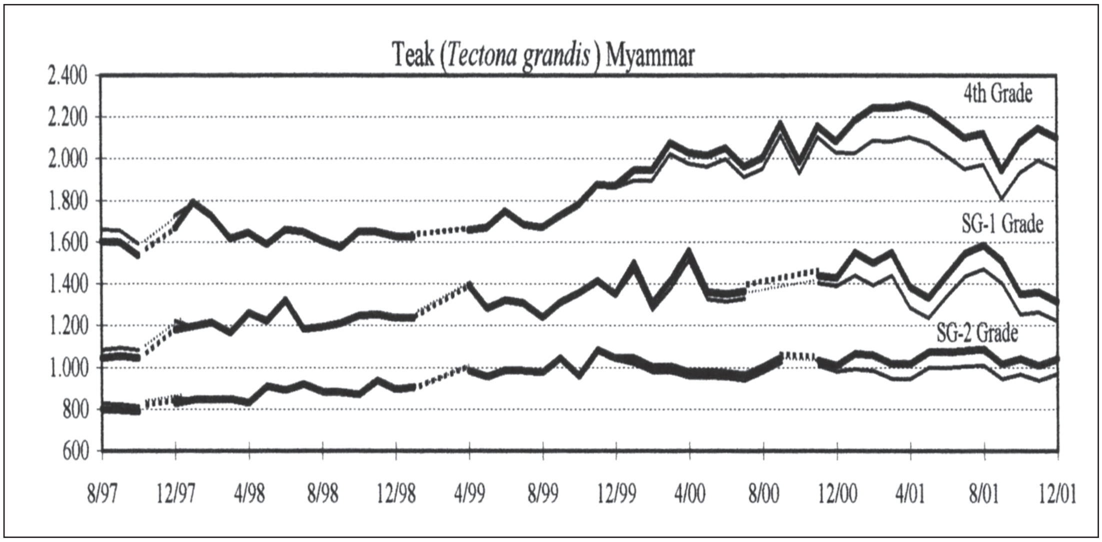

Fig. 3. Teak prices (FOB, US$ m^{-3}) in Myanmar for the period 1997-2001 according to ITTO (2001).

Current teak prices

It is notoriously difficult to get accurate and regular wholesale and export prices for teak wood. This relates to the whole nature of teak production as it stands today. There is no organized market and the majority of the products come from unregulated or illegal sources, which have no interest in giving details or their dealing to anyone. Table 1 summarizes the information on teak wood prices publicly announced in different companies' web pages, who offer attractive returns on investment to potential buyers.

Severe criticism has been raised against companies promoting the marketing of fast growing teak with prices between 720 and 2100 US$ m^{-3} of standing volume, suggesting that according to independent studies mature teak logs were likely to fetch 400 to 550 US$ m^{-3} (Centeno, 1996, *Traders of illusions* and *Teak sting*. Internet documents: www. ciens.ula.ve/~jcenteno/Teca.htm)

The highest prices (up to 2000 US$ m^{3}) are achieved by naturally grown logs from Myanmar which can be processed into veneers. Thinned young logs from rapidly expanding plantations, such as those so far exported from Central America, are placed in the lowest price category and yield prices of about 200 US$ m^{-3}. After deducting transport costs and other diverse outlays, the supplier in Central America achieves 60-90 US$ m^{-3}. Teak logs with a diameter of more than 40 cm can yield a price of up to 300 US$ m^{-3} when exported to India. Selected 25-year-old logs cost around 600 US$ m^{-3} in Costa Rica and prices can go up in some cases to 900 US$ m^{-3} (SOURCE: Precious Woods web page, www. preciouswoods.ch).

