Global Overview of Teak Plantations

J.B. Ball[1], D. Pandey[2], S. Hirai[3]

Paper presented to the Regional Seminar
Site, Technology and Productivity of Teak Plantations
Chiang Mai, Thailand 26-29 January 1999

1. Introduction

Although teak has been grown in plantation conditions for one hundred and fifty years, the high value of teak timber due to its appearance and mechanical properties, the strong markets for teak products combined with increased distance to and declining stocks from natural stands have attracted increasing attention to the potential of teak plantations as an investment with an attractive return in the last decade. Such interest is not new; one of the early bodies established as a subsidiary of the FAO Asia-Pacific Forestry Commission in the 1950s was the "Teak sub-commission" with eleven member countries[4]. Its aims, which were similar to those of the present TEAKNET, were to promote international collaboration in the study of all scientific, technical and economic aspects relating to teak and the issues discussed in those days were remarkably similar to those of today.

This paper examines trends in the establishment of teak plantations worldwide and identifies some of the environmental and economic issues and challenges for investors in these programmes.

2. Historical review of teak plantations

Teak occurs naturally in parts of India, Myanmar, Lao PDR and Thailand and it is naturalised in Java, where it was probably introduced some 400-600 years ago (Troup 1921, Kadambi 1972, White 1992). It has been widely established in plantations as an exotic species for producing high quality poles and timber outside the countries of its natural distribution.

The earliest plantation of teak, apart from Java, has been traced back to 1680 when a Dutchman, Van Rhede (Perera 1962), successfully introduced it to Sri Lanka. Teak planting in India began in the1840s but major planting took off from 1865 onwards. In Myanmar and Indonesia, teak plantations using the "taungya" method were initiated in 1856 and around 1880 respectively.

Early introductions of teak outside Asia were made in Nigeria, where the first introductions were of Indian origin in 1902 (Horne 1966) and subsequently were of Burmese origin. Teak planting in what is now eastern Ghana started around 1905 (Kadambi 1972) and a small plantation of teak was established in the Ivory Coast in 1929 from (plantation) seeds obtained from then Togoland. Teak was introduced to countries of Tropical Africa to supplement local timber supplies because of its excellent timber properties.

Perhaps the first pure teak plantation in Tropical America was established in Trinidad in 1913 (Keogh 1979) with seed from Burma. Planting of teak in Honduras, Panama and Costa Rica started between 1927-29.

Reliable area statistics on the historical progress made in teak plantation are incomplete, but it appears that the major area under teak plantation, of about 0.31 million ha, was in Java (Indonesia) until 1950.

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[1] Senior Forest Officer, Forest Resources Development Service, FAO, Rome
[2] Director, Forest Survey of India, Dehra Dun
[3] Associate Professional Officer, Forest Resources Development Service, FAO, Rome
[4] Reports of the sessions of 1956, 1957 and 1960 are available from FAO.

Along with other species plantations of teak in tropical countries gradually increased during the 1950s and 1960s until the reported plantation area of teak by 1970 was estimated as 0.891 million ha, using data quoted in Kadambi (1972) and Tiwari (1992). The pace of planting teak further accelerated in the late 1970s thanks to financial support provided by external donor agencies. The total area of teak plantation increased to 1.72 million ha in 1980 (Pandey 1983) and 2.2 million ha in 1990 (Pandey 1995), more than 90% of which was situated in Asia.

3. Reported and net areas and planting rates

Figures on teak plantation areas were derived from a general questionnaire requesting data on plantation programmes up to base year 1995, which was sent to governments by FAO's Forestry Department in 1996. Information received was supplemented by information from literature searches of published reports and "grey" literature and from personal contacts. The figures thus obtained were adjusted by a reduction factor, since they were usually not based on inventory but on planned programmes, they had not been adjusted for losses, and it was believed they frequently included double counting of plantation areas through the inclusion of replanting. The reduction factors were based on inventory and survival rates in the country or region, and on expert opinion. The value of the reduction factor varied from 1.0 (no reduction) where a country's data had been derived from recent inventory and was believed to be reliable, to 0.5 where the area figures were known to be unreliable.

