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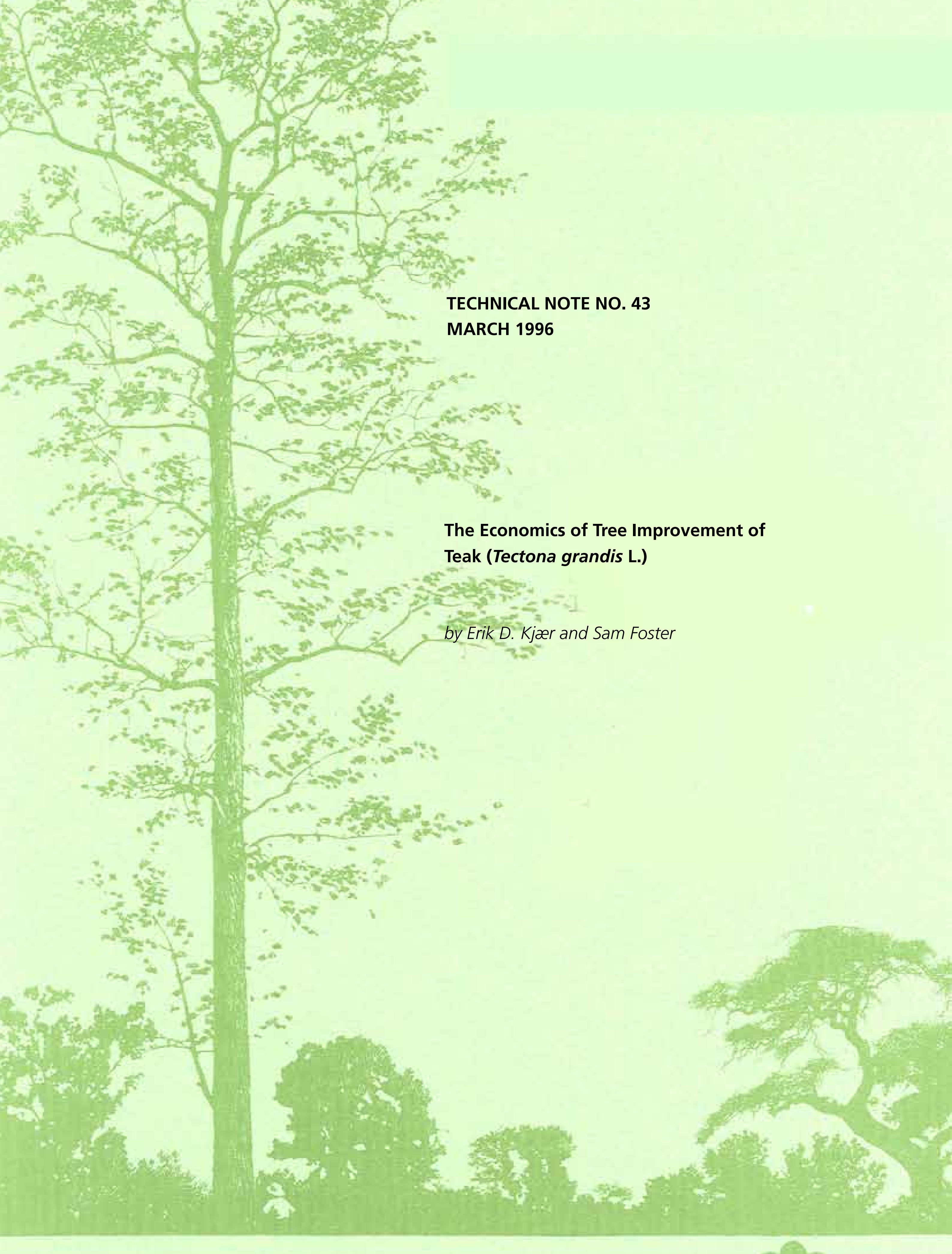

TECHNICAL NOTE NO. 43
MARCH 1996

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DANIDA FOREST SEED CENTRE

Titel
The Economics of Tree Improvement of Teak (*Tectona grandis* L.)

