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Promotion of the Utilization of Bamboo
from Sustainable Sources in Thailand

Review of Bamboo Management



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Review of Bamboo Management

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1. Bamboo : Review on Ecology, Sustainable Management and Silviculture

Introduction

Bamboo is in a unique groups of giant arborescent grasses in which the woody culms arise from underground rhizomes (Liese, W. 1985). They are shrubs, which have a tree like habit, their culms are erect and sometimes climbing. Bamboo is characterized by woody, mostly hollow culms with internodes and branches at the culms' nodes. They are part of the grass sub-family called Bambusoideae, which is in the Gramineae family. The name bamboo was introduced by Linne in 1778 from the Indian word "Bambu" or "Mambu". The biology of bamboo itself is remarkable and peculiar from many points of view.

For a long time bamboo has played an important role in the lives of people in many tropical countries, especially in Asia (Liese , W. 1985). Curiosity about these peculiar plants with their widespread distribution has gained much attention recently according to Liese. Bamboo's rapid rate of growth and multipurpose uses, has contributed greatly to its popularity. The yield of raw material from bamboo can be harvested faster than from trees. Bamboo has several uses such as food, a building material, an energy source, paper, and many others. The bamboo forest has a greater significance to the rural people than the food alone derived from the trees. The abundance of bamboo and its ability to grow rapidly and spontaneously, has been some of the hindrances in the past of neglecting to develop this natural resource. The depletion of this resource, due to population pressure, has renewed interest in this group of plants. Bamboo is being rediscovered as a traditional raw material, its special natural beauty and as a material for different technical uses. Its socio-economic importance for the rural population is increasingly being realized. It should be emphasized that this report on bamboo is not exhaustive because bamboo is but one branch of a very large family of plants. Despite its universal utilization, our knowledge is incomplete. These gaps may be due to the diversity of bamboo itself within their wide ecological range.

Qualities and uses of Bamboo:

- the fastest growing plant on this planet
- plays a crucial role in the balance of oxygen and carbon dioxide in the atmosphere
- a viable replacement for wood
- an enduring natural resource
- it is versatile with a short growth cycle
- it is a critical element of the economy
- it is an essential structural material in earthquake architecture

- a renewable resource for agro forestry production
- a natural controllable barrier
- an ancient medicine
- integrally involved in culture and the arts
- a tool for erosion control

As a soil conservation tool, bamboo is an instrumental component of landscape design. Its anti-erosion properties create an effective watershed by stitching the soil together. This can be accomplished along fragile riverbanks, deforested areas, and in places prone to earthquakes and mudslides. The sum of stem flow from bamboo is around 25%.

Distribution

Bamboo grows naturally in all continents except Europe (Liese , W. 1985). From Asia, to Pakistan and Japan, bamboo is represented by about 320 species, of which more than half are located in the India/Burma region. Africa is poor in bamboo with only about 12 species of genera known to inhabit the continent.

On the other hand, there are roughly 25 species, which are native to Madagascar. In the western hemisphere, their natural range extends from southern USA to Argentina and Chile with about 200 species. North America has one native species, *Arundinaria gigantean*. Only the genus *Arundinaria* occurs in both hemispheres.

Bamboo can grow at sea level, in the tropics, or up to 4,000 meters above sea level in temperate regions. Although bamboo is more common to the tropics, it also occurs naturally in subtropical and temperate zones of the world, except in Europe.

The geographical distribution of bamboo is governed largely by the conditions of rainfall, temperature, altitude and soil. For good growth, most bamboos require a temperature range between 8 to 36 degrees Celsius, a minimum annual rainfall of 1,000 mm and high atmospheric humidity. They form an important constituent of many deciduous and evergreen forests. In nature bamboo seldom occurs in pure crops but is normally found in the under storey of the following forests: tropical evergreen, tropical moist deciduous, montane sub-tropical, montane wet temperate and wet temperate Himalayan. Generally, the genera *Bambusa* and *Dendrocalamus* are found in tropical conditions, whereas the *Arundinaria* and its allies occur in the temperate regions and are most common among high elevations in the western and eastern Himalayas. *Dendrocalamus strictus* predominant flourishes in dry deciduous forests, while *Bambusa* bamboos thrive best in moist deciduous forests. The most important bamboo of the semi-evergreen forest of the Andaman is *Gigantochloa rostrata*.

Bamboo is usually found in moist valleys, sheltered depressions along streams and lower hills slopes. However, it occasionally occurs on higher slopes and hilltops. They usually occur mixed with other tree species except in cases where they form secondary brakes and then they are more or less pure. Though many species form brakes, those of the *Arundinaria*, *Ochlandra*, *Melocanna* and *Bambusa* bamboo are typically more extensive. Where shifting cultivation is practiced, the bamboo brakes are more common.

(Uchimura, E. 1981). From Uchimura's observations concerning the latitudinal range of bamboo it has found bamboo growing in warm temperate zones as well as in tropical zones that differed in types of rhizomes. This can be concluded as follows:

- 1) Most bamboo culms in temperate and warm temperate zones grow from lateral buds of the rhizome, which run underground. These are called a non-clump forming monopodial types because the culms on the ground are distributed sporadically.

- 2) Bamboo buds attached at the base of culms, which grow in the tropics, elongate on the ground at the distal end. The distribution of these culms becomes gregarious which is also designated as clump forming or sympodial type.

Concerning latitude, bamboo grows horizontally in latitudes zones between 40° north and south. Non-clump forming types grow in low mountain zones ranging between 30°-38° in northern latitudes. The clump forming bamboos grow in latitude zones between 25° north and south.

Intensive large areas of natural bamboo forest occur in tropical Asian countries including India, Burma, Thailand, and southern areas of the People's Republic of China. These range from 15°- 25° in latitude. No natural bamboo forest exist in Europe and few bamboo forests occur in Africa or Central America within these latitudes.

Altitude and Distribution

Bamboo can grow at sea level or as high as 5,000 meters in the Andes. The temperature of the altitude is an important factor for their distribution. The transition from clump forming to non-clump forming is more regular in the horizontal distribution than those influenced by altitude. The distribution of bamboo as well as their rate of growth is influenced by temperature. A higher temperature will promote growth, and a lower one will inhibit growth. The altitudinal effect can be regarded as a temperature influence.

Rainfall

The mean annual rainfall in most growing areas of bamboo is more than 1,000 mm. For active growth of non-clump bamboo, a minimum rainfall of 50–100 mm is required during the month before and during sprouting period of the rhizome. In the tropics, an average rainfall of more than 200 mm is needed monthly for at least 3 months. In the existing bamboo forests, growth rates and temperatures are highly correlated. The lowest temperature in the coldest month of the northern limit for bamboo growth in Japan is -7°C .

Soil composition also plays a role in bamboo distribution. Most bamboo forest areas are flat gentle slopes on river alluvial soil. Sandy or clay loam with good drainage is also suitable for bamboo growth. Some bamboos like *Bambusa polymorpha* in Burma and *Bambusa arundinaceae* are distributed widely in the tropics. They can grow in boggy soil or fertile wet soil with good drainage under tree crowns. *Bambusa tulda*, *Oxytenanthera albociliata*, *Dendrocalamus strictus*, *Bambusa blumeana*, and *Bambusa multiplex* are species, which have strong drought resistance and prefer growth in sandy areas. They survive during the dry season by reducing vaporization through defoliation, as do those species which grow on open land. *The Cephalostachyum pergracile* grow in intermediate conditions between species already mentioned. Bamboo can grow in soils of pH 3.5, but the optimal soil acidity is between the range of pH 5.0 and 6.5. Bamboos show low tolerance to saline soil.

The ecological requirement vary widely among the numerous bamboo species (Liese, W. 1985). Many species are indigenous to the monsoon areas of tropical Asia, but the natural distribution has greatly been changed by human intervention. The latitudinal range is between 40° north and south. Mostly they are concentrated in the tropical and sub-tropical climates with annual mean temperatures between 20° - 30°C . The higher temperatures normally encourage growth. Some species can tolerate temperatures between 40° and 50°C , like *Oxytenanthera abyssinica* in central Africa. Others species such as the *Phyllostachys mitis* in China can with stand snow and the *Arundinaria annabilis* can tolerate temperatures as low as -8°C .

Bamboo mainly grows at altitudes between 100 and 800 meters. Certain species can grow at sea level or in mountains as high as 3,000 meters such as *Arundinaria racemosa* and *Thammocalamus aristata*. Other examples would be the *Chusque andina* in the Himalayas and *Chusquea aristata* in Chile and Ecuador. Young bamboo is sensitive to wind but older plants have the advantage of providing shelter for each other.

Rainfall in both a tropical climate and sub-tropical climates are suitable. Bamboo species also grow in semi deciduous savanna forests which have a pronounced dry season. In a dense evergreen forest with an equatorial climate, climbing species occur especially on alluvial sites. On the average, a minimum annual rainfall of between 1,000–2,000 mm is needed, with at least 300 mm per month during the growing season. For the drought resistant *Dendrocalamus strictus* in India, the minimum rainfall needed is between 750 – 1,000 mm per annum. In the Sudano Sahel zone in Africa, *Oxytenanthera abyssinica* can exist with only 750 mm of rainfall.

Bamboo can grow on a wide variety of soil types. They prefer however well drained sandy loam to loamy clayed soils derived from river alluvial or from underlying rocks. The optimum soil acidity lies between pH 5 and 6.5. No species seem to adapt well to salty soils.

Ecology

Bamboo often occurs in the medium to lower stories of moist tropical forests. They grow in competition with other shade loving species, but rapidly invade any area where the canopy has been opened. In the moist semi-deciduous forests, bamboo like *Melocanna bambusoides* and *Bambusa polymorpha* spread over large areas and may even suppress tree growth after harvesting or burning.