Kauai Tropical Timber's (www. kauaitimbers.com) projections are based upon a starting price of $3.50 per board foot (1537 US$ m^{-3}) for teak. According to the International Tropical Timber Organization (ITTO) June 2003 Market Review publication, Forest Products Prices, the actual average export/ import prices of teak averaged $4.50 per board foot (1967 US$ m^{-3}) ranging from $3.54 to $5.43 (1547-2373 US$ m^{-3}), depending upon dimension and quality. Prices for teak for the earliest thinnings

Table 1. Teak wood prices publicly announced in the internet by reforestation companies.

Source	Information	Price (US$ m^{-3})	Observations
Tropical Plantations Ldt. USA www.tropicalplantations.net	FOB price for teak logs	1260	Based on average pricing from ITTO, and USA retail prices
Inversiones el Rosario (INROSA). Costa Rica www.natureinvest.net	FOB price for teak logs of different ages	12 year-old: 260 (local) 18 year-old: 919 (export) 20 year-old: 1131 (export) 25 year-old: 1403 (export)	"The United States Wood Association informs that teak has had an increase of 625% in price from 1988 to 1992." "The wood for construction that was sold for US$ 3.0-4.5 per foot (US$ 1311-1967 per m^3) is now sold for US$ 10 per foot (US$ 4370 per m^3)."
Tropical American Tree Farms. Costa Rica www.tropicalhardwoods.com	Value per tree	7-year-old: 73 10-year-old: 176 13-year-old: 755 17-year-old: 2165 21-year-old: 6900	No further information.
Global Green Services. Costa Rica www.globalgreenservices.com	Report of international teak prices	Year 1990: 450 Year 1994: 650 Year 1995: 700 Year 1996: 800	Consider that the basis of calculation includes conservative future teak prices.
Kauai Tropical Timbers. Kauai, USA www.kauaitimbers.com	Value per tree	8-year-old: 145 12-year-old: 792 16-year-old: 2724 20-year-old: 6069	See further description in the body text below.
Friendly Forest Products. USA www.exotichardwood.com	Current Teak lumber inventory. FOB Miami	Clear: US$ 7.0 per BF (US$ 3059 per m^3)Clear one face: US$ 6.0 per BF (US$ 2622 per m^3)Character grade: US$ 4.0 (US$ 1748 per m^3)	Character grade: sound knots, minimal sap and possibly some pith.
Myanmar Inter Safe Co. Myanmar. www.forest-treasure.com	Diversity of products, from squares to boards and decks and of different grading or quality	For teak squares, for example, prices vary from US$ 4190 per ton of 50 ft^3 (US$ 9744 per m^3) to US$ 3100 per ton of 50 ft3 (US$ 7209 per m^3), this for SELECTED SPECIAL TEAK. Common or "market" teak show prices of less than half of those of selected teak.	Teak is difficult to obtain in Myanmar as it is strongly controlled by the State, who sells it by auctioning and re-sellers increase the price considerably. Prices correspond to those registered in the Myanmar Timber Enterprise (MTE). MTE is the sole and major government-owned enterprise in the timber business.
Panacea Growth Limited. Belize www.panaceagrowth.com	Market price for teakwood (no specifications)	US$ 830 (although stated that as of today it has risen to US$ 1900).	These Prices are used in the financial analysis of the growth scenarios. See detailed description in the body text below.
Prime Forestry Panama. Panama www.primeforestry.com	Growth scenarios with Incomes and log prices	4-year-old: 52 7-year-old: 160 10-year-old: 210 14-year-old: 340 20-year-old: 525	Prices correspond to merchantable volume in logs. Different profit scenarios are presented with 0%, 3%, and 6% yearly teak price increments.

may be less so a price of $3.50 per board foot was chosen for the company's projections. The projections are based upon the price of teak increasing at 6% per year and the harvest and processing costs increasing at the same rate. According to the FAO Forest Products Prices, the median export/import prices of teak actually rose at an average rate of 9.7% from 1970 to 1988, the last day of that report. More recently, teak prices have been rising at a rate greater than the 6% used in these projections.