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Contributor
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Publisher
Danida Forest Seed Centre

Series - title and no.
Technical Note no. 43

ISSN:
0902-3224

DTP
Melita Jørgensen

Citation
Erik D. Kjaer and G. Sam Foster, 1996. The Economics of Tree Improvement of Teak (*Tectona grandis* L.). Danida Forest Seed Centre, Humlebæk, Denmark

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This paper was prepared as a joint effort between the World Bank and Danida Forest Seed Centre.

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1. INTRODUCTION

This paper discusses the economics of improving the genetic quality of teak through forest tree improvement. The question is addressed from a general point of view, but the situation in each country is of course unique. The paper can be considered as a guide to the evaluation of the economics of genetic improvement of teak in a specific country - and also as an example of the gains that can be obtained under realistic conditions.

1.1 The global plantation area

Teak has been used for decades in plantation establishment, either as an indigenous or an exotic species. The species is easily established in plantation regimes compared to many other high value tropical species. Teak is used for many purposes, but the most important end use is timber, mainly for furniture and other high value products. The quality of the wood is therefore very important.

The total area afforested with teak can only be estimated with some caution, as no complete survey is available. White (1991) refers to several estimates of teak plantation areas in different countries in Asia, Africa and Latin America. Most of the area is located in Asia, mainly Indonesia, India, Thailand and Myanmar (formerly Burma), but the species has potential as an exotic in many other parts of the tropicai world.

1.2 The tree improvement option

Forest tree improvement activities have been reported from several countries e.g. Tanzania (Madoffe and Chamshama 1989), Thailand (Wellendorf and Kaosa-ard 1988, Kaosa-ard 1993), India (Chandha and Patnik 1990, Kumaravelu 1993), Indonesia (Harahap and Soerianegara 1977, Suhaendi 1990, Indonesia Forest State Enterprise 1993), Myanmar (Htun and Kaufmann 1980, Gyi 1993), Bangladesh (Huk and Banik 1990, Banik 1993), Papua New Guinea (Cameron 1968), Sri Lanka (Maddugoda 1993), China (Bingchao and Shuzhen 1993) and Costa Rica (Gamboa and Montoya 1992).

Teak is interesting from a tree improvement point of view because:

(i) it is used on a large scale,
(ii) the timber is of high value,
(iii) it is normally regenerated artificially, which allows introduction of improved genetic material. Coppicing is used in parts of India, and introduction of improved material in these parts will require a new silvicultural practice.

The costs of improving teak are unfortunately increased by poor fruit setting capacity and low seed quality. The seed shortage is increased by wasteful nursery practices, which (with present technique) only produce one seedling per 20 sown fruits. Wellendorf and Kaosa-ard (1988) estimated (assuming planting of 800 - 1500 stumps/ha) a seed demand of 8 - 15 kg teak seed per ha of plantation to be afforested. Kaosa-ard (1991) has calculated that this would require at least 1 ha clonal seed orchard for each 16 ha plantation to be established annually. The seed consumption varies between countries and regions due to differences in germination percent and nursery technique. Srimathi and Emmanuel (1986) report a survey from India, where the average seed consumption per ha planting varied between 2.5 kg seed in Tamil Nadu (Southern India) to 30 kg per ha in Andhra Pradesh and 43 kgs in Gujarat (Central India). Part of these large differences is due to differences in germination percentage, but it must also be due to sub-optimal nursery technique. A substantial reduction in seed consumption through improved nursery technique should therefore be possible. This would be very beneficial from a tree improvement point of view, as it would reduce the required seed orchard area.