The dry deciduous forest provide an optimum habitat for most bamboos. Examples of these are the *Tectona grandis* with *Dendrocalamus strictus* and *Dendrocalamus membranaceus* in India, and the *Pinus mekusii* with *Dendrocalamus membranaceus* in Central Java. Pure bamboo stands are formed by *Phyllostachys pubescens* in China, but also on the drier sites by *Oxytenanthera abyssinica* in Ethiopia and Mali. In the high mountains of Africa at altitudes of 2,500 to 3,000 meters, stands of *Arundinaria alpina* can be found with hardly any competition from other trees. Some bamboos exhibit retardation in growth because of allopathic substances in leaves from other species such as the *Sinocalamus latiflorus* or *Bambusa oldhamii*.

Vermoh, J.C. and K.N. Bahadu 1980, describe five major bioclimatic regions for bamboo in India.

1) Alpine region

In this region, there are a limited number of bamboo species, such as the *Arundinaria microphylla*, *A. racemosa*, *Chimonobambu pojaunsarensis*, *Semiarundinaria pontlingii*, and *Thamnocalamus aristatus*.

2) Temperate forest region

This region is located at an altitude of between 1,500 to 3,050 meters, with a minimum annual rainfall of 2,000 mm and a dense mist

prevailing during monsoons. The temperature range in this region is from freezing up to 25°C. Principal bamboos growing wild in the northern temperate region are *Arundinaria*, *Chimonobambusa*, *Phyllostachys*, *Semiarundinaria*, and *Sinobambusa* and *Thamnocalamus*.

In the southern temperate region, the main bamboo found here are species of the genera *Bambusa*, *Chimonobambusa*, *Dendrocalamus*, *Indocalamus*, and *Oxythenanthera*.

3) Sub-tropical region

This region lies between the altitudes of 1,000 to 2,000 meters. The main sub-tropical bambusoid genera would be *Arundinaria*, *Bambusa*, *Cephalostachyum*, *Chimonobambusa*, *Dendrocalamus*, *Dinochlor*, *Gigantochloa*, *Indocalamus*, *Neohourea*, *Ochlandra*, *Pseudostachyum*, *Sinobambusa*, and *Thamnocalamus*.

4) Tropical moist region

In this region *Bambusa*, *alra* grows on tidal swamp forests. The other bamboo genera found in the tropical moist region are *Bambusa*, *Cephalostachyum*, *Dendrocalamus*, *Melocanna*, *Ochlandra*, *Oxythenanthera*, *Schizostachyum* and *Teinostachyum*.

5) Dry tropical region

Bambusa arundinaceae and *Dendrocalamus strictus* are the two main bamboo species of this region, both of which have a wide distribution. Also, *Cephalostachyum pergracile* is common and some other genus and species are present.

Dransfield, S. and E.A Widjaja (1995) stated that in southeast Asia bamboos can be found in a wide range of habitats; from the lowlands to mountain forests in dry or humid tropics. They may also be found in wastelands, swamps, and in dry or regularly flooded riverbanks. There are no records of bamboo growing in mangrove forests. However, very little has been published on the ecology of bamboo.

Southeast Asia has various climates ranging from per-humid to semi-arid tropics and subtropics. Some bamboo species are common in drier tropics and subtropics where as others are found in the humid tropics only. *Dendrocalamus strictus*, for example is found in abundance in regions where the dry season is pronounced: the Indian subcontinent, southern China, southern Yunan and Vietnam. It may be found that it can grow in mixed forests or in a pure bamboo forest. *Thyrsostachys siamensis*, for instance is a native in the drier areas covering central Thailand, Vietnam and Burma. It is often found in pure bamboo forests, although both species usually grow in dry areas. They also perform well when planted in the humid tropics. Most

species of *Schizostachyum* are encountered in the humid tropics on lowland and hill dipterocarp forest. Most species of *Racemobambos* and *Nastus* usually grow in the mundane forests of the humid tropics. Bamboo species in the humid tropics rarely form pure bamboo forests, but they may become dominant in over logged forests. The *Dinochloa* species for example, is usually found in lowland and hill dipterocarp forests. However, after the forest has been disturbed by logging, they become as abundant as weeds causing much concern that they may prevent the regeneration of commercial timbers. On the Malaysian peninsular species such as the *Dendrocalamus pendulus*, *Gigantochloa scortechinii* and *Schizostachyum grande* commonly dominate the landscape in areas where forests has been logged or cut (Riddley Holttum). This phenomenon has been observed in Indonesia and southern Thailand as well.

Bamboo is remarkably adaptable to any kind of soil. For example *Bambusa vulgaris*, a pan-tropical species, grows on a wide range of soils. However, bamboos normally perform best on well-drained rich soils rather than on poorer soils which produce culms that are shorter and have a much smaller diameter. *Dendrocalamus elegans* is found however only on limestone hills in the northern Malaysian peninsular and southern Thailand (Riddley Holttum). Other species which are both from Sabah such as the *Dinochloa obclavata* S. Dransf and *Racemobamboo rigidifolia*, are confined to forests on ultramatic rock (Holttum).

Ecology of selected species.

Bambusa blumeana in its natural habitat can grow at altitudes of up to 300 meters on heavy soils with marginal space. It grows well along riverbanks, hill slopes and freshwater creeks and is tolerant of flooding. Its Optimum pH level is 5-6.5; it cannot tolerate saline soils.

Bambusa multiplex is only known from cultivation. It may have originated from Indo-China, but it is now widely cultivated throughout the tropics and subtropics including Southeast Asia. In Southeast Asia, it is cultivated at altitudes of up to 1500 meters on various soil types. It thrives well on sandy loams and can withstand several degrees of frost.

Dendrocalamus asper - The origin of this species is unknown, but it is thought to be somewhere in Southeast Asia. It grows throughout tropical Asia, and in many parts of Malaysia. It has also been introduced in other tropical countries such as Madagascar, Sri Lanka and in Australia. In tropical Asia *Dendrocalamus asper* is planted or naturalized from low altitudes of 1500 meters. It thrives best however at altitudes of 400-500 meters above sea level with areas that have an average annual rainfall of about 2400 mm. The *D. asper* will grow in any type of soil but it prefers

heavy soil with good drainage. In Thailand, according to local farmers, *D. asper* grows well on sandy acidic soils.

Dendrocalamus strictus is a widespread species and native to India, Nepal, Bangladesh, Burma and Thailand. It is most common in India, especially between the Ganges and the Ramganga rivers. Outside its native area, it is sometimes cultivated in botanical or experimental gardens such as in Sri Lanka, Indo China, Indonesia, Malaysia, Philippines, Puerto Rico, Cuba, and the United States. This species occurs naturally in tropical and subtropical regions of Southern Asia. The optimum annual mean temperature is between 20 – 30°C, but it can withstand extremes as low as -5°C and as high as 45°C. Mature plants are frost hardy but young plants are not. Optimum annual rainfall is between 1000 – 3000 mm with 300 mm needed per month during the growing season. *D. strictus* is however a very drought resistant tropical bamboo which can still grow rather well with only 750–1000 mm of rainfall per year. It prefers low relative humidity and is found from sea level up to altitudes of 1200 meters on hilly ground with cooler and drier conditions. It grows on all soils with good drainage preferring sandy loams on stony subsoil with pH levels of 5.5 – 7.5. *D. strictus* thrives in relative open types of mixed deciduous forests.

Gigantochloa albociliata is a native bamboo of Burma and Thailand where it is widely distributed in dry forest hills in central and northern parts of the countries. It has also been introduced to India and Indo China. The natural habitat of this species is dry tropical mixed forests at low to medium altitudes. It also requires an average annual rainfall of between 800–1300 mm, and a mean temperature of 28°C. The ideal soil condition is well drained with poor to medium fertility. In Burma it is common at low altitudes in mixed forests but it normally does not enter savannas.

Bamboo Management

According to Fu Maoyi and R.L. Banik (1995), the productivity of bamboo is relatively high. Theoretically, the dry weight yield per hectare could total as much as 32–38 tones of biomass per annum. This estimation is base on the efficient use of solar energy by bamboo. In current practices of management, the productivity is still far below this estimation. It is obvious that there is great room for improvement in bamboo management and maximizing productivity. The studies of bamboo management categorize production management practices into 5 end-use categories: timber stand, shoot stand, pulp stand, ornamental stand and water/soil conservation stand. The species and the management systems involved will vary depending upon the end-use.

According to Fu Maoyi and R.L. Banik (1995) the management for culm timber of bamboo has been described by the following methods.

For large sized monopodial species such as the *Phyllostachys pubescens*, the end product is a 7 to 8 year old culm. The recommended age grouping of the culms in the stands after harvesting is: 1 to 2 years old, 3 to 4 years old, 5 to 6 years old, and over 7 years old in the ratio 3:3:3:1. The culm density in the stands for high, medium and low production is about 3000, 2225 and 1500 culms per hectare. The corresponding relative annual yield per hectare of culm timber in fresh weight being 7-10 tones, 3.5-7 tones and below 3.5 tones respectively. Harvesting is done in the winter season of the "on year" culms which will be felled at the age of 4 years for mid-sized monopodial species such as *P. viridis*, *P. glauca* and *P. bambusasoides*. The stand after felling is preferably kept at the density of 10,000 to 15,000 culms per hectare, with an age structure of 3:3:3:1 for 1 to 4 year old culms.

The sympodial species such as *Dendrocalamus strictus*, *Bambusa bambos* and *B. textilis* produce the end product of 3-4 years old culms. Culms are harvested at the rate of 30% in winter or dry season. The recommended stand density is 700 clumps per hectare, with each clump containing 10 to 20 culms at 1 to 3 years of age. The annual yield of culm timber generally ranges from 3 to 10 tones, sometime reaching 15 to 33 tones, per hectare.

Some species can be grown for both culm timber and edible shoots, thus leading to the timber stand or multipurpose stand. The management for a multipurpose stand differs from those single purpose stands. In the case of *Phyllostachys pubescens*, multipurpose stands are usually kept at medium density of 2225 culms per hectare. They are managed more intensively for ensuring that the yield of edible shoots contributes over 10% of the total output of intended end products. The management for multipurpose sympodial species, as in the case of hybrid species, ensures that only nine culms from ages 1 to 3 years are retained. A well-managed stand can yield 3 tones of edible shoots and 9 tones of culm timber per hectare annually.