Table 1. Estimated net plantation area of Teak, by sub-region in 1995 (1,000ha)

Sub-Region	Estimated net area of total plantation	Estimated net area of teak plantation	% of Teak plantation area	Estimated Annual planting
West Sahelian Africa	242	4.02	1.67	0
East Sahelian Africa	640	14.85	2.32	--
West Moist Africa	324	87.88	27.1	4
Southern Africa	790.6	2.80	0.35	0
Tropical Africa	**1896.6**	**109.55**	**5.78**	**4**
South Asia	13322	1099.60	8.24	55
Continental SE Asia	2382	302.28	12.67	26
Insular SE Asia	3279	706.01	21.53	12
Tropical Asia	**18983**	**2107.89**	**11.10**	**93**
Tropical Oceania	132	3.03	2.30	0
Tropical Oceania	**132**	**3.03**	**2.30**	**0**
Central America	238.7	22.29	9.34	4
Caribbean	466.1	8.06	1.73	--
Tropical South America	5271	2.72	0.05	0
Tropical America	**5975.8**	**33.06**	**0.60**	**4**
TOTAL	26987.4	2253.53	8.35	101

Source: Pandey, 1998.

* "0" means that there is some new planting but it is less than 1 000 ha/yr; -- means that there is no new planting.

Note that the figures above refer to net total area and net teak area of plantations established in all countries (whether they actually have teak plantation programmes or not) and for all purposes (not just for veneer- or saw-log production).

It appears that the increase in the net area of teak plantations in the world has been only marginal since 1990 (Pandey 1995). The authors believe that this anomalous result, given the reported rate of new planting of over 100 000 ha yearly, was the result of general slowing down in the rate of new plantation establishment in many tropical countries after 1990, and also because a large, but unknown, part of the reported new planting is in fact replanting following harvest.

Of the net area of teak plantations in 1995, about 94% lay in Tropical Asia, with India (44%) and Indonesia (31%) contributing the bulk of the resource. Other countries of the region that contributed significantly were Thailand (7%), Myanmar (6%), Bangladesh (3.2%) and Sri Lanka (1.7%). About 4.5% of teak plantations were in Tropical Africa (largely in West moist Africa - in Côte d'Ivoire and Nigeria) and the rest were in tropical America (mostly in Costa Rica and Trinidad and Tobago).

Most planting reported in 1995 was in India, Myanmar, Thailand and Indonesia in Tropical Asia and in Costa Rica and Panama in tropical America. In India, most of the new plantations of teak are now mixed with other species.

Teak constituted about 8% of the net plantation area in the countries, which reported. It formed an important component of the plantation programme in West moist Africa, and in SE Asia.

4. Productivity and volume estimates

The productivity of teak plantations has been studied both within and outside its natural range through permanent sample plots. The first yield table of teak was constructed by von Wulfing (1932) for Java plantations. Laurie and Sant Ram (1939) constructed a yield table for teak plantations distributed over present-day India, Burma and Bangladesh, which was later superseded by a new yield table for Indian teak plantations (Anon 1959). Subsequently yield tables have been made using permanent and temporary sample plots for teak plantations established outside its natural range, including provisional yield tables for Trinidad by Miller (1969), Ivory Coast by Maitre (1983), Nigeria by Abayomi (1984) and Sri Lanka by Phillips (1995). Most of the yield tables referred to fully stocked stands. An important feature of all the yield tables of teak is the early culmination of mean annual volume increment (MAI), generally between 6-20 years. Since teak has been planted and managed for timber, size therefore, plays the decisive role for harvesting rather than the age of maximum volume production. The rotation age of plantation teak in its natural range has varied between 50-90 years while outside its range it is between 40-60 years. Assuming 50 years as an average age of harvest, the MAI at 50 years and at the culmination age of maximum volume production derived from the various yield tables are given in the following table for comparison.

Table 2. MAI maximum and at 50 years rotation age in m^3/ha/year on best, average and poor site classes

Country	Best		Average		Poor	
	MAI (max)	MAI (50)	MAI (max)	MAI (50)	MAI (max)	MAI (50)
India	12.3	10.0	7.9	5.8	2.7	2.0
Indonesia	21.0	17.6	14.4	13.8	9.6	9.6
Myanmar	17.3	12.0	12.5	8.7	5.9	4.3
Nigeria*	23.8	13.3	18.5	9.0	13.1	6.8
Ivory Coast	17.6	9.5	12.2	7.5	6.8	4.3
Trinidad*	10.2	6.5	7.5	5.0	5.5	3.9

*Yield tables have been prepared based on inadequate number of sample plots and are provisional.