Teak is a slow growing species, and tree improvement therefore a long term investment. The rotation age is traditionally high (60 - 100 years). Application of improved material will reduce the rotation age, because of the improved growth rate. The rotation age of teak plantings grown for traditional products could therefore be reduced to 40-50 years by using improved planting stock. Still, ten to fifteen years may pass from the initiation of an improvement programme before the first improved seeds are available, and another 40-50 years will then pass before the timber from the first rotation of improved planting stock is harvested.

The slow growth rate of the species is a drawback in a tree improvement context for two reasons: the internal rate ofreturn (IRR) may be low due to the discounting factor, even if the tree improvement activities result in a large increase in annual value production on harvesting. Further, the superior plus trees will be selected at a mature stage, but their breeding value will be assessed from progeny tests (collecting seeds from the plus trees and growing them under field trial conditions), and these must be evaluated at a young stage in order to save time. One must therefore rely on a good concordance between the juvenile performance and the performance at harvesting age.

The preferred rotation age may change in the future due to the development of new products like joinery or parquet floors. New plantation programmes in Costa Rica and Brazil plan rotation ages of 20-30 years. The end use is expected to be wood products, based on small dimension timber.

2. GENETIC VARIATION

2.1 Genetic variation at the provenance level

Teak has a wide, but discontinuous natural distribution covering India, Myanmar, Thailand, Laos and probably Indonesia. The species is distributed over an area with large variation in edaphic and climatic condition. For example, teak in India can be found in areas with annual rainfall from less than 900 mm (in the interior) to more than 2500 mm (on the west coast). Teak is also grown in plantations outside the natural distribution area. These new areas with teak plantings in Africa and Central America have offered teak further variation in conditions of growth. Continued selection of individuals adapted to local climates and soils may have formed "land races" in these new areas, each with its own distinctive characteristics.

The large differences in growth conditions within the natural range of teak indicate the probability of genetic differences between origins. These differences were tested through an international network of provenance trials (Keiding et al. 1986, Kjaer et al. 1995), which probably provides the best available information on general provenance variation. The trials reveal genetic variation between a number of provenances (indigenous and land races) tested at locations within and outside the natural distribution area. The general results from these and other trials are that the local seed sources should normally be preferred when teak are established within the natural distribution area (White 1991). The local seed sources are not always the most fast growing, but they generally give an acceptable result. The correct choice of seed source outside the natural distribution area is more difficult. For example, the Nigerian »land race« should not be preferred for industrial plantations in Nigeria, because of poor stem form and growth. The local seed sources may, however, be suited for other uses in Nigeria, as the survival is very high. The question of selecting seed sources in teak when planted outside the natural distribution area is therefore complex. Some assistance can be found in Keiding et al. (1986) and Kjaer et al. (1995) which identify some of the south Indian and Indonesian provenances as very stable under different conditions. Additional local trials may be necessary.

2.2 Genetic variation within provenances

Only little is known of the variation within provenances, as most clonal and progeny trials are still young. The few available data do, however, reveal genetic variation in both growth and stem form (Harahap and Soerianegara 1977, Wellendorf and Kaosa-ard 1988).

Wellendorf and Kaosa-ard (1988) have calculated that selection of 25 percent superior clones in a clonal trial is expected to increase the growth rate by 6 percent (measured as juvenile height). The oldest available data from progeny testing (half sibs) probably originates from Tanzania (Persson 1971). This progeny trial was established in 1966. At age 18 the 25 percent best progenies were 15 percent taller than the average. The genetic response from selecting the best 25 percent of the parent clones can be estimated at 6 percent in height at age 18 (Wellendorf, unpublished).

The possibilities of genetic response in terms of qualitative characteristics have not been thoroughly investigated, but may be as important as in growth. Quality characters such as stem straightness, absence of epicormics, long clear bole, fluting and colour are all very important traits, and may be possible to improve. Investigations in Thailand have revealed important phenotypic variation in colour characteristics, but much of the observed variation may be due to differences in soil or climate (Kaosa-ard, pers. com.).