The management of bamboo stands for shoots is outlined by the same authors in the following manner. A shoot stand consumes more mineral nutrients from the soil than the timber stand and hence, the fertilizer application is vitally important.

A reasonable stand density for shoot production for the large size monopodial species would be 2,225 culms per hectare. It would have an age ranging from 1-6 years old, and for one medium sized, the density would be between 9,000 to 12,000 culms / hectare at an age between 1 to 3 years old.

For sympodial species, it can be planted between 4 x 5 m or 5 x 5 m of spacing, and each clump can have 6 to 8 culms from 1 to 2 years of age. A few 3 years old culms may be retained in the case of some species, such as

Dendrocalamus latiflorus. This management can yield from 10 to 20 tones of edible shoots per hectare annually for monopodial species and 10 to 30 tones for sympodial ones.

The management of a pulp stand

Since the maximum fiber content in a culm is already achieved by the time the culm is one year old, and since lignin and silicon accumulation increase with age, the culms for pulping should be harvested when they are young. This would be 5 years old for large size monopodial bamboo and 3 years for sympodial ones. A high stand density of 3,000 to 4,500 culms per hectare for large monopodial bamboos, and clumps spaced at 3–5 meters apart for sympodial ones is recommended. It is necessary to remove old stumps and rhizomes periodically. In the case of monopodial bamboo, stump and rhizomes above 8 years old must be removed every 2 to 3 years, while 4 years old stumps and rhizomes of sympodial bamboo need to be removed every 1 or 2 years. Cutting of the top parts should be avoided since this will make the culm very fragile and is detrimental for pulping.

Tending of the bamboo stand.

Damage from people and grazing animals to shoots during the shooting stage and mother culms must be avoided. Weak shoots need to be cut off in the early and last stages of shooting in order to ensure enough nutrients get to the healthy shoots. Shoots are cut below the soil level. After cutting the shoots, it is necessary to leave the part remaining exposed to the sun for three to five days if it is sunny, or for five to seven days if the sky is cloudy. The exposed part should then covered with soil, in order to prevent excess sap flow and bacterial infection.

The soil must be loosened to a dept of 10-15 cm near the clump and 30 cm away from the clump. Shoot quality and yield will be improved if the loosened soil can be covered with more soil to a height of 15-30 cm. The soil at the base of the culm may be opened, just before the shooting stage, and the shoot buds allowed to receive sunlight for about 10 days. This will ensure adequate soil temperature for better shoot growth and also facilitate fertilizer application. If there is no rainfall for 15 days during the growth season, watering will be necessary, especially for shoot stands.

Bamboo Agro forestry

As mentioned by Salleh Mohd. Nw (1995), there is one school of thought which says that biodiversity is highest in the tropical forests which are in an intermediate state of disturbance compared to forests in a secondary or climax state. This means that a bio-production system in the tropics will be more efficient by a multi species planting system with proper management with a certain degree of disturbance. The agro forestry system

is an ideal system to fulfill such a requirement. Therefore a bamboo agro forestry system for the bamboo plantation is one of the attempts to improve plant production under sustainable management. Fu Maoyi and R.L. Banik (1995) have also suggested dividing bamboo agro forestry models into three groups: the Bamboo Agriculture (forestry) Model, the Bamboo Fishery Model and a Special Purpose Model for bamboo agro forestry. The Bamboo Agriculture and or Forestry Model can also be subdivided to various sub groups such as (1) bamboo + tea plant (2) bamboo + conifer and broadleaf timber trees (3) bamboo + agricultural crops.

1) Bamboo + tea plants

This bamboo system could be beneficial to the northern mountainous regions of Thailand which grow tea as a cash crop. In this model sympodial species grown for either culm timber or edible shoots can be employed, but in the case of monopodial bamboo only timber producing species may be planted. Since the rhizome of monopodial species can grow all around the stand and adversely affect the other crops, it is essential that the culm density and distribution be regulated through selective felling. Bamboo is often planted at a spacing of 6 x 4 meters and tea plants at 2 x 0.5 meters. Intercropping of annual crops, such as soybean and vegetables, can be done for one to three years after planting, but intercropping should leave enough space for the unhindered growth of bamboo and tea plants in order to ensure an adequate nutritional supply to each of them.

2) Bamboo + conifer and/or broadleaf trees

This model can be established either by converting a semi-naturally mixed stand or planting new ones. The ratio of bamboo to trees is important, and in semi-naturally mixed stands this may be a 7:3 to 8:2 for bamboo and broadleaf trees, or 6:1:3 to 7:1:2 for bamboo, conifer and broadleaf trees. In the planted bamboo and broadleaf tree stand, the ratio can be 6:4 and annual crops can be intercropped within three years after planting. The planting time for bamboo and trees should be determined based on the growing rate of the tree species involved.

3) Bamboo + agricultural crops

Bamboo is planted at a spacing of 4 x 4 meters for large - sized species or 3x2 meters for small ones. Intercropping with crops employed in bamboo plus trees model should allow a bamboo plant to have 1 m² in area to ensure its nutritional supply. This should be done for a maximum of four years after planting the bamboo. All three models mentioned above involve agricultural crops or trees. In planting trees or bamboo, full soil preparation may be employed on plain land. On sloped land, strip preparation by leaving alternate unprepared strips to prevent water and soil erosion is

recommended. It is necessary to place adequate fertilizer in the planting pits before planting is done.

4) Bamboo + crop + fish pond

This model is usually made on plain lower and wetter lands where fishponds are built. One to three rows of shoot producing sympodial bamboo may be planted on the banks of the pond, and crops such as soybean and rye intercropped between bamboo clumps to form a complete food chain. Crops can be harvested as food for fish feed. Bottom mud from the ponds may be dug out in winter and used as fertilizer for bamboo clumps. The clumps need to be replanted between 8 – 10 years of age.

5) Bamboo + edible fungi

There are large numbers of edible fungi regarded as natural food rich in vegetable proteins. Among these are the *Dictyophora tomentosa*, *Pleurotus ostreatus* and *Auricularia auricula judoe*. These can be cultured into bamboo stands which satisfy the fungi's need for humidity, shade while providing a fertile bed. A bed of decayed bamboo litter and cotton shells, placed evenly on the ground up to a height of 10 cm, is used as the substrate. Inoculation of *Dictyophora sp* is done in September for varieties that grow in normal temperatures and in May - June for those that require a higher temperature. Harvest is after 4 to 8 months, depending on the fungus' variety. *P. ostreatus* is inoculated in March and harvested two months later. *An auricula - judoe* needs to be cultured in bags filled with the growth and hung on the bamboo.

6) Bamboo + medicinal plants

This model is suitable for hilly areas in the sub-tropical monsoon climate zones which have a mild climate and adequate rainfall. The medicinal plant should be chosen to suit the topography of the site. Some plants such as *Cayratia japonica*, *Premna microphylla* and *Tetrapanaxpopyrifera* can be grown without much tending since they have good adaptability. Some other species such as the *Paris polyphylla* and *Currma domestica* need to be planted in valleys at altitudes of 800 – 900 meters.

A few such as the *Allizia kalkora* and *Mentha haplocalyx* need slopes which get adequate sunshine; while others like *Mahenia japonica* and *Holboellia caricea* for example need shaded sites. In the management of bamboo (Lin quingyi 1995), it is recommended that for symposium bamboo like *Dendrocalamopsis oldhamii*, suitable sites would be loose and fertile sandy loam. The planting pits size is 50 x 50 x 40 cm with spacing of 5 x 5 meters and a density of 600 clumps per hectare (Lin Quingyi 1995). He also recommended the method of raking the top soil of bamboo clumps for the following reasons: to expose bamboo buds to higher

temperatures and sunlight, to loosen the soil, to stimulate shoot sprouting, to prevent bamboo roots from getting crossed and entangled, for ensuring proper growth of bamboo branches and leaves, and increasing nutrient supply for shoot production. This operation should be done every year in the middle of February, and six weeks after fertilizer is applied. About 10–20 kg of composted organic manure (15 - 25 kg of human waste or 10-15 kg of barnyard manure) or 150–200 kg of pond silt may be applied per clump. This should be done around June. The other fertilizing, called top dressing is carried out between June and August, when bamboo shooting is most active. Application is by ditches dug around the clumps. Each clump may receive 10-15 kg of human waste or 0.5 kg of chemical fertilizers such as urea or ammonium sulfate 10-12 kg of fermented barnyard manure. After application the ditches must be covered with soil. Strong fertilizer should not be allowed to come in direct contact with young shoots lest the shoots wither and die. Watering should be done at this stage to ensure proper nutrient distribution. Covering the shoots with wet soil will improve the shoots quality. He also (Lin quingyi 1995) mentioned the traditional practice by spraying a low concentration of human urine or urea in the place where the bamboo shoot in cut, and covering it up firmly with earth would facilitate regeneration and sprouting.

Normally the annual shoot yield of *Dendrocalomopsis oldhamii* is 5–6 tones/hectare but intensive management gives a much higher yield. In order to guarantee vigorous growth of the bamboo stand, cut taller shoots and retain shorter ones, while retaining at least 4 – 6 culms / clump annually.

In harvesting management on the natural stands of *Gigantochloa scortechini*, it was recommended that 40% felling could be applied when the intended end product is the culm, and 80 % felling intensity for shoot production (Azmy Mohamed , Hg 1995). Only mature stems of 3 years or older were selected for felling. The culms that were felled were all well spaced and from within the clump and not from the clump periphery. The culms were cut at a height of about 15 cm above the ground using a small chain saw. In his experiment the application of fertilizer could improve production for shoot sprouting. For example, 2 kg of NPK 15 : 15 : 15 applied to every clump resulted in a 30 % increase in the sprouting of the shoot. Intensive management by mulching for shoot production might be essential in order to improve and increase the productivity of shoots. The study with *Phyllostachys praecox* by Qungen , Cao and ct al. (1995) concluded that mulching increased the soil temperature which made the shoots emerge earlier and prolonged the shooting period thus raising the yield and value of the shoots. The results of comprehensive evaluation showed that rice chaff was the best among the eight mulches tested.