There is a paucity of data on *actual yield obtained on harvest of teak from different site classes* and countries. Limited data available from Indonesia and India reveal that the actual yield obtained from teak plantations is much lower than the yield indicated in the above mentioned Tables. In Indonesia, the average mean annual increment obtained at harvest age (rotation varying between 40-90 years) was 2.91 m^3/ha/year (Anon 1986). Perum Peruhtani, which manages the major teak plantation areas of

Indonesia, has confirmed that the actual yield of teak in final felling was about 100 m^3/ha at about 70 years and a similar volume was obtained from thinnings, making MAI at rotation age about 3 m^3/ha/year[5]. Similarly in India, the actual yield obtained from thinnings and final fellings in Koni forest division of Kerala State averaged 172 m^3/ha on a 70-year rotation, giving a MAI of about 2.5 m^3/ha/year (FAO 1985). The site class for teak in Koni forest was considered to be between the best and the average, but poor stocking was considered the main reason for such a low yield. Similar yields were also found during plantation inventory of teak in Bangladesh. However, in teak plantation inventories of Benin and Ivory Coast, the estimated MAI at 40/50 years rotation age was found to range between 8-11 m^3/ha/year. The estimated yield in Costa Rica at 40-year rotation is 6.9 m^3/ha/year[6].

Nevertheless, the general conclusion is that *the actual productivity of teak plantations has been often much less than indicated in the yield tables* and this has influenced the choice of MAI used in the calculations of indicative volumes in Section 5 (below).

Based on the data derived from yield tables of different countries mentioned above, and their meteorological data, Pandey (1996) has developed a model to predict the potential productivity of teak plantations at global/regional level using climatic factors. The model is:

$$Y_p = -47.791 + 0.0019\, MRf + 12.688 \ln MH + 0.178\, T_1 - 4.095 \ln G$$
$$(SE = 1.39,\ n=86,\ R^2 = 0.589)$$

where Y_p = potential yield in m^3/ha/year at 50 years rotation age
MRf = modified average annual rainfall in mm
MH = modified average annual relative humidity in percent
T_1 = mean maximum temperature of the warmest month of the growing season in degree Celsius
G = length of growing season in months
ln = natural logarithm
n = number of permanent sample plots used in the study
SE = standard error

Climatic variables explained 59 percent of the variance of the potential yield of teak plantations. *Relative humidity* and *annual rainfall* were identified as the most important climatic factors influencing the growth of teak. An increase in their annual values above certain upper limits, however, resulted in successively less increase of the potential yield. These upper limits for rainfall and relative humidity were found to be 2000 mm and 70% per year respectively. The model underestimated the potential yield of teak in Indonesia and Nigeria on average by about 30% and of Ivory Coast by 20% when compared with yield table figures. The model can be used to forecast potential yield of teak plantations even prior to their establishment, as the crop properties (top height etc.) are not required. It was used to calculate the yield of teak in the moist semi-deciduous and the forest savanna transition in Ghana for example, giving MAI of 12 m^3/ha/year and 6 m^3/ha/year respectively (Odoom 1998).

5. Indicative estimates of teak plantation standing volume

Diminishing supplies of teak timber from natural forests have, as already noted, contributed to the recent increase in teak plantation programmes. Will these new areas meet future demands? This section looks at the possible contribution of plantations to teak timber supplies.

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[5] Personal communicaion to DP from Perum Perutani, November 1998
[6] Personal communicaion to DP from Mr Manuel Gomez, Economista Forestal, CATIE, Costa Rica

The calculation of future availability of standing volume in planned teak plantations would seem simple enough - the factors in the equation for the calculation of standing volume are area, establishment rate, growth rates, and rotation. Unfortunately the values assigned to these factors are most often, if not always, imprecise, being derived from estimates or even expert opinion. The uncertainties surrounding the calculation of true values of figures for existing plantation areas have already been mentioned in Section 3 above, while the planned plantation programmes are subject to unknown political developments, as well as to such unknowns as the availability of land. Very little information is available on the existing age structure of teak plantations, although it is known that much, if not most, has been planted since 1980. Applying a blanket rate of mean annual increment country-wide involves assumptions about the uniformity of growth rates and ignores the local variability of soils and climate, while rotation lengths may be changed according to market conditions, developments in conversion technology, or economic conditions. Finally, future markets for high quality teak timber and veneer are likely to continue to be strong, but whether plantation-grown teak will be of sufficiently high quality remains unknown.