3. WHAT CAN BE GAINED FROM TREE IMPROVEMENT?

Tree improvement activities involve selection and utilization of the most valuable part of the genetic variation. The possible gain will therefore depend on (i) the size of the genetic variation and (ii) the intensity and efficiency of the selection. A detailed guide to estimation of genetic gain in yield characteristics is given by Foster (1992). The question is here discussed in less detail with specific reference to teak.

The provenance trials described in section 2.1 have shown the importance of selecting the right provenances, especially when teak is grown as an exotic species. Keiding et al. (1986) report differences in performance between best and worst provenances of 30-40 percent or more (both in quality and production) from trials in countries exotic to teak. It is therefore considered vital to focus on selecting the right provenances before dealing with the question of selecting plus trees within good provenances.

Once the right provenances have been identified, further gain can be achieved through traditional improvement activities. In the initial stages of a simple tree improvement programme, the gain will originate from selection at two stages: i) plus tree selection and ii) progeny testing.

3.1 Gain from selecting phenotypically superior plus trees

The first stage is selection of phenotypically superior trees (plus trees) from native stands or plantations. Mature trees will normally be selected, because they are able to produce seed and because they are close to rotation age and exhibit the desired mature trait. The gain from this selection may be fairly low, because the selection is based on the visible performance of the trees (i.e. their phenotype), which is a product of the environment as well as their genes. We have found no adequate data which would allow us to calculate a good estimate of the expected gain from plus-tree selection. Generally the gains achieved from plus-tree selection are in the magnitude of only a few percentage points in increased growth rate, but the gain in stem form may be substantially higher. Two to four percent gain in value may apply to many situations. Sometimes higher values can be achieved, especially when considering the importance of stem form.

3.2 Gain from selection based on progeny trials

The second selection cycle involves selection of the best proportion of the phenotypic plus trees and using them for mass propagation. This selection is based on the average performance of offspring from the plus trees rather than their own phenotype. Selection for fast growth in particular can be performed much more efficiently in progeny trials than by simple phenotypic selection. Several offspring are used for each plus tree (»replications«), and the field trials are established on fairly homogeneous locations, where the differences in environmental influence can be controlled much better than in native stands.

The Tanzanian trial, referred to in section 2.2, suggests a genetic gain of 6 percent in height at age 18. The gain depends on the differences between the progenies, and the heritability. This figure cannot be applied directly, as the important measure is the gain in volume at rotation age, rather than height at juvenile age. It is therefore not simple to estimate the gain at maturity based on juvenile selection. One option is to use available yield tables to describe the growth curve of the species on a given locality, and then project the juvenile gain according to the yield tables. The idea is to convert »gain in percent height at the young age« to »gain in site class« at this age. The yield tables can then be used to determine how much the given gain in site class will improve the production over the entire rotation. The gain at mature age is thus predicted from the gain at juvenile age by assuming that differences between improved and unimproved material can be treated as equivalent to differences in site class. The difference in height (20 years) between the Indonesian teak site class (bonita) I and II is e.g. 29 percent, see Table l, (Suharian et al. 1975). The corresponding difference in average volume increment over 50 years can be found in the yield table to be 46 percent. For example, a 10 percent gain in height corresponds to an improvement of .35 site class, equivalent to a gain of .35 x 46 percent = 16 per cent gain in volume production. One percent gain in height therefore corresponds to 1.6 per cent gain in volume over a 50 year rotation.

Table l. Yield table for teak in Indonesia

	Bonita I	**I**	**Bonita II**	
Age	**Height (m)**	**Mean annual increment (cub. m/year)**	**Height (m)**	**Mean annual increment (cub. m/year)**
20	14.4	5.3	18.6	9.0
50	20.2	6.7	25.4	9.8

The relationship between site class II and III is a little different, but not much. Based on all combinations of site classes the relation can be estimated to be approximately 1.3 percent gain in volume over 50 years for each one percent gain in height at age 20. This relationship is relatively independent of which of the two site classes used, but dependent to some extent on which yield tables are used. An examination of other yield tables reveals that a 1.2 percent gain in volume over the rotation for each one percent gain in height at age 20 seems to be an acceptable estimate as average for different yield tables (calculations are not shown).