The maturation of culms is important in order for the decision to be made on whether to fell bamboo for culm harvesting. According to Liese W. and G Weiner 1995, they reported that a bamboo culm matures in two to three years and has reached its maximum strength.

Silviculture and management.

Abd. Latif 1996 reported that age and culm height of two bamboo species the *bambusa vulgaris* and the *Gigantochloa scortechinii*, showed a greater impact from chemical compositions (particularly carbohydrate content) than site and harvesting month. The harvesting and processing of bamboo should be accomplished at a minimum age of two years with ideal usage made of the basal and middle portions.

In the management of six-year-old *Thyrsostachys siamensis* at the Gamble plantation, with 4 x 4 meter spacing by Atiruttanapuny, Wiroach 1993 by different intensity of felling, it was shown that 50% felling produced the greatest number of shoot production. The most intense felling at 75% did not result in the mortality of the clump. It was concluded that one and two-year-old culms are the most active for

shoot and culm production. Shoot harvesting during the period up to the second week can give rise to the most new shoot production, but shoot development to become culms is lowest at only 17%. However, no shoot harvesting will produce the lowest number of new shoots with the highest survival per clump.

The result from the spacing experiment at 1x1, 2x2, 3x3 meters with *Dendrocalamus strictus* by V.C Patil and S.V Patil 1988, has shown that the number of culms per clump increased in corresponding enlargement in both height and diameter as the clump density increased. This trend was observed during the periods of 207, 388, and 572 days after planting. The closer spacing of clumps increased clump size, productivity and also were better establishment.

The results from thinning experiments in the natural stand of *Schizostachyum lumampoa* by Ferlizarlo, D. Virtucio and Carlos C. Tomboe 1991, indicated that selective thinning was the optimum prescription for managing bamboo natural stands. They came to this conclusion after moderately cutting culms at 3 years of age and above the felling cycle of 2 years. The studies of A.C., Lakshmana 1991 on thinning revealed that soil working, and ½ kgs. of fertilizer application along with M-shaped thinning, gave better production with an average of 15.6 new culms per clump. The average green weight of bamboo is 17.1 kg. This led to an increase in annual yield from 5 to 8 tones per hectare. The increase is nearly 300 %.

Normah and Bahadur (1980) reported that the earliest experiments on how different felling methods could affect clump development was conducted on *Dendrocalamus strictus* in India in 1910. The experiment was done by cutting the culms above the first nodes, above the third node and above the fifth node working on a rotation of 1, 2, 3 and 4 years. The height of cutting had no effect on the health and production of new culms. The longer the rotation, the thicker and fewer culms were produced. However, the felling of all the clumps caused the death of 2-3 year old clumps. They also reported other experiments conducted between 1934 and 1947 in India in order to determine the best felling cycle and treatment for *D. strictus*. The experiments were unable to determine the best felling cycle and treatment for *D. strictus*, but found that a felling cycle of 2 years was disadvantageous on all culms except the newly produced culms. This resulted in a high mortality as well as fewer and poorer quality culms.

Sharma (1980) reported that bamboo forests in the Asia Pacific region are generally managed by selective cutting. In Burma the bamboo areas are usually divided into sections, and felling is rotated so that a section is cut and is left for 2, 3, or 4 years depending on the felling cycle. He also further reported that in Japan felling is also selective and carried out in autumn with cutting cycles varying from 3 to 5 years for *P. reticulato* and 5 to 10 years for *P. edulis*. Yudodibroto (1985) reported that in Indonesia, bamboo stands are harvested selectively. It recommends cutting of 3-4 years old culms, and 5 culms per clump during the first year and 10 to 20 culms per clump as the age increases. Some people cut their bamboo every 3 years rather than annually.

Yong Chi and Ying Tu Huang (1981) stated that in the management of bamboo in Taiwan the culm reaches maturity at the age of 3 or 4 years and this is the most suitable age for harvesting and should be cut for use. If the culms are not cut when they are ripe they will decay. Therefore, in order to maintain sustainable yield management the annual cut must be equal to the number of new culms produced. A small bamboo forest can be managed for sustainable yield if its age distribution is adequate. Their research purposed 2 assumptions for management: (1) the number of new culms sent up is equal to the number of culms of the youngest age group, and (2) the new culms just sent out are uniformly distributed in the bamboo forest. They further recommended that it is not necessary to harvest the same amount of culms each year as long as no damage is done to the soil and water conservation. More can be harvested when the market is brisk and less when the market is dull. This will accommodate the fluctuation in demand and bring more revenue to the bamboo grower.

Wasan Kaitpraneet and et al (1978) studied the management system for *Thyrsostachys siamensis* natural stands. Their study showed that the

selection system is most suitable for the management of this bamboo. According to this system the culms at 3 years of age and older will be cut off and culms of only 1 and 2 years of age will be retained using a 3 year felling cycle. Using this system of management within an area of 15 square kilometers, will produce sufficient raw material for annual consumption of approximately 5,200,000 culms. This area will be divided into 3 felling sectors with an area of 5 square kilometers on a 3-year rotation. This will be a sustainable management to supply annual bamboo raw material sufficient for local pulp and paper plant consumption at Kanchanaburi.

According to Wasan, K, (1978) the proper thinning should be done according to age. This is because only one year is need for culm development since sprouting to maturation and the one and two-year-old culms are the strongest with the most vigor. They can produce most of the assimilation to the rhizome reserve for further culm production. Therefore the current years culm production will be mostly dependant upon the number and vigor of the one and two year old culms that are present in the clump. The clump productivity will be less dependant upon the clump density. The fertilizer application at the sprouting period will not increase the culm dimension but will mostly affect the number of culms produced and their dimensions in later periods. The most effective selection method for sustainable management must retain one and two year culms and harvest only culms of 3 years of age and older. This will ensure that all the culms in the clump will be under the most vigorous conditions. Thinning without considering age discrimination will reduce the vigor and eventually the productivity of the clump with the same results as not thinning old culms. Wisut, S. (1982) followed the work of Wasan, K. (1972) in the investigation of productivity of the second felling cycle of *Thyrsostachys siamensis* natural stands. He concluded that the productivity remained the same when compared with the first rotation. This indicated that selection cutting or thinning using a 3-year age class as criteria is very successful for sustainable management in the bamboo stands of *Thyrsostachys siamensis*. This method may be applicable to other bamboo species as well.

Prasad, Ram (1988) reported that the management of natural bamboo in Madhya Pradesh, India is managed on scientific and systematic lines. This is to ensure for an adequate supply of raw material for the paper mills and to meet the requirements of the rural consumption. *Dendrocalamus strictus* is the only species exploited on a commercial basis. The felling cycle has been fixed at four years throughout the state. The bamboo areas can be differentiated by 4 types of bamboo based solely on density and height. The marking of bamboo to be retained in each clump is done with black paint at breast height. The number of culms for retention in a clump is written on a prominent reserved culm of the clumps. Records of

both the culms to be felled and those to be retained are maintained. The marking of the culms is based on the following rules.

1. One and two year old culms will not be cut under any circumstances.
2. The rhizome will not be dug out and exposed.
3. The height at which the culm should be cut is no less than 15 cm or more than 4.5 cm. By no means should the culm be cut below the first prominent node.
4. All cut debris will be kept at least one meter away from the clump.
5. Felling of bamboo will not be done in the period between the 1st of July and the 15th of October.
6. Clumps showing sporadic flowering will invariably be cut provided they have shed their seeds.
7. In the event of gregarious flowering all flowered clumps, irrespective of their location in the coupe, under working or elsewhere will be clear felled after they have shed their seeds. Disposal of such bamboo to be is expeditiously arranged so that they do not deteriorated and also cause a fire hazard.
8. Felling of bamboo shall be completed by the end of March.
9. Bamboo forests should be strictly protected from fires. In no circumstances should a fire threaten the forests during cultivation or harvesting.
10. Grazing will not be allowed during the rains or in the worked up bamboo forests of the first year.
11. Each clump shall be individually distinguishable with its periphery easily differentiated from adjacent clumps, irrespective of their distance apart.
12. The minimum number of culms to be retained in a clump of various quality classes is as follows:

Quality I	20	culms
II	15	culms
III	10	culms
13. The retained culms should be well spaced and preferably at the periphery. These are retained in order of preference as shown below :
 - a) one year old culms
 - b) two year old culms
 - c) young green bamboos
 - d) older live bamboos
 - e) others as per availability

14 Commercial felling will only be done on Type I areas which have well stocked and well grown bamboos. In other type areas only cultural operations consisting of felling dead, dying, over mature, burned, broken or damage bamboo will be done. Congested clumps are clear felled by forming triangular segments and the clump is clear felled over three seasons.

15. Type III areas are supplemented by establishing bamboo plantations. The above mentioned bamboo management rules came into force in the year 1974. The result of this work in the bamboo forests has been a continuous increase in yield, but it is still not sufficient for fulfilling the requirements of the paper mills and other users. Efforts have been made to increase the yields by clear felling congested clumps, soil management in flower areas, and protection from grazing for a period of 5 years.

Chaturvedi (1988) proposed a prescription for bamboo management. The goal of these guidelines were for obtaining high productivity with the desired quality of culms.

1. All bamboo culms above three years of age should be harvested.
2. Harvesting preferably should be done each year. In natural forest where harvesting every year is impossible, it should be done in alternate years. In the intervening years where work is done after a gap, all the coppice shoots should be removed and intensive cultivative operations carried out.
3. Where congestion has already set in, the congested culms must be removed even if it leaves only the current year's culms.
4. Where the young culms are twisted from the top, they should be cut so that the new culms grow freely.
5. No felling operation should be carried out between April and October.
6. Bamboo areas should be strictly protected from grazing.
7. Mounding or heaping earth around the bamboo culms should be carried out each year before the rainy season.
8. Trees providing light shade to bamboo should not be removed, as bamboo grows better under the shade of a tree such as neem, siris, amala or other light crowned species.
9. In no case should bamboo clumps be clear felled. The clear felled clumps generally degenerate into a bushy form.