Despite these uncertainties and the unreliability of the figures thus derived the attempt has been made to obtain an indication of future supplies of teak timber from existing and planned plantation programmes, if only to see if such "ball-park" figures suggest that present policies are more or less likely to meet predicted future demand. Such indicative estimates are, however, neither reliable in the dictionary sense of being assured, nor in the sense of statistical confidence.

A model was developed to derive indicative estimates of future hardwood plantation standing volumes (Leech 1998), as part of a wider project to study hardwood plantations in the tropics and sub-tropics[7]. The model uses the factors of area, future establishment rate, growth rates, and rotation as listed above to estimate standing volumes by 10-year periods to 2050, but the factors are adjusted for uncertainty based on published information where available and expert opinion where not. One of the adjustment "modifiers" is for existing area while the other three cover new planting rates and volumes. They are:

- A reduction factor for reported plantation areas. Since the reported area often means "accumulated planted area", which may be very different from the actual area existing, a reduction factor was applied to adjust the reported plantation areas, described in Section 3, Table 1. The reduction factor was derived either from inventories where available, or by expert opinion. It does not necessarily reflect the "true" figure. The figures in Table 1 were further adjusted to include only areas established for veneer- or saw-log production.
- A modifier to adjust the current rate of new planting as plantations mature and the new planting changes to replanting of logged plantation areas, or as land is no longer available for expansion. The value was based on expert opinion if sources with experience were available, but otherwise arbitrary values were used.
- A modifier to adjust the volume increment figure downwards for losses due to competition-induced mortality or other possible reductions, or upwards for possible increases due to tree breeding or better management practices.
- A modifier to adjust the volume for availability, that is to allow for the age structure of existing stands and for the unavailability of increment early in the rotation of new plantations, by partitioning the increment between the increase in standing volume and that available (from thinning) for use.

To further take account of the uncertainty of the indicative estimates, three scenarios were tested on the model by adjusting the volume increment estimates: a pessimistic scenario, with mai of $3m^3$/ha/yr, a realistic scenario of $5m^3$/ha/yr, and an optimistic scenario of $8m^3$/ha/yr.

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[7] *Hardwood plantations in the tropics and subtropics*, GCP/INT/628/UK, a project funded by the Department for International Development of the UK, implemented by FAO.

Hedged about with the qualifications regarding reliability, or more correctly unreliability, Table 2 contains the results from the three scenarios.

Table 2. Indicative estimates of teak standing volume (industrial wood) annually available by region ($000m^3/yr$)

Region	2030	2040	2050
PESSIMISTIC			
Africa	678	773	852
Asia	12,942	14,861	16,247
Oceania	40	47	52
America	861	944	1,012
TOTAL	14,521	16,625	18,163
REALISTIC			
Africa	1,114	1,270	1,401
Asia	21,292	24,455	26,734
Oceania	67	78	86
America	1,171	1,291	1,386
TOTAL	23,644	27,094	29,607
OPTIMISTIC			
Africa	1,767	2,016	2,224
Asia	33,818	38,847	42,004
Oceania	107	124	137
America	1,662	1,839	1,978
TOTAL	37,354	42,826	46,343

Considering the “realistic scenario”, it is predicted that most of the standing volume of teak plantations would be in Insular Southeast Asia in the year 2000, with Indonesia contributing the bulk of the supply from that region. Other countries with estimated large standing volumes of teak plantation timber would be, in descending order of magnitude, India, Thailand and Myanmar, followed by Costa Rica and Côte d’Ivoire outside the Asia-Pacific region. In every region, one country alone would contribute half of regional total. In Asia, it would be Indonesia, in Africa it would be Côte d’Ivoire, and Costa Rica in the Americas.

Although the Asian region clearly provides the most standing volume of each scenario, the relative contributions of Africa and America change; in the “pessimistic scenario”, Africa will produce less than America, in the “realistic”, they are the same, while in the “optimistic”, Africa will produce more than America. These different contributions arise from the differences both of rotation and of the proportion of new planting rate to reported plantation teak area.