Apparent cumulative differences in various wood properties between natural and plantation grown teak, coupled with the much smaller dimensions offered by the latter, seems to have established the fact that plantation teakwood is no match for mature-aged natural teak in the market place. Differences in export prices are a good indicator of this: the 300 US$ m^{-3} fetched on average by plantation teak logs is markedly less than the average price of 700 US$ m^{-3} for natural forest teak. Even within natural-grown teak the wide range of prices reflects differences in quality: at the end of 2003, FOB (free-on-board) prices for natural teak sawlogs ranged between 420 and 1615 US$ m^{-3} depending on log grade (ITTO bulletins, 2003/2004).

FAO published a working paper (Working Paper FP/19) from a research study on teak carried out in Costa Rica informing of single local market pricing of rough boards for export at 500 US$ m^{-3} (FOB), after Costa Rican Forestry Chamber (CCF) reports in 1998. In addition, the FAO report presents different prices paid for teak logs in Sri Lanka and Central/South America, according to log sizes (Table 2).

Table 2. Teak *(Tectona grandis)* log prices by diametric class, from Sri Lanka, Central and South America.

Mean diameter (cm)	Sri Lanka (US$ m^{-3})	Central and South America (US$ m^{-3})
15 – 20	243	Na
21 – 30	304	Na
31 – 40	386	190
41 – 50	426	200

Source: ITTO Market report, 1995; Phillips (1997), cited by Varmola (Ed.) 2002.

Table 3. Average log prices for teak wood in Costa Rica.

Average Size (cm)	Price (US$ m^{-3})
6.0 x 15.0 x 200.0	400 - 600
7.0 x 20.0 x 250.0	600 - 800
Blocks of 3-4 meters length, no pith, no sapwood	1300

Source: Gardino (2001).

Another recent study on the market of forest products in Costa Rica, Central America, revealed that on an average, teak prices vary between 400 and 1300 US$ m^{-3}, depending on size and quality (Table 3).

Mundo Forestal (www.mundoforestal.com), an electronic bulletin for business opportunities in the forest sector, receives offers from teak wood traders, among others. For November of 2002, the highest price of teak logs from the offers they received was 330 US$ m^{-3} and for board feet 770 US$ m^{-3}. Teakwood offered within this business sector refers to 15-25-year-old coming from Central or South America, mainly, with maximum sizes of 40 cm.

One company that has placed young teak (ages between 6-7 years) in the international market is Flor y Fauna S.A. The company has participated in several international fairs in the United States with a variety of prototypes. So far, they have consolidated, with great success, the following products: 1) bed sofa, 2) tables for lamps, 3) occasional table, 4) small trunk, 5) components for computer tables and 6) floorings. These products are being marketed at prices higher than 1000 US$ m^{-3} (Products 1 to 4 – 1500 US$ m^{-3}, Products 5 and 6 - 1200 US$ m^{-3}). The company has also developed a market for garden implements in USA, with very good results but, as these products have to be at low prices to make them competitive, they are considered as marginal.

Another initiative, developed by the CCF (Costa Rican Forest Chamber) and the CACH (Regional Forest-Agriculture Center - Centro Agrícola Cantonal de Hojancha), achieved the export of teak lumber at 655 US$ m^{-3} with the following specifications: sound knots, healthy, free of the fungi and insects attacks, free of sapwood, with up to 50% white color and 50% golden color, without cracks, sawn four sides. (*Source*: FAO Report, Working Paper FP / 19: Teak in Central America).
Perum Perhutani, the governmental company in charge of all teak plantations in Indonesia, sells part of their wood stock on a regularly basis by public auctioning. As usual, prices vary according to size and quality (Table 4).

without certification. The only requisite is a minimum diameter of 30 cm, and prices vary depending on diameter and wood quality, from 200 to 800 US$ m^{-3}.