According to Chaturvedi (1988), bamboo of clump types reach their full height in 60 to 120 days. The rhizome generally grow at an upward inclined angle. The angle of the incline depend on the species and the conditions of the soil. During this period of growth, any exposure to

sunlight usually stops rhizome development. Consequently, the bamboo clumps that are covered with earth or humus produce more culms, whereas in areas where soil erosion takes place the production of new culms is reduced. Rhizome development is not peripheral as generally believed. Rhizomes may develop in any direction and the culms may appear anywhere in the clump, provided overhead light is available for the emergence of the culm. It is only in the congested clumps that new culms appear to grow at the periphery. In most bamboo forests, the cutting cycle ranges from three to four years. It is also prescribed that the cope which is not worked in the year, when it is prescribed, will only be worked when it is due in the next cycle. Many working plans also prescribe retention of a minimum number of old culms varying from 6 to 10 for providing support to the new culms. Development of new culms, however, takes place near the previous year's culms. Consequently, culms older than three years do not provide any support to the new culms. Suwannapinunt (1988) has shown from the harvesting trial by the horseshoe method in *Gigantochola hasskarliana* natural stands, that treatment with 100% felling of all culms in the clump older than three years, has the best culm production. But clear felling produces no new culms and eventually that clump will die out. It is concluded that sustainable management could be accomplished by harvesting culms 3 years and older. This practice also resulted in better quality culms as well. This harvesting could be done every year. Kigomo (1988) reported on the prescription for the management of bamboo in Africa. He stated that the production of new culms is influenced by the amount of rainfall occurring during the previous one or two years. Therefore abnormal drought may result in only sparse production. Clear cutting depresses the rate of recovery for bamboo after cutting. It took eight or nine years to obtain full sized culms after clear cutting. When 10% of old culms were left standing evenly distributed, full size new culms may appear in the seventh or eighth growing season following cutting. If 50% of the number of culms are left standing, evenly distributed, the recovery period may be as short as three or four years. The cutting cycle is governed by rainfall, cutting intensity and recovery period. For *Arundinaria albina* Kigomo (1988) reported that the cutting cycle is 14 years and may be as long as 21 years on poor sites where recovery to the normal full size is delayed. Fires also lengthen the recovery period of regenerating shoots of *A. alpina*. Regenerating shoots are small, more per hectare and are also more variable in size. This will mean a longer cutting cycle for a crop that has gone through a fire.

Kumar (1988) described bamboos and bamboo reed management in Kerale that the management, in general, involves a selective felling system with a felling cycle of four years. The rules for felling are as follows:

1. Culms less than two years old should not be cut and removed.

2. All the new culms and 25% of the old culms should be retained.
3. No clump should be clear felled except after flowering and when seeding has been completed.
4. Culms should be cut as low as possible leaving one internode above ground.
5. Cutting should begin from the side opposite to where new sprouts are emerging.

This management system has been performed in Kerala for a long time. The clear felling practice, as a result of pulp and paper industries, has made the system suffered badly. This is because this will reduce productivity which leads to unsustainable production as a sacrifice to maximized short-term production.

Dah – Doronon , Jean Z (2000) reported that in West Africa, the management of bamboo should consider the felling of 3, 4, or 5 years and up in the species. This practice will be used in conjunction with retention of 2n, 3n, or 8 culms per clump with a minimum of 6 old and new culms. The felling cycles are minimum ages at which a culm is harvested, the age of full maturity, and the life of the culm depending on the species and the local conditions. The people in Benin West Africa use fire as an effective management technology for bamboo, contrary to the sound management rules generally accepted. To them when a stump of bamboo is burnt after harvesting, the very strong and straight culms coppice in such a way that the production is improved in quantity and value.

Thaiutsa (2000) tested bamboo plantations in the north of Thailand. He suggested that plantations in monocultures should use 5x5 meter spacing between clumps and retention of no more than 5 culms per clump in order to manage for shoot production. For agro forestry systems, the normal spacing of *Dendrocalamus latiflorus* is 8x8 meters intercropped with ginger, taro, upland size, and *Amorphophallus companulatus*. The tree species used in agro forestry with *Dendrocalamus lotiflorus* is *Paulownia taiwaniana* which grows successfully at the high elevations. Thaiutsa (2000) also reported that shoot yields of *Dendrocalamus lotiflorus* are dependant upon age after out planting, monthly rainfall, soil working and irrigation in the management. The irrigation prior to the rainy season can stimulate early shoot production. Shoot yields per clump are affected by the number of culms per clump rather than clump spacing. He recommended that 5x5 meter spacing would produce a higher shoot yield than wider spacing. The average shoot yield of 45.08 kg per clump is obtained in his tested locations. The recommendation is that each farmer should have one hectare of *Dendrocalamus lotiflorus* plantation if the main source of income comes from bamboo shoots.

Cusack, V. (2000) describes certain conditions in the establishment of commercial *Dendrocalamus asper* plantations for shoot production in Australia. He recommended that planting density should be about 2000 plants per hectare, which are planted on a 7x7 or 8x6 meter grids. He produced no evidence that fertilizer requirements, growing or harvesting techniques would need to vary greatly from those used in Thailand. He stated that fertilizing heavily during harvest produced larger, darker colored shoots lacking a crisp texture. They also had excessive culm leaf content with reduced edible flesh which bruised easily and a shorter shelf life. He recommended the Thai and Chinese technique of applying large amounts of fertilizer for 2 months prior to the start of the shoot season. The amount suggested was 450 to 500 kg / ha / year total nitrogen. He also suggested adopting the Thai management practices used for inducing early harvest which exclude light to improve shoot quality. These have been found to be more favorable after researching because it is less labor intensive. Chantanaparb, L (1994) reported that plantation establishment of *Dendrocalamus asper* in the northeast of Thailand will get lower rates of survival, at about 30%, if watering and termite attacks are not curbed. The planting under dry evergreen forest also resulted in a low survival rate of between 30-40% if no maintenance was practiced.

Subansenee, W. (1996) recommended for establishing and managing *Dendrocalamus asper* to use 4x4 m, 6x6 m, and 8x8 m spacing depending upon plant varieties and site quality. The clump management will be done by cutting out culms older than 1 year. The method of cutting will be to cut close to ground level, between the months of November to March which is the appropriate time. The first cutting period should be done during 3-5 year after planting. Culms at 2-3 years of age will be cut as described. For shoot harvesting the period from May to October is the most suitable time. Shoots should be harvested once every other day during this period. The application of urea or ammonium sulphate will improve shoot production and a potassium supplementation can improve shoot quality. The fertilizer 13-3-21 should be applied as a supplementation.

The September/October period will be the time to cut the branches used for propagation and to improve income. During the October/November period, just after harvesting, plowing should be implored in order to reduce weeds and as a means for sub-soiling. New growth should be checked at this time. From November to March is the dry period, and in order to limit growth, control burning near the clump may be done to facilitate this process. However, it is essential that this operation is never performed during conditions with strong winds. This will also be the period for culm cutting in order to reduce clump size and facilitate selling the culms. The period from March to April will be the time prior to rainy season, when fertilizing with manure together with chemical fertilizer application should

be done to improve growth during coming periods. April to May is the beginning of the growing period and the shoot will start to grow off the ground.

Subunsenee, W. (1996) also described clump management for shoot production stands of *Dendrocalamus asper* as follows:

- The first year there will be 5-6 culms in each clump and all culms should be left to grow.
- In the second year 5-6 culms will follow and these shoots should be left to develop as culms.
- In the third year about 30% of the shoots can be harvested.

The shoots at the periphery of the clumps which are strong and vigorous should be left to develop as culms.

Shoots in the middle of the clumps, or ones close together should be harvested in order to expand the clumps. This helps them not to be congested during culm and shoot harvesting in the following year.

After the third year, between 5 to 10 culms at 3 years of age or older should be cut off in order to manage the clumps and improve shoot production.

The scheme of management for shoot and culm production can be summarized in the following tables.

Table 1 Shoot Management

Year	Total shoots	Shoots harvested	Shoots retained for culm development	Total number of culms	Number of culms harvested	Remaining culms in the clump
1	5	-	5	-	-	-
2	5	-	5	5	-	5
3	13	8	5	10	-	10
4	20	15	5	15	3	12
5	25	20	5	17	5	12
6	25	20	5	17	5	12
7	25	20	5	17	5	12
8	25	20	5	17	5	12

Table 2 Culm Management

Year	Total shoots	Shoots harvested	Shoots retained for culm development	Total number of culms	Number of culms harvested	Remaining culms in clump
1	5	-	5	-	-	-
2	5	-	5	5	-	5
3	13	8	5	10	-	10
4	20	10	10	15	5	10
5	25	17	8	18	8	10
6	25	17	8	18	8	10
7	25	17	8	18	8	10
8	25	17	8	18	8	10

Khumlert, and et al (2000) studied 5 promising clones of *Dendrocalamus asper* which were selected from 3000 families for shoot production. He reported that clumps that were partially harvested produced 22 shoots per clump with an average weight of 1.9 kg per shoot. While clumps that were completely harvested produced 63 shoots per clump with an average of 1.7 kg per shoot. This data were collected over a 4-month period 18 months after planting.

2. Bamboo Research Projects

Experiment 1

Species and spacing trial of bamboo

Introduction

Bamboo is the most important plant species that Thai people in the rural areas depend upon on a daily basis. It is used to help generate income for families. With lack of knowledge on propagation, planting and management of bamboo, this natural resource which was once prosperous is now almost depleted. The natural bamboo growing areas have been abused and have low productivity. The proper knowledge for sustainable production is vital to the improvement of local living. The suitable species of bamboo for planting and management for sustainable production will be the major contributions for bamboo resource management. In this study we will consider 5 selected bamboo species that are already well known for their usefulness. They are *Dendrocalamus asper*, *Dendrocalamus strictus*, *Bambusa blumeana*, *Bambusa multiplex* and *Gigantachloa albociliata*. They will be studied in various clump emplacements in order to determine the optimum system for sustainable production.