In considering whether the expanded teak plantation programmes will meet future demands, the question posed at the beginning of this section, the authors have found no reliable estimates of future demand for figured hardwoods as veneer- or saw-logs. Putting the estimates in Table 2 in perspective, however, it is estimated that sawnwood (including veneer) consumption in the Asia-Pacific region alone, in the year 2010, will be of the order of 142 million m^3/year of product (FAO, 1998). The teak roundwood estimates, if converted with 60% recovery, would still constitute a very small proportion of total consumption. The conclusion is that markets for quality teak will continue to be strong.

5. Economic aspects

The cost of plantation establishment and maintenance depends on numerous factors such as topography, soil type, remoteness of the area, availability and cost of labour, plantation technology, intensity of management, plant spacing etc. The plantation cost, therefore, varies from locality to locality. The plantation cost of teak per ha excluding the cost of land in India at present varies between Rs.12500 (equivalent to $US298[8]) in Kerala and to Rs. 16800 ($US400) in Maharashtra with stump planting on 2 m x 2m spacing. This is a complete package from seed through the nursery stage, site preparation, planting and maintenance up to 5 years including replacement of losses[9].

In Costa Rica the total cost of teak planting in June 1998 for the first year at 1300 plants/ha with two weedings and fertiliser treatment was $US924. The estimated cost of establishing a teak plantation with spacing of 3 m x 3 m without genetically improved seedlings was $US1052 and with genetically improved seedlings was $US1150 for first five years (de Camino and Alfaro, 1998).

The cost of teak plantation establishment in Indonesia with seed at 3 m x 1 m spacing or with seedlings at 3 m x 2 m spacing with about 25% casualty replacement in first and 2nd year was $US140 per ha, with an overhead cost of about $US12 per ha per year[10].

Size (girth and length) and quality are two major factors affecting the price of teak logs besides market and other factors. In India the price of teak timber has been increasing by 13-18 percent annually. The price of teak logs with mid girth more than 90 cm in northern part of India during October, 1998 varied between $US540 to1008 per cubic meter. Teak logs of Nigerian origin were relatively cheap at $US630 per cubic meter while teak logs from natural forests in Maharashtra fetched the highest price of $US1093 per cubic meter. Logs of smaller dimension with mid girth 61-90 cm fetched price between 400 to 600 US$ per cubic meter (Anon 1998). In Indonesia the price of teak logs with more than 90 cm girth in 1998 was varying between 200 to 400 US $ per cubic meter and of lower girth between 100 to 200 US$ per cubic meter[11].

Strong demand for teak poles is reported in many countries growing teak (e.g. Ghana) and sales of thinnings early in the rotation can significantly increase the returns on the initial investment. There is, however, a danger that markets for poles may lead to “creaming” of the stand, with the largest stems of best form being removed, leaving poor material for the final crop.

A number of studies have been carried out on the potential returns on investment in teak plantations. Such calculations rely heavily on assumptions concerning growth rates, costs and timber prices, on which reliable data are scarce. The following may be quoted:

A study of teak plantations in Costa Rica (de Camino and Alfaro 1998) quoted an internal rate of return (IRR) of 12% where MAI was assumed to be 15 m^3/ha/year and rotation 25 years. An analysis of different assumptions of MAI, rotation length, price and costs showed the sensitivity of IRR to these factors, and emphasised the importance of reliable estimates. A similar IRR for teak of 14-15% was quoted for Papua New Guinea (Hammond, 1998).

In Ghana a study (Odoom, 1998) noted a Benefit/Cost ratio at 10% discount rate on fertile sites in the moist semi-deciduous zone of 2.4 (large-scale >100 ha) and 4.9 (small scale, <10 ha), and in the forest savanna transition on poor sites of 0.8 (large-scale) and 1.9 (small scale). The same favourable results with small scale farmers were reported for financial rates of return, of 15% for large-scale farmers and 20% for small-scale, due to the assumed returns from inter-cropping with cash crops to give a return in the early years of the rotation.

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[8] exchange rate 1US $ = 42 INR in November, 1998
[9] Personal communication to DP from Forest Departments of Maharastra, Kerala and Madhya Pradesh (India)
[10] Personal communication to DP from Perum Perhutani, November 1998
[11] Personal communication to DP from Forest Departments of Maharastra, Kerala and Madhya Pradesh (India)

Returns from a number of teak plantation scenarios were investigated for Malaysia (Krishnapillay, 1998). It was found that IRR for a 15 year rotation of teak was 17% for large-scale plantation and 16% for small-scale, but the study noted that, even allowing for income from thinnings, small-scale farmers were unlikely to be able to afford to wait so long for a return on their capital. A mixture of rubber and teak, however, grown on a small scale on a 20 year rotation gave an annual income from latex from early in the rotation and was calculated to give an IRR also of 16%, and Benefit: Cost ratio of 1.5, while remaining viable even at 20% reduction in revenue.