Prices for certified wood are still fragmentary nowadays, since most certified companies are relatively young (with plantations aging less than 15 years), therefore, the introduction of high quality teak wood coming from certified plantation forests has not been clearly stated. Many companies in Central and South America have been certified by FSC or SGS, and are currently introducing their products in the international (European) wood market. Usually, public reports do not include the prices either used for sales or for projections. Only one public report, carried out by SGS Forestry Division (Société Générale de Surveillance) in Bosques Puerto Carrillo (currently Panamerican Woods), Costa Rica, indicates that the company has sold thinnings (ages less than 10 years) at prices of 85 US$ m^{-3}.

Few countries have developed certain classification norms for teak trading. Trinidad &

Table 4. Prices use as base in public auctioning of teakwood in Indonesia according to size and quality.

Quality/Diameter	15-20 cm	20-30 cm	30-40 cm	50-60 cm
	Price US$ m^{-3}			
First	95	187	672	917
Second	87	170	603	823
Third	79	154	534	728
Fourth	73	137	464	645

Source: Perum Perhutani, Solo, Indonesia.

Perun Perhutani is selling wood to locals, 50 year-old teak for example, for 160 US$ m^{-3}, mainly because of ignorance or lack of trading experience, as this wood is worth over 1000 US$ m^{-3}. Indeed, they have sold teak for over 800 US$ m^{3} (personal communication). The wood industry in Java is supplied mainly by Perum Perhutani, even

Tobago, through a private company (internal document, no authorization for public use), has been exporting teak products to Europe for about 20 years, using very rigorous classification systems for acquiring teak logs and board feet. Linking these classification norms to those of ITTO, a price-related comparison can be established in order to

Table 5. Classification of logs and processed wood (board feet) used in Trinidad and Tobago and the corresponding prices based on ITTO (2002) for *T. grandis.*

Characteristics of logs	Characteristics of board feet	Price for logs(a) and board feet (b)(US$ m^{-3})	Grade (1 to 4)
Diameter at smaller end >45cm	- 1 living knots per linear meter (diam <1.3cm) - Max. 10% sapwood - no pith	(a) 1300 (b) 2400	1
Diameter at smaller end >45cm	- 2 living knots per linear meter - Max. 20% sapwood - 10% of the piece length with pith (6mm wide, 3mm depth)	(a) 950 (b) 1800	2
Diameter at smaller end 30-45cm	- Living knots on both sides (3.8cm, 1 knot every 30cm) - Max. 30% sapwood - No more than 50% of the length with pith	(a) 600 (b) 1200	3
Diameter at smaller end <30cm	- Living knots accepted - Max. 50% sapwood - Pith only on one side, along all the surface.	(a) 500 (b) 950	4

give a price value according to size and quality (Table 5).

Teak prices presented here correspond to experiences developed in different countries from the harvest of young and middle aged plantations (max. 50-years-old), which have had in general a poor silvicultural management (Table 6). Therefore, the quality and the size of the trees are below the potential of this species and it is very likely that the price for teakwood coming from intensive managed plantations will be higher than those presented below. In addition to this, the productivity of this new era of teak plantations concept will be evidently greater than actual records, guaranteeing the economic feasibility of this culture.

As part of the internet research on pricing and demand of teak wood products, a well-known furniture company in Indonesia shared publicly part of their buying profile for teak wood as raw material for their business

DISCUSSION

Teak wood prices are still set up based on visual assesment and on case-to-case basis, i.e., there are no systematic or consistent grading rules with corresponding values. However, some quality and log size begin to mark the ground with basic requirements, such as age (related to wood quality) and log diameter (relative to size and yield). Based on the information collected for the present study, average teak wood prices for different log quality and size were defined (Figure 4). The quality was assumed to be related to log shape, defects such as pith eccentricity and knots, and sapwood content.

Based on the wood price definition for teak at present, and for three different qualities (Figure 4), different price trends were defined for the next

Table 6. List of teak prices from a field research (personal visits to companies) in Costa Rica and from a bank of data from previous literature review.