Knowe and Foster (1989) give a detailed example of application of growth models for estimating genetic gain when more sophisticated modeis are available.

3.3 The aggregated gain

The total gain in volume from a simple tree improvement programme (plus tree selection, establishment of clonal seed orchards, progeny testing and a moderate rogueing (genetic thinning)) can thus be summarized to be around 10 percent:

- the plus tree selection may yield 2-4 percent, and
- the progeny testing may give additional 6 percent in height at age 20, which should correspond to 6-8 percent volume for the entire rotation (6 percent height (20 years) multiplied by 1.2).

Gains in stem form, clear bole and other quality traits are difficult to estimate based on available data. Stem-form gain from the plus tree selection may be relatively large (higher heritability than for volume), but the corresponding gain from the progeny testing may be a little less than for volume (due to low correlation between young and old ages). The overall value gain in production and quality may therefore be equally important. Several other traits can be included in the improvement programme, but it should be remembered that the more traits included, the less the improvement will be in each trait.

An estimate of the total gain in value from a simple improvement programme in teak may therefore be 10 percent. This figure is used in the rest of this analysis, but it should be remembered that the estimate is »at the lower end«. Advanced breeding programmes may of course also result in larger gains, but will also be more costly.

3.4 The question of regional differences in growth conditions

Teak is grown at a number of different sites covering an ecological amplitude from semi-moist to semi-dry areas. The soil conditions also vary within and between the teak regions. The superior genotypes at one (e.g. moist) location may therefore be inferior at another (e.g. dry) location. This situation is called interaction between genotype and enviromnent (GxE-interaction) (reviewed by Matheson and Raymond 1984). The practical implication of interaction between sites and genotypes is that the relative performance of a particular genotype changes from site to site. It is therefore not possible to identify and select »overall best« plus trees: the plus trees must be tested and recommended within a number of »breeding zones« . The breeding zones consist of areas with reasonably homogeneous ecological conditions. Breeding zones are theoretically equivalent with seed transfer zones (described by e.g. Barner and Willan 1983 and Westfall 1992). The incentive for making the breeding zones as large as possible is, however, stronger than in the case with seed transfer zones. The costs of the improvement work is almost proportional with the number of breeding zones, because all the breeding activities must be made separately for each zone. Each breeding zone will therefore almost always include small differences in growth conditions and enclosing these differences in a single large breeding zone will reduce the expected gain. The size of the loss depends on the size of the interaction. Experience from temperate conditions suggests loss in the order of 20-40 percent, but at least on the provenance level, interaction seems less serious for tropical tree species (Matheson and Raymond 1984).

3.5 Size of the planting area

The size of the possible gain is only one key factor in determining the benefits from tree improvement. The overall gain at a national level will be proportional to the size of the planting area.

The size of teak planting areas varies among different countries. Results from tree improvement programmes can, however, be extended to countries within any homogeneous region (that is a region with small GxE interaction). Such extension could take place in terms of commercial trade of improved seed between countries. The size of the area planted with the species will be of paramount importance in allocation of tree improvement priorities to species. Even very large genetic gains may be of little national importance if they are achieved in species of minor use. Altenatively the economic value of improving the production of widely planted species by only a few percent may be very great.

3.6 Productivity of the forest area

An important factor is of course not the simple area afforested with the species, but rather the *total volume* - or even more precisely the *value of total volume* - produced on this area.

The increased return from teak improvement programmes was estimated above in percent of total value production. The size of the afforested area in combination with estimates of the productivity of these soils - and the value of the production - is therefore the major factor in determination of the total benefit to be derived from an improvement programme.