In summary, if the figures used in the calculation of economic and financial returns quoted above are reliable, especially as they concern to price, the results confirm that the decisions made by investors, especially by smallholders, for the establishment of teak plantations appear to be soundly based. The lack of reliable data on present costs and (especially) on future prices, however, must sound a cautionary note against optimistic extrapolation of economic returns.

6. Recent Trends

(a) Shift from large-scale to small-scale

The private sector has become more involved in the establishment of forest plantations than ten or twenty years ago, and the direct role of the public sector has diminished. Within the private sector there is a trend towards increasing numbers of small scale farmers acting as “outgrowers”, who incorporate trees into farming systems, or as small blocks, and who grow trees to supply large-scale industries. Examples are the growing of eucalypts by farmers for pulpwood in Brazil, India or Thailand or of poplars for peeler logs for matches and plywood in India. The same trend is apparent in teak, for example in Thailand, Costa Rica, and Ghana. Labour shortages in rural areas in Peninsular Malaysia have made the traditional labour-intensive crops such as rubber less economically attractive and have led to a dramatic increase in the involvement of small farmers in the growing of teak (Krishnapillay, 1998). Associations of growers have been reported in Central American countries, to represent the private sector and to help small growers obtain fair prices for their produce. The favourable economic returns on investment to small-scale growers have already been reported above) for Ghana.

Odoom (1998) described the three management models used for private tree crops such as oil palm and rubber in Ghana. They are:

- the smallholder system, where the smallholder does not own the land but is allotted it by a large company, which owns the land and which provides a guaranteed market, a loan, advice and inputs of planting material, fertiliser etc
- the outgrower scheme, which is similar to the smallholder system, but the farmer owns, leases or share-crops the land;
- the leaseback system, in which a farmer owns the land but does not farm it, leasing it instead to a private company

All of these systems are being tested in Ghana for small, private teak plantations

(b) Incentives

The use of incentive payments to encourage the establishment and maintenance of tree plantations, especially by outgrowers, has been reported by several countries. Such payments are required in general because of the lack of other credit or of collateral for credit, but are especially important for teak plantations due to the relatively long rotations.

Several Central American countries have had incentive schemes in place for several years, but have recently refined the systems, which have led to greatly increased planting rates (de Camino and Alfaro

1998). In Costa Rica the incentive system is specifically related to the provision of environmental services financed by a selective consumption tax on hydrocarbon fuels. It includes exemption from various taxes as well as access to credit and payment of a subsidy in the first five years of the plantation's life. Teak now constitutes 17% of the plantation area established between 1979 (the system was first introduced in 1969, but has been considerably modified over time) and 1996. Much of the expansion has been on the land of smallholders. In Panama investment in forestry is fully deductible for income tax purposes, while import duties are waved on equipment and machinery used in plantation activities.

Ghana has initiated a Forest Plantations Development Fund, which is intended to provide subsidies for the establishment and maintenance of plantations. Malaysia has recently offered "pioneer status" to investors in forest plantations, consisting of full exemption from corporation tax for 10 years, and an investment tax allowance on all income for 5 years; nevertheless these may not be sufficient to attract private sector investment to meet the country's ambitious plantation targets and other incentives may be required as well, such as access to credit or soft loans.

(c) Reduced rotation length

Teak has traditionally been grown on long rotations of 60 to 80 years or more for the production of veneer- or saw-logs, but there is a trend to shorter rotations with the move towards the ownership of teak plantations by small landowners or by outgrowers who cannot lock up capital over long periods. Teak has for many years been grown on short rotations for the profitable production of poles; now shorter rotations of 20 to 30 years are being tested and advocated for saw-log plantations in such countries as Malaysia, India, Brazil, and Costa Rica. A study carried out on the strength properties of teak timber produced from 20 year old canal strip plantation in India found properties matching well with standard teak (Sanyal et. al 1987). Studies on ornamental characters of the young teakwood are, however, lacking.