List No.	Price ($/m3)	Country	Buyer/seller	Age (years)	Product description	Observations	Reference
1	42	El Salvador	**Seller:** Private owner: Eng. Alvaro Remberto Guardado Email: aramis@navegante.com.sv Tel. (503) 273 44 35	9	Logs of different lengths	Trees sold in the plantation, dbh 10-15 cm and total heights of 15 m.	2003. Personal contact with owner after reading the advertisement in the forest e-bulletin “Mundo Forestal.com” www.mundoforestal.com
2	250-500	Costa Rica	**Seller:** Reforestaciones Tecatica Internacional S.A. Email: tecatica@racsa.co.cr Tel. (506) 241 11 11	12 - 18	Squares or blocks, and logs	Price at Costa Rican port	2003. Personal contact with owner after reading the advertisement in the forest e-bulletin “Mundo Forestal.com” www.mundoforestal.com
3	450	Costa Rica	**Seller:** Private Owner: For. Eng. Jaime Raigosa. Email: raigosa@racsa.co.cr	22	Logs	Price is for logs loaded on the truck in the plantation	2003.Personal contact with owner after reading the advertisement in the forest e-bulletin “Mundo Forestal.com” www.mundoforestal.com
4	300	Costa Rica	**Buyer:** Spanish Royal Teak Email: indmora@racsa.co.cr Tel. (506) 282 40 10	25	Logs	Wood purchased from a plantation without any management at all.	2002. Field trip to different sawmills in Costa Rica. Personal visit to the company.
5	460	Costa Rica	**Buyer:** Diamond Teakwww.diamondteak.com Email: kevin.yardley@verizon.net Tel. (877) 874 83 25	20	Logs	Minimum log diameter 15 or 20 cm, depending on other quality factor such as heartwood %, straight bole, taper.	2002. Field trip to different sawmills in Costa Rica. Personal visit to the company.
6	1200	Costa Rica	**Buyer:** Cabo Ricowww.caborico.com Email: info@caborico.com Tel: (954) 462 66 99	>15	Parquet	Product must be free of knots and sapwood, other specifications are of secondary importance	2002. Field trip to different sawmills in Costa Rica. Personal visit to the company.
7	590	Costa Rica	**Seller:** Aserradero Del Rio Daniel Del Rio Tel: (506) 779 83 59	<15	Processed wood, any dimensions	Wood only with heartwood, any dimensions are possible by using finger joint techniques	2002. Field trip to different sawmills in Costa Rica. Personal visit to the company.
8	500-1300	Myanmar	Range of prices for different international teak markets in Myanmar	- -	Processed wood, many dimensions	Prices vary with quality grading, which includes wood defects, heartwood%, pith eccentricity, max. dimensions, etc	2002.Internet document from ITTO (International Tropical Timber Organization) www.itto.org.jp

(contd...)

List No.	Price ($/m^3)	Country	Buyer/seller	Age (years)	Product description	Observations	Reference
9	66 200	Costa Rica	**Seller:** CONFIDENTIAL	5 10	Logs Squares	Min. diam. of 12 cm Blocks 14 x 14 x 250 cm	2002. Field trip to different sawmills in Costa Rica. Personal visit to the company.
10	780-2500	Asia	TEAKNET Asia: Pacific Regionhttp://www.fao.org	25	Processed wood	Short dimensions or scantlings	2002. Internet Document from FAO - Teaknet
11	450	Costa Rica	**Buyer:** International German Company (no additional info) supplied by the **Seller**:CONFIDENTIAL Tel. (506) 384 94 02	15	Logs or squares	Prices FOB	2002. Personal Communication. Strong research relationship with this company
12	63 100 180 380	Costa Rica	Different sources, average for Costa Rica	7 12 15 20	Logs	Prices are for wood coming from poor managed plantations, i.e.	2003. Report published in the e-bullin Mundo Forestalwww.mundoforestal.com
13	540-1000	India	Research Report	——	Logs	Diameter greater than 29 cm. October of 1998	Ball, J. B.; Pandey, D.; Hirai, S. 2000. Global overview of teak plantations. In: Proceedings of International Seminar “Site, Technology and Productivity of Teak Plantations”. Chiang Mai, Thailand, 26-29 January 1999. FORSPA publication 24/2000. 11-33 p.
	630	Nigeria			Logs	Year 1998	
	400	Indonesia			Logs	Year 1998. Diameter greater than 29 cm	
14	1100-5500	Myanmar	Myanmar Timber Enterprise	——	Logs	Prices are for good and top quality teak.	Maung, U. 2000.Teak plantations in Myanmar. In: Proceedings of International Seminar “Site, Technology and Productivity of Teak Plantations”. Chiang Mai, Thailand, 26-29 January 1999. FORSPA publication 24/2000. 83-98 p.
15	400-1375	India	Research Report	—-	Logs	Prices according to diameter and quality classes during 1995.	Chundamannil, M. 2000.Teak plantations in Kerala-An economic review. In: Proceedings of International Seminar “Site, Technology and Productivity of Teak Plantations”. Chiang Mai, Thailand, 26-29 January 1999. FORSPA publication 24/2000. 239-259 p.