Yield tables for teak have been published for a number of countries, and regions within countries. Yield tables from regions with comparable soils and climate may be used as a guideline if no local yield tables are available:

From Asia:

Indonesia (Suharian et al. 1975, Pandey 1983), *The Philippines* (Gonzales 1985), *Myanmar* (Tint and Scheider 1980), *India* (Singh 1981, Pandey 1983), *Thailand* (Royal Forest Department undated).

From Central America and Caribbean:

Trinidad (Miller 1969, Pandey 1983), *Puerto Rico* (Friday 1987), *El Salvador*, *Jamaica*, *Trinidad* (Keogh 1980).

From West Africa: *Ivory Coast* (Dupuy 1990).

The growth differs greatly between the countries, and between site classes within countries. The economics of tree improvement will be most favourable on the best site classes, and an assessment of the site quality of actual or potential teak soils is an important step in evaluating the economics of a given improvement programme.

3.7 Value of teak timber

The development in the value of the timber is as important as the volume production. Currently teak is one of the most valuable plantation species in the tropics. Prices of teak sold in Thailand (1988) averaged 454 US$, in India (1982) 350-430 US$/cub.m. (Source: FAO, 1989). The value will probably increase in the future, as tropical hardwoods become increasingly rare. The price of sawn teak wood has increased by 6 percent per year in **real terms** during the last 20 years (Kirmse 1992). There is no reason to expect that this tendency should change in the nearest future.

4. ECONOMICS OF IMPROVING TEAK AN EXAMPLE

4.1 Summary of the steps in calculation of economics

The economics of an improvement programme in teak depends on several local and regional conditions as described above. Therefore, the economics must be evaluated separately for each national/regional programme. An example of the economics of one alternative is calculated in this paragraph in order to clarify the question and to suggest a level of realistic economic return.

The economics in this example is evaluated in a stepwise manner in order to look into the different elements:

- gain in value production over the entire rotation (discounted values)
- costs of propagating improved material
- cost of research and development activities performed in order to select and identify superior genotypes, and finally
- the internal rate of return of the entire tree improvement activities.

We start out by estimating the gain per ha of plantation from using improved material. The calculation is based on our estimate of gain described in section 3. The gain is discounted to the time of establishment of the improved plantation at various discount rates in order to establish the present value of the gain from increased future production.

We assume that one ha plantation is established with 1110 seedlings. The discounted gain can be divided between the 1110 seedlings planted per ha to give the value added to each seedling due to the fact that it originates from improved material rather than unimproved seed source (the seedling's »extra value«). In other words, it is the extra price that a tree planter can pay for an improved seedling.

The next step is to estimate the costs involved in mass propagating the improved seedlings. That is the cost of establishing and maintaining seed orchards plus growing the seedling, or the costs of vegetative propagation by means of tissue culture. The cost can be calculated per ha planting, or per seedling. In the latter case it allows us to compare the mass propagation costs with the »extra value« of the improved seedling. *It is only economically beneficial to mass-propagate an improved seed source, if the »extra value« of seedlings from this source exceeds the propagation cost.*

Propagation costs are calculated in net present value at the time of plantation establishment in order to be able to compare the costs of (rapid) vegetative propagation with the cost of (slower) traditional propagation through seed orchards and seedlings. The costs include only the additional costs of producing improved planting stock, over and above the basic costs of producing standard unimproved stock.

The Net Present Value (discounted profit) obtained by using the improved planting stock is calculated next. This is estimated as the present value of the increased production (extra value) minus the additional cost of propagation (propagation costs). This figure multiplied by the total annual plantation area gives the annual benefit of the improvement programme.

Finally, the overall economics is measured by calculating the internal rate of return of the entire improvement enterprise. This calculation is made in order to compare the profitability of tree improvement with other types of long termed investments. The Net Present Value (discounted profit) is formally the most correct way to calculate the economics, as the amount of input factors can vary so much.