The effect of reducing rotation was tested in the case of Malaysia, which is changing to short rotations, using the same model of indicative volumes as was used to obtain the data in Table 2. Three scenarios, testing different rates of mean annual increment (mai), were tested for each rotation:
- a pessimistic scenario, where plantations were assumed to be confined to infertile sites and were poorly managed,
- a realistic scenario and
- an optimistic scenario, where plantations were established on fertile sites, there was good management practice and improved planting stock was available.

Two rotations were compared within each scenario, a short rotation of 25 years and a long rotation of 50 years. The rotations and scenarios are summarised in Table 3.

Table 3. Rotation and Increment Scenario (m^3/ha/year)

Pessimistic		Realistic		Optimistic	
short rot.	long rot.	short rot.	long rot.	short rot.	long rot.
8	3	12	5	15	8

Table 4 (below) and Figure 1 (annex) show the effect of reduction of rotation.

Table 4. Effect of Reduction of Rotation, Malaysia

rotation	increment	standing volume(1,000m3)					
(yrs)		2000	2010	2020	2030	2040	2050

a	25	8	46	78	104	123	135	144
b		12	68	116	157	184	202	216
c		15	86	145	196	230	252	270
d	50	3	17	30	42	52	61	68
e		5	29	50	69	87	102	113
f		8	46	79	111	140	163	180

Only where the short rotation "pessimistic" scenario and the long rotation "optimistic" scenario used the same increment (8m^3/ha/year), was the volume of the long rotation greater than that of the short rotation. Otherwise the volumes from the short rotation scenarios were always larger than those of long rotation scenarios, but it is clear that not all the volume from the short rotation can be used as timber and it is necessary to consider the technical problems of conversion, timber quality and economic return. Thus the volume of sawtimber from the short rotation may not be larger than that of the long rotation.

(d) Tree breeding

Teak has been incorporated into provenance testing and tree breeding programmes for thirty years or more, due to the historical importance of teak as a plantation tree and the availability for selection of a wide range of genetic material growing on many different sites. Improvement has been sought in growth rates, stem form (both straightness and absence of fluting) and in branching habit. An international provenance trial was sponsored and co-ordinated by the DANIDA Forest Seed Centre in the early 1970s, and 21 trials were evaluated in the 1980s when they were 9-10 years of age (Keiding, *et al*. 1986). Despite an imbalance in the representation of provenances between sites it appeared that there were large differences between provenances in a number of characters assessed. This conclusion was confirmed at the second evaluation (Kjaer *et al.* 1995) which showed large provenance x "trial region" (geographic region covering a number of sites) interactions for the traits investigated.

Constraints to rapid gains from tree breeding or from provenance trials include the long period between planting and flowering, the relatively low seed yield and viability of seed, difficulties in controlled pollination, and the long period before characters are expressed and can be evaluated (Kaosa-ard *et al*. 1998).

Tree improvement will be intensively discussed in Technical Session II of this workshop, so no attempt is made here to review the subject in depth, beyond noting the potential of tree improvement programmes to increase productivity and the potential of teak for tree breeding, and for the development of vegetative propagation

(e) Environmental impact

Many researchers on teak plantations in many countries have reported site deterioration, largely expressed as soil erosion. The cause is the lack of understorey or undergrowth in relatively dense single-species, even-aged teak plantations, made worse by fires in the dry season which burn the leaf litter and leave the soil surface unprotected from heavy rains, particularly at the beginning of the rainy season before the overstorey has developed new leaves. It is known from experience that plantation sites may deteriorate within and between rotations, but there is a lack of information about the effect on yields of the second rotation. There is also little recent experience in the use of mixtures of different species with teak; an extensive literature review, carried out as part of a general study on mixed tree species plantations in the tropics (FAO 1992) showed many examples of teak grown in species mixtures in the 1930s largely from India but also Indonesia, Nigeria, Benin, and Sri Lanka

The trend towards the use of species mixtures in teak plantation has been revived in India in the recent past, especially in large scale state owned plantations as result of critic by environmentalists. The species used in the mixture are often bamboo, *Gmelina arborea*, *Acacia catechu*, *Dalbergia sissoo* etc.

7. Conclusions

Attention has been focused on teak plantations as an investment in recent years due to the strong interest shown by private companies and individuals. Confidence in teak plantations as an investment appears to be justified by indicative forecasts of the relatively small (although increasing) volumes of teak wood available in the future in the light of the increased planting rates, and by calculations of costs and benefits showing favourable returns to investors. Nevertheless, caution needs to be exercised by investors in evaluating these projections, as explained below.