Objective

The productivity of various bamboo species planted at different spacing will be compared for shoot and culm production. The optimum emplacement for each species will be determined from this study.

Location

This experiment will be conducted at Pakchong, Nakhon Ratchasima province, which is in the northeastern part of Thailand.

Materials and method

The five bamboo species in this experiment are among the top ten commercial bamboo species in the country. The first one is *Dendrocalamus strictus*, which is wide spread all over Thailand except in southern regions. *Dendrocalamus asper*, which is a popular commercial species all over the country. The remaining three are *Bambusa blumeana*, *bambusa multiplex*, and *Gigantochloa albociliata*. The three spacings used between clumps in this experiment will be 4 x 4 m, 4 x 8m, and 8 x 8m.

Experimental design

The field experimental design is a split plot design constructed by allocating 3 spacing treatments in the main plots, with a 5 specie treatment as sub-plots, in 4 block replications. The detailed design is shown in figure 1. The main plot size is 40 x 88 m, and each block contains 3 main plots with 5 sub-plots for a total dimension size of 120 x 88 meters. The total area of this experiment covered approximately 26.4 rais.

Site preparation.

The area was cleared and plowed prior to staking according to the spacing require. After staking, the planting holes were prepared by digging holes 30 x 30 x 30 cm. The soil dug out from each hole was mixed with manure and compost before replacing into the hole approximately half full. The soil left over was used to cover the plant roots at planting time. Chemical fertilizer formulas 15 -15 -15 was added to the soil mix in order to improve fertility and to stimulate early growth.

Planting

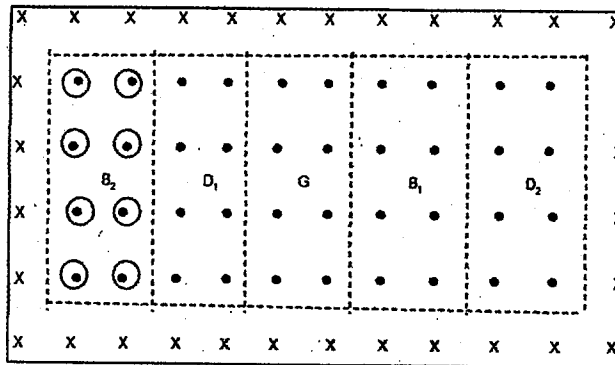
The seedlings of all species were planted in the prepared holes according to design. A total number of 366 seedlings from each species was used for this experiment. Planting must be done as early as possible after the beginning of the rainy season. Soil moisture is suitable normally after 200-300 mm of rain. Irrigation may be needed to improve survival and early growth, in the case of uneven raining or dry spells.

Split plot design : spacing main plot. 3 , spacing sub - plot. 5

ระยะปลูก 4 x 4 , 4 x 8 , 8 x 8 m.

ชนิดไม้ 5 ชนิด *Dendrocalamus asper* , *D. strictus* , *Bambusa blumeana*
B. multiplex , *Gigantochloa albociliata* , D_1 , D_2 , B_1 , B_2 , G sub - plot 1 2 3 4 5

88 m.



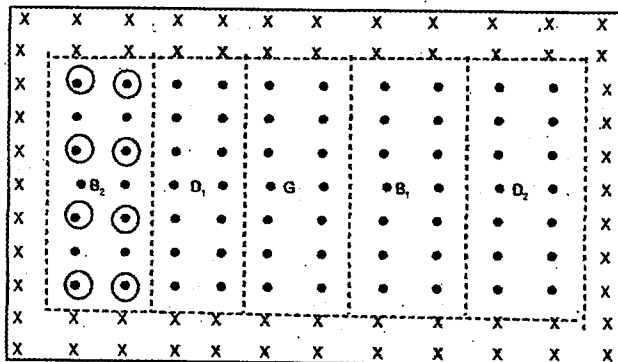
main Plot size = 40 x 88 m²

Block size = 120x88 m²

Total of 4 blocks = 26.4 ไร่

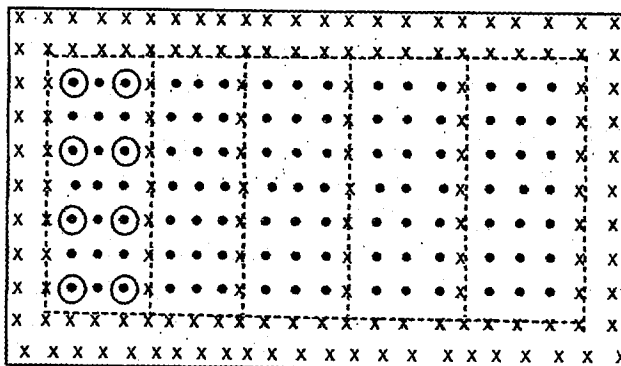
plot 1 Spacing 8 x 8 m.

number of clumps / Plots
 = 72



plot 2 spacing 8 x 4 m.

number clumps / plots
 = 132



plot 3 spacing 4 x 4

number of clumps / plots
 = 253

Total number of clumps

Per block = 457

Total number of clumps

in 4 blocks = 1,828

Total number of clumps

For each species ~ 366

Total 504

Block I - Block IV

X border clumps , • within plot clumps for data collection

⊙ data collection clumps.

Maintenance of the experiment

During the early period of the experiment maintenance is very important. Weeds can suppress bamboo growth very early in the rainy season and if preventive measures are not taken in time, good results are unlikely. Spot weeding by clearing all weeds around the bamboo seedling in a radius of 50–75 cm is needed at least 3-4 times in the first year. Whole area weeding should be done at least twice in the first year of planting. Fertilizer application and spreading manure at least once a month will accelerate early growth and allow for better establishment.

Data collection.

The number and quality of shoots which sprout and the number of culms developed from shoots will be recorded. This information will be collected from 8 clumps in each sub-plot, already specify in the detail design. All information will be subjected to statistical analysis in order to determine the performance of each bamboo species and the effects of spacing on its productivity. The data collected will be the number and quality of shoots produced in each clump, the number of culms that fully develop in each clump, and the height and diameter of each culm.

Expected result

The information gained from this three year experiment should reveal the proper methods in managing a bamboo plantation for shoot and clump production. Another objective is to discover the optimum spacing between various bamboo species. This information hopefully will be a future benefit to bamboo management.

Experiment 2

The effect on bamboo productivity by harvesting according to age.

Introduction

Bamboo produces new culms every year. How to harvest the culms without jeopardizing long term production is the major concern on sustainable bamboo management. The bamboos in all our experiments are sympodial or clump forming species. The culms in the clumps vary in age. The experiment is based on the premise that shoot sprouting will mostly arise from the previous year's rhizome, which is connected to last year culms. These young age culms are the most active contributors of energy reserves in the rhizome system. The culms at one and two years of age will contribute energy mostly for shoot sprouting and new culm development. The age of the culms harvested might have some effect on bamboo production.

Objective

This experiment is to investigate the effect of culm harvesting by different age classes (selective cutting), on the performance and productivity of two bamboo species, *Dendrocalamus strictus* and *Gigantochloa albociliata*.

Materials and method

This study will be conducted at the natural bamboo stands in Chiangmai. Two bamboo species, *Dendrocalamus strictus*, and *Gigantochloa albociliata* will be selected for this study. Each species in the natural stands will be separately studied. There are four treatments of harvesting in this experiment:

1. Clear cutting; in this treatment all culms in the clump will be harvested
2. Cutting all culms in the clump older than 1 year
3. Cutting all culms in the clump older than 2 years
4. Cutting all culms in the clump older than 3 years

In each species, there are 3 blocks of 16 clumps each for the experiment. Each particular block should be located on a uniform environment with 16 clumps in each block. The clumps should be similar in size, and will be subdivided into 4 plots of 4 clumps each. Each will be subjected to a particular treatment of 1 to 4 as described in figure 1 below.

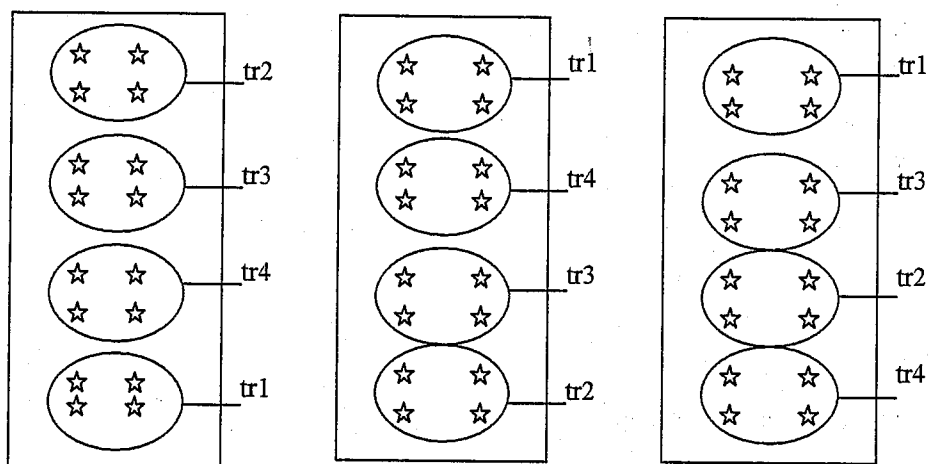


Figure 1. Diagram of treatment allocation

After the selection of the areas and demarcation of the bamboo clumps for the experiment is finished, the cutting and harvesting should be

done between December to April. The cutting work should finish before the shooting period.

Data collection and analysis

The data on the number of culms obtained from each clump in all the treatments will be recorded every year after harvesting. The quality of culm in height and diameter, will be subjected to statistical analysis in order to determine the treatments effects on productivity and quantity.

Expected result

The effect of selective cutting on culm age in production will be reveal. This information will be useful for sustainable production of bamboo in the plantation.

Experiment 3

Management trial for shoot and culm production

Introduction.