4.2 Assumptions

Standard assumptions in this example are based on the discussions above. All prices are converted to 1989 level. Further assumptions are listed below:

4.2.1 Rotation age

Rotation age is assumed to be 50 years. The rotation age may be reduced in the future as described above. The effect on tree improvement economics will be discussed in paragraph 4.8.1.

4.2.2 Estimate of improved production

Use of improved planting stock is assumed to result in a 10 percent increase in value production compared to seedlings from traditional seed sources. The gain may originate from increased volume production, improved quality, or a combination. The gain refers to the first breeding cycle, and advanced generations of breeding will increase the total gain, probably of the same magnitude. In this example however, we only focus on the gains and costs involved in the first breeding cycle. The estimate must be considered to be at the lower end, as discussed in paragraph 3.3.

4.2.3 Commercial volume from thinning and clear felling

The total harvestable commercial volume is assumed to be 500 cum per ha per rotation distributed as shown below:

Year	Harvested commercial volume
10	O
20	50 Thinning
30	50 Thinning
40	50 Thinning
50	350 Clear felling

The estimate is based on several yield tables (see references in paragraph 3.6). It must be considered a crude average, as the productivity is highly dependent on the soil type. Significantly lower production must be expected on poor sites. Teak belongs, however, to fertile soils. The assumed production is fairly low for these optimal teak soils, and therefore it should be acceptable as an average for plantation areas which also include a minor proportion of less fertile soils.

4.2.4 Value of harvested timber

The value of clear felling is assumed to be 600 US $/cub.m. (1989 prices). The value is expected to increase by l percent per year in real terms. This increase is much below the recent 6 percent increase of relative teak prices mentioned earlier, but we assume it is a fair estimate for long term development. The economics of the improvement will be much better if the present increase in prices continues for one or more decades. Alternative calculations are made in paragraph 4.8.3 assuming two alternatives: (i) stable prices and (ii) an annual increase of 2 percent in real terms.

The volume from thinnings is expected to be sold at 100 US$/cub.m., increasing l percent per year in real terms. Thus the value is assumed to be 600 US$ for clear felling and 100 US$ for thinning (both increasing l percent per annum). This price equals an average price of 450 US$ per cub.m. (600 US$/cub.m. 350 cub.m. clear felling plus 100 US$/cub.m., 150 cub.m. thinning *divided* by the total production of 500 cub.m. per ha).

Extraction of the additional volume (felling and transportation) is estimated to cost 10 US$/cub.m. This cost is assumed to follow the development in the teak prices.

4.2.5 Assumptions concerning seed orchard productivity and costs

The costs of mass propagating the improved material are high in teak. The analysis is based on the assumption that the propagation is done in grafted clonal seed orchards. This technique is expensive in teak due to the low seed production per tree, as mentioned above. It is assumed that one ha of seed orchard annually produces 180 kg seeds, that production commences at age 10, and that the seed orchard remains productive for 20 years. Further, it is assumed that an average of 6 kg of seed orchard seed is required to establish one ha of teak plantation. Thirty ha of teak plantations can thus be established every year from the seed yield of one ha of clonal seed orchard.

The cost of establishing one ha clonal teak seed orchard is estimated at 3,000 US $. The maintenance may be assumed to be 150 US $/ha per year. The cost for land-use is not ineluded.

4.2.6 Rate of interest

The increased cash flow from using improved seedlings can be calculated based upon the assumptions presented above. However, the costs and benefits will appear in different years, and all future costs and returns must therefore be converted into present values by an appropriate discounting factor. The discounting factor depends on rate of interest. Different rates may be applied in different situations. The rate used for discounting should be the real rate, less the nominal rate, less inflation. For example, the real rate will be only 5 percent, if the nominal rate is 20 percent, but the annual inflation is 15 percent.

Interest rates of 3 percent or less are often used in long termed socio-economic calculations in developed countries. Developing countries may apply higher rates of interest (e.g. 5-8 percent), as more profitable investments are available. The interest rate should be selected with caution in each case, as it has paramount impact on the result of the economic analysis. An interest rate