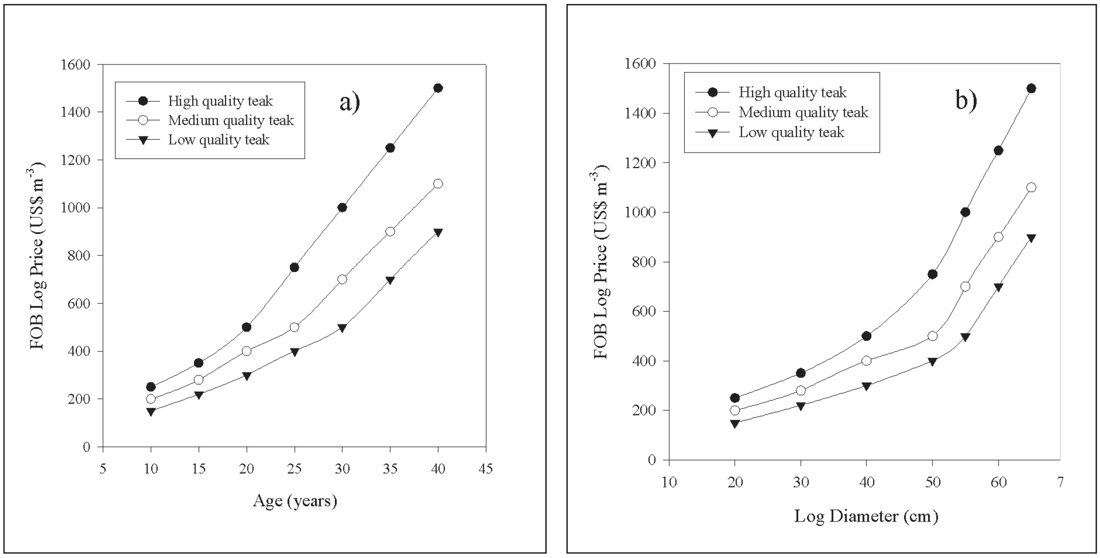

Fig. 4. Estimated average prices for plantation teak wood in relation to (a) age and (b) log diameter (b) at present.

15 years, at different yearly price increments. Figure 5 shows an optimistic price scenario, i.e., showing high-price average values for plantation –grown teak at 6%, 3%, and 0% yearly interest growths. In average, for high quality teak wood coming from plantation forests, in the next 15 years prices are estimated to overcome 1500, 1000, and 750 US$ m^{-3} for 6, 3, and 0% interest rates, respectively, with highest values reaching over 3000 US$ m^{-3}.