The bamboo shoots are a very important commercial product of bamboo stands. Bamboo shoots as food is growing in popularity among people in various countries of the world, especially in Southern Asia. This product alone can generate a great deal of income for local people. Thailand also receives income from exported bamboo shoots, therefore this item is an important product of the country. The management for both shoot production and culm production has to be studied. The bamboo shoots in this experiment will be harvested with different number of shoots left to develop into culms in each year. Therefore clump size will be different according to each treatment. In each year all culms at the fixed age of more than 2 years old will be cut off.

The management will regulate the clump to a fixed size according to the number of shoots left to develop to culms.

Objective

The effect of clump size on shoot production for a particular bamboo species is the primary concern of this experiment.

Material and method

This study will be conducted at Pakchong, Nakhonratchasima province. The bamboo species for this study is *Dendrocalamus asper* which is special cultivar for shoot production. It will be established as a small bamboo plantation. *Dendrocalamus asper* bamboo will be planted into 3 blocks of 9 clumps each, with a spacing of clumps at 4 x 8 meters. In each

block, 3 clumps will be subjected to a particular treatment plot. The treatments used in the study are as follows:

Treatment I. In each clump, all shoots that sprout will be harvested except for three which will be left to develop into culms in every season.

Treatment II. Do the same as in treatment I. except that the number of shoots left to develop into culms will be 6 in every season.

Treatment III. Do the same as in treatment I. except the number of shoots left to develop into culms will be 9 in every season.

The spacing of the shoots retained and the quality of shoots allowed to develop to culms has to be done in such a way that the clump will not be congested in order to maintain a good culm quality.

For this experiment, in order to maintain fixed clump size, all culms older than 2 years were cut and harvested yearly.

The criteria of each treatment can be summarized as follows:

	Number of culms in the clump aged less than 1 year	Number of culms in the clump from 1 to 2 years old	Clump size	Yearly harvest
Treatment I	3	3	6	3 culms / clump
Treatment II	6	6	12	6 culms / clump
Treatment III	9	9	18	9 culms / clump

The statistical design for this experiment will be a completely randomized block design with 3 replications. Field layout for the treatments will be as shown in figure 2.

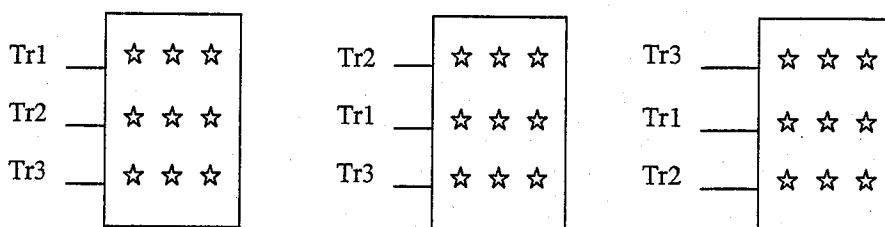


Figure 2 Experimental layout

Each block will cover an area of 32 x 16 meters, with the total area for this experiment be approximately 1 rai.

Data collection and analysis

The number and weight of shoot production from all treatments will be recorded. This information will be subjected to statistical analysis in order to gain the effect of clump size on the shoot production. The quality of the shoots produced will also be studied.

Expected result

This experiment will keep the culm age to no more than two years for all of the treatments. The number of culms left to produce reserve food will be different. The influence of the number of culms in the clump for shoot productivity will be determined as a result of this study. The impact of clump size on shoot quality will also be known.

Experiment 4

Trial on bamboo in the agro forestry system

Introduction

In order to improve sustainable production for rural development in major agricultural areas, the agro forestry system for production will be necessary. This system will increase biodiversity and reduce the risk of catastrophic effects such as pestilence, disease, drought and weeds. This is an important necessity in a tropical climate in which the nature of the ecosystem is very complex. In order to maintain production at optimum levels, requires a much more complex and sophisticated system than a temperate climate. A pure cropping system can be vital only if outside energy sources have been used as an input to production. This method though presents a big risk of incorrect supervision and management. The development of the agro forestry system for production is in need in the tropical zone for more efficient production. The incorporation of bamboo in the agro forestry system will be very beneficial to the system, as bamboo can generate quick annual returns with low investment. The bamboo production process is simple, and the products can be used as food and raw material for a variety of other products. The bamboo can play vital roles in both protection and production at the same time with ease of management for sustainable production. The success in using bamboo in the agro forestry system will contribute much to the well being of the local people and the economy of the country.

Objective

This research will investigate how to incorporate the potential of tree and crop species that can grow well with selected bamboo species. The advantage and disadvantages of the system will also be considered in this

experiment. This study will also be used as a bamboo agro forestry demonstration plot for interested people and for local farmers.

Materials and method

There are two locations selected for this demonstration and study. One is at Chiangmai, in the north and the other is at Pakchong, which is located in the northeastern part of the country.

The five selected bamboo species for this agro forestry experiment are *Dendrocalamus strictus*, *Bambusa blumeana*, *bambusa multiplex*, and *Gigantochloa albociliata*. Every species will be planted at a species plot using spacing of 8 x 8 meters. Each plot will cover an area of 8 rais, with the total area of 40 rais for the entire project. Tree and crop species other than bamboo will be grown in the space between bamboo rows. Some annual and perennial crops may be grown under trees or bamboo, especially the shade loving variety. The tree species used for growing in the studies will be fast growing species such as *Cedrela toona*, *Alstonia scholaris*, *Acacia auriculaeformis*, *Cassia siamea*, *Azadirachta indica*, *Ficus sp.*, *Swietinia marcrophylla*, *Leucaena sp.* and maybe some eucalyptus species. The non fast growing species will be *Hopea odorata*, *Dipterocarpus alatus*, *Pterocarpus macrocarpus*, and *Tectona grandis*. The other species will be those which can be used to produce food, e.g. fruit trees and other species like *Eugenia spp.* for *Cinnaomum sp.*

The annual and perennial crops can include, spices, and some vegetable and medicinal herbs. In the northern location, tea should be the main intercrop species under the bamboo and tree species.

3. Vegetative propagation of bamboo

It is already well known that the flowering period of bamboo is very long taking more than 20–30 years. It takes about 80 years for *Dendrocalamus asper* in Thailand to flower. The propagation of seeds for commercial purposes is undependable. Other factors which compound the problem are seeds with low viability and loose germination capacity in a shoot period of time. Therefore, propagation for a large area plantation normally takes place by vegetative means rather than from seeds.

The vegetative propagation of bamboo in general can be carried out in different ways. The simplest methods are offset planting, culm cutting, rhizome cutting, branch cutting, layering, tiller separation and sub-branch

cutting. It should be understood that from all these propagation methods, the new plants would be developed from the sprouting buds present at nodes of culms and rhizomes and branches. Care must be taken to keep these buds in good condition. Healthy and vigorous buds can be stimulated to sprout easily. Buds from young plant material, from 1 to 3 years of age, are considered to be the most suitable for propagation. The younger plant material has more food reserve to support sprouting, development and growth.

The proper environment and conditions for stimulating sprouting is also important. In order for the propagation to be successful, a green house or nursery for the bamboo is necessary. The green house function is to maintain relative humidity and temperature in the optimum range in order to stimulate bud sprouting and to enhance growth for intensive root development. The temperatures around 30–35°C and relative humidity of 85–95% are considered to be the optimum conditions. The medium for rooting is also important. A medium which has a good water holding capacity and at the same time provides sufficient aeration for rooting should be used. One of the most suitable mediums is a 40% coconut peat and a 60% rice-husk charcoal mix. In addition, an application of 50 grams of complete N:P:K fertilizer dissolved in 20 liters of water applied weekly to all propagation material after sprouting will encourage vigorous growth and reduce the time for propagation. It should be noted that bamboo does not tolerate flooding, and if drainage in the propagation beds is insufficient, sprouting and root development may be hindered. Therefore great care should be taken in order to ensure for good drainage in the nursery especially during the rainy season.

The greenhouse may be constructed as a curving roof frame structure using either wood, bamboo culms, split bamboo, steel rods or any other equivalent material. It needs to be strong enough in order to support transparent plastic sheets for the roof and resistant against wind. The curved roof structure is easy to build and is stable in the strong winds. The transparent plastic sheet cover will allow sunshine to penetrate for bamboo growth. In case of too much sunshine resulting in a high temperature inside the nursery, shading on the roof with syran net will be helpful. The side wall of the greenhouse may be cover by plastic or some other material which can keep moisture inside the greenhouse. Watering should be done by a top sprayer inside the greenhouse for watering plant materials and keeping moisture in the optimum range. The watering can also help reduce the temperature during the day time. The propagation beds should be arranged on raised ground in the greenhouse. These beds will be covered with a propagation medium using a mixture of 40 % coconut peat and 60 % rice-husk charcoal as already described. If no problems of drainage exist, then the simple preparation of digging a long narrow ditch along the length of the

beds would be adequate. Place the propagation medium into the ditches. The plant material to be use for propagation should be arrange along these ditches and covered with medium. This will facilitate, with minimum root disturbance, in lifting the propagules for field planting or transplanting them into plastic bags after they have grown a sufficient root system. Plant material for propagation will be put in the greenhouse until they sprout and develop strong culms with extensive root systems, which also can survive under normal environmental conditions.

Another method of propagation is by using a plastic bag as a container instead of propagation beds. This method will facilitate in the management however the cost will be higher. A plastic bag about the size of 20-30 cm in diameter would be appropriate. For this method the plant material will be placed into the bags together with the growing medium as describe. The propagation bags will be arranged inside the greenhouse for sprouting where they will develop culms and rhizome systems with extensive roots. When the plants are strong enough, they may be transfer outside for hardening prior to field plantation. This containerized propagation will have some advantage compared with those in the beds, but as mentioned earlier the cost will be higher. The farmers can choose the method of propagation that best suits their circumstances.

When the preparation of the greenhouse for propagation is complete, the decision on the proper propagation technique can be decided. These simple methods of propagation are provided for alternative means by which to propagate bamboo.