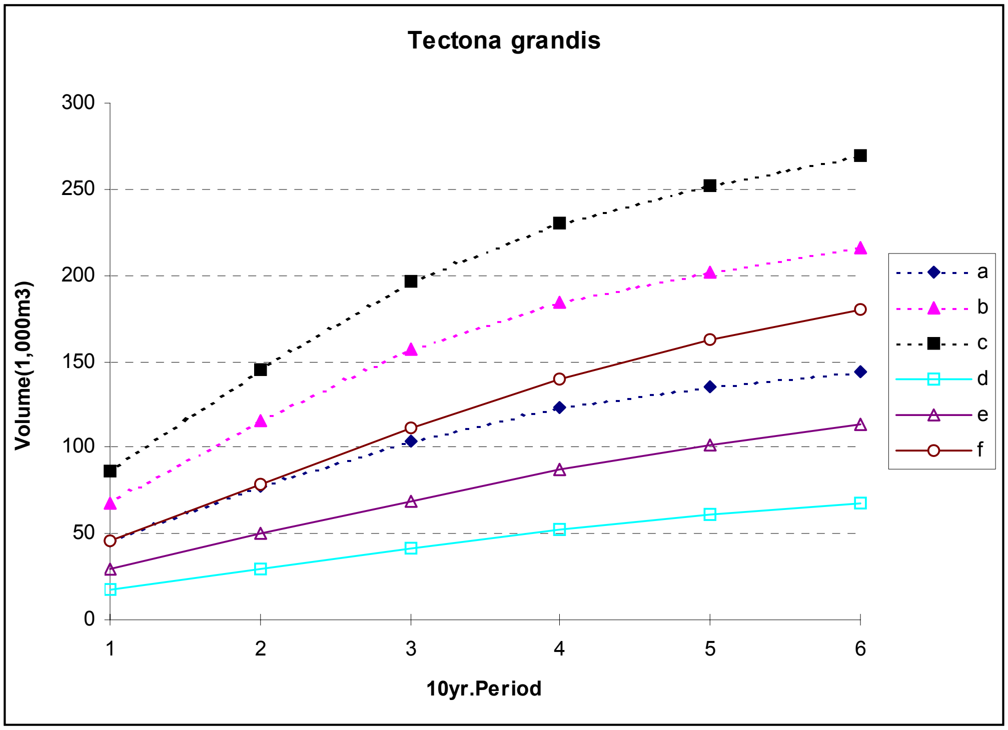
Technical developments in tree breeding and in the option of reduced rotation lengths may enhance returns, but considerable research is essential into many aspects of teak plantation silviculture, management and utilisation. In particular further investigation is needed into the differences in timber properties that may exist between short-rotation plantation-grown and teak from natural or other long-rotation stands, including the effects of provenance and site on growth rates and wood quality. New research is needed into such aspects as the effects on growth and wood quality of pruning, the effects on the site of growing teak in mixtures (where experiments established in the past might be re-evaluated), sustainability of productivity of short rotation plantations and differences in yield or timber properties from second or subsequent rotations, effect of site or provenance on appearance, conversion techniques for small sized timber, and techniques for reconstituting small saw wood as larger material.

But above all, considerable uncertainty exists regarding the basic information needed to plan future teak plantation programmes. There is a lack of reliable information on yields and costs but especially on future markets and prices for plantation-grown teak wood for the calculation of returns. There seems indeed to be a lack of information on future markets for "luxury" hardwoods in general. Such information is required not only to give investors a reliable indication of the likely return on investment, but also for policy decisions related to the payment of different kinds and rates of incentive for teak plantation establishment.

The need for reliable and objective information is especially important to the growing number of investors in the private sector, especially small landowners who may lack the means or the knowledge to carry out their own evaluations of the potential risks and rewards from a stake in a teak plantation. Such risks may not only be financial but may be environmental as well.

Annex

Figure 1. Effect on Timber Production of Teak, through Reduction of Rotation, Malaysia (see text, pp. 11-12)


Tectona grandis
Volume(1,000m3)
300
250
200
150
100
50
0
1
2
3
4
5
6
10yr.Period
a
b
c
d
e
f

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