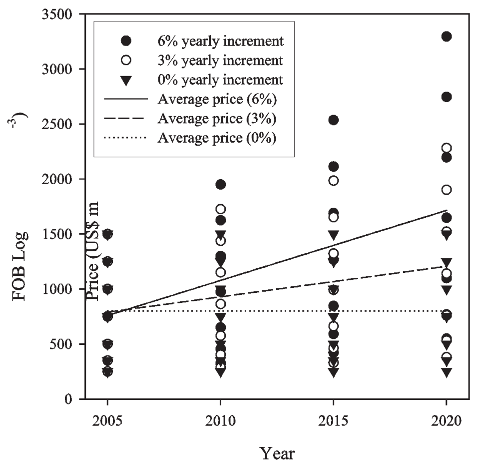

Fig. 5. Price growth projection under an optimistic scenario and for high quality plantation-grown teak.

Figure 6 shows a less optimistic price scenario, i.e. showing "realistic" or 100% feasible-to-achive price values for plantation –grown teak at 6%, 3%, and 0% yearly interest growths. In average, for high quality teak wood coming from plantation forests, in the next 15 years prices are estimated to overcome 1250, 750, and 500 US$ m^{-3} for 6, 3, and 0% interest rates, respectively, with highest values reaching over 2500 US$ m^{-3}.

Figure 7 shows a pessimistic price scenario, i.e. showing the minimum feasible-to-achive price values for plantation –grown teak at 6%, 3%, and 0% yearly interest growths. In average, for high quality teak wood coming from plantation forests, in the next 15 years prices are estimated to overcome 1000, 600, and 400 US$ m^{-3} for 6, 3, and 0% interest rates, respectively, with highest values reaching over 2000 US$ m^{-3}.

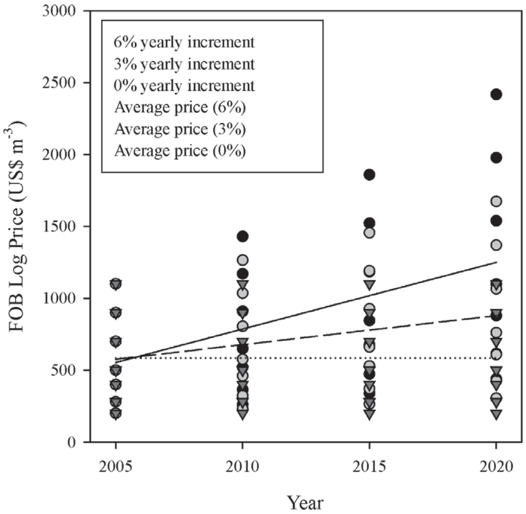

Fig. 6. Price growth projection under a realistic scenario and for high quality plantation-grown teak.

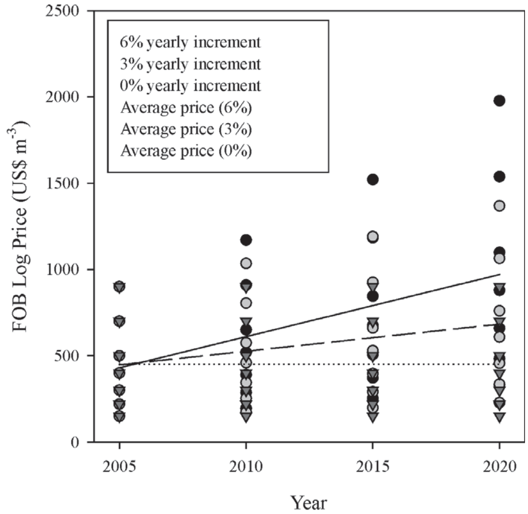

Fig. 7. Price growth projection under a pesimistic scenario and for high quality plantation-grown teak.

A evidenced by the information presented in this study, teak price classification and valuing norms are still lacking. It is important to understand that plantation-grown teak should receive a different "treatment" than natural teak, as they are totally different "materials". New markets need to be developed for all the new products coming from plantation-grown teak, which will produce less mature wood, but with less defects (due to intensive management practices) and with the attractiveness of the ecological and sustainable production label.

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