1) Offset planting

This method will separate a group of culms together with a rhizome system from their mother clump. This will happen normally at the periphery of the clump with culms that are no more than 1 year old. The culms will be cut off approximately 75 cm above ground level. The small cluster at the basal part of younger culms together with the rhizome system can be used as plant propagules for directly planting in the field. The time for direct planting into the field must coincide with the early growth period which is generally the early rainy season. The offset plants can be place in large poly bags with propagation medium, then put into the greenhouse for shoot sprouting and development. Doing it in this way will improve survival and is better than direct field planting, however it will cost more. The propagules can be prepared long before planting season and in large quantities. This practice would be more suitable. The offsets in the plastic bags should be arranged in the greenhouse to stimulate sprouting and shoot development until they are strong enough for field planting. This generally takes at least one month. The disadvantage for offset planting is the large requirement of plant material needed to produce plant propagules. In

circumstances where a large establishment is needed this method would be unsuitable.

2) Culm cutting

The culms or part of the culms will be used as plant material for propagation. The important thing is that the sprouting will come from the buds at the nodes along the culms. Therefore, care must be taken in order not to disturb or loosen these buds during branch cutting and trimming. If there are no buds, then it is impossible to stimulate sprouting with this method. The whole culm can be used or it can be cut into sections. At least one piece of the bud or node must be present. The whole or part of culms will be cover with plant growing medium to provide moisture for sprouting. Normally the bud portions should be cover by the medium. The whole propagation work will be kept in the greenhouse for proper conditions, to stimulate sprouting, and for shoot development. It normally takes about two weeks to see sprouting and 2 months for the roots to develop from these new culms.

The plant material, or in this case bamboo culms, should have at least one year and not more than three years for good sprouting. After new culms develop a good root system and maybe a rhizome system, it will be ready to plant into the field. This process should be done during the rainy season. The new propagules can be transplanted into plastic bags for better development. These bags will also be kept in the greenhouse. When the propagules develop a good extensive root system, then they are ready to be planted in the field.

Whole culms

In this method the whole cut culm will be lied down on the propagation bed and covered with medium. An internode may be cut in order to make a hole for water to go into hollow portion as a way to keep better moisture for sprouting. The culms will be arrange is such a way that buds will be at the two sides of the culms instead of at the top and bottom to facilitate shooting. Prior to planting, the culms will be cut to separate individual plants for field planting.

Culms cut into pieces

Each piece normally consists of one node with an intact bud. The culms pieces will be put in the medium keeping the basal part deep enough that the node will also be cover. The culms are placed at a 60-degree angle to the ground. The top part of the node should be filled with water to keep it moist all times. The propagation will be accomplished in the greenhouse beds or in the plastic bag containers. It may take 2 to 3 months until the

shoot matures and develops a strong root system. After maturing, the field planting of the propagules can be accomplished.

3) Rhizome cutting

In this method, rhizomes with basal culms at 70 – 80 cm in length will be separated individually from the mother clump to be used as propagules for propagation. The rhizome used should be between 1–3 years old. Care should be taken that all buds in the rhizome region and at the culm node should not be disturbed.

These individual rhizomes with culms will be put into the propagation beds or in the plastic bags. They should be covered with medium to the level of 20 cm in order to cover the rhizome portion and also some basal parts of the culms. This work will be done in the greenhouse in order to control moisture, temperature and to stimulate sprouting. The shoot will sprout either from the rhizome buds or culm buds. It normally takes between 2–3 months for the new shoots to be strong enough with a good root system, before they are ready to be transplanted into the field. This technique is easiest with the small culms bamboo species similar to those used in offset planting. In areas of good and even rainfall, the propagules can be directly planted into the field, but a lack of maintenance may reduce survival.

4) Branch cutting

Some bamboo species with large culms and intensive branches like *Bambusa blumeana*, benefit the most from branch cutting as a means for propagation. Branches from healthy vigorous culms aged between 1–2 years should be cut from the culms. The branches, which consist of two nodes, are mostly used for propagation material. The cut branches will be put in the propagation medium in the beds or plastic bags. They should be put in in such a way that the medium will cover the lower basal buds and almost the bud above. It is important to note that sprouting will occur from the buds so all buds should be in good condition. After putting then in the propagation beds in the greenhouse, with the proper humidity and temperature, sprouting should take place in the second week. The whole propagation period may take about 3 months. At this time, the new shoots should be strong enough and have a good root system to be transplanted. This method uses small plant material for propagation, so it is suitable for a large-scale operation. However, some species cannot be propagated by this method.

5) Layering

Bamboo layering is similar to what is done with other plant species, but not identical because bamboos do not have a cambium layer like many other plants. This method is suitable for species where the basal nodal part

of the branch, which is connected to the culm, develops aerial roots. In order to stimulate an extensive root system, the basal rooted nodes need to be covered with medium in order to retain moisture. This can sometimes be accomplished by partly cutting the culm below these nodes to further enhance root development. This method with proper care will take a shorter time to produce plant propagules, because the initiation of the root development has already started. The moist medium cover will enhance root development to be extensive and strong enough to allow the branch to survive after separating from the mother culms. When the roots are strong and extensive enough the branches with root systems will be separated from the culms. This will normally take about 15 days after being covered with medium and raised in the plastic bags in the greenhouse. Under the proper greenhouse conditions, in another 15 days to 1 month, they should be strong enough for field planting in the rainy season.

6) Tiller separation

The tillers, which originate from seedlings, may be collected from the wild or from seed germination for propagation. Tiller's have a small stem with a diameter less than 1 cm. They also have intact leaves, which sometimes are in pairs with 2 to 3 together. It has a rhizome and root system that separate from each other from small young clumps that develop from seeds or other sources. The individual tiller may be put in the plastic bags or in the propagation beds with the proper medium in the greenhouse. The mother tiller will be stimulated and will produce more tillers within a month. About the third month, with proper watering and application of fertilizer, the tiller will increase to about 5-10 times its size and be strong enough with a good root and rhizome system that can be separated again. This can be repeated many times within a year using the original propagules. Some of the tillers can be placed in the plastic bags for propagation following the same methods as with the beds. The plastic bag tillers when strong enough with small clumps of a good rhizome system and extensive roots, can be transplanted into the field during the rainy season. The propagules will develop similar to the plants from which they came from. This method may be propagated all year round and can produce large amounts of propagules for planting in a small area of propagation beds. The initial tiller can be received from seedlings or other propagation methods with proper management to produce micro clumps. This method requires more investigation for some species in order to produce a large amount of planting material for a large-scale plantation.

7) Sub-branch cutting

When the top portion of the culms are cut off, the buds at the node of the branches will be stimulated to sprout more sub-branches with swollen basal portions with root initiation. When these sub-branches were used as a

material for cutting, they initiate and developed root systems easily, and the sub-branches grew to a small culm. This culm develops more culms, which grow larger than the previous one, and can be used for planting in the field. The sub-branch will produce more when the sprouting at the mother clump rhizome is inhibited by rib off the buds during the initial sprouting process. The production of sub-branch cutting may be managed successfully in greenhouse conditions due to the control of humidity and temperature together with fertilizer application. This method of sub branch propagation needs more study in order to produce a larger amount of plant propagules of species and some varieties for a large-scale plantation.

4. Conclusion and discussion

1. In the management, the application of fertilizer and spreading manure can improve the productivity and quality of shoots and culms as with other plants. The balance between nitrogen and potassium will resulted in quantity and quality of shoots respectively.

2. Watering and irrigation can also greatly improve the production as bamboo needs much water for sprouting. Irrigation can also stimulate early season production of shoots. This practice when conducted in ideal environmental conditions can extend the period of shooting and culm development. This practice combined with good fertilization will also improve production. By this means, almost all year round shoot production can be accomplished.

3. It is interesting that on the shoot production management, harvesting most of the shoots, increased shoot production. This is why Thai farmers practice leaving only 1 to 2 shoots annually after the middle period of shoot production. This is to develop the culms in order to maximize shoot production. With irrigation, fertilization and proper management on shoot harvesting, it is expected to see that shoot productivity could be greatly increased. More studies on this aspect would be very profitable.

4. On the spacing aspects, the spacing between clumps does not have any meaningful influence on either shoot or culm production. It has been suggested to use narrow spacing to increase productivity, as long as it does not interfere with other operations in management or harvesting. This aspect must be considered for study in more detail in order to improve productivity and reduce cost.

5. Bamboo grows better under light shading of other tree crowns. Our findings supported this information in our experiment where the dense bamboo stand had greater productivity. In light of this finding, the bamboo

agro forestry system has great potential to increase both productivity and biodiversity.

6. The bamboo agro forestry system will be the right channel for the development of increased productivity in the tropics. This system needs more intensive investigation and diversification for agricultural development in the tropics.

7. Bamboo has great worth in its role in environmental protection. These plants can be managed in their dual roles as provider and protector simultaneously or separately.

8. It is also interesting that harvesting old culms can improve clump production, if it is performed in the proper way.

9. It can be concluded that the proper harvesting of culms is by selective felling according to age. The culms at 1 and 2 years of age should not be cut off, because they are the most vigorous to produce reserve food for the rhizomes. Some 3 year old culms of some species may also play this role but with less of a degree of importance. Most shoots will sprout from the buds of one and 2-year-old rhizomes, then shooting will mostly connect with current year culms. Therefore, current year culms will play a vital role in shoot and culm development. The quality of new culms will be mostly dependant upon the mother culms, as well as the quantity of new culms. This makes bamboo management much easier if culm production and harvesting is simultaneous. Harvesting must take into consideration culm age in order for future production not be interrupted. It can be stated in general practice that cutting all culms aged more than 3 years old will do no harm to future production but rather increase it. For species which are managed for shoot production, harvesting all culms 3 years and older will also improve shoot production. This method can be managed under a sustainable basis to optimized productivity.

10. Bamboo stands should be protected from grazing and fire when the plants are young and during the moist season.

11. The effect of earth working by sub-soiling and earthen up could also improve production. This could be done by plowing during the dry period in order to reduce weeds at the same time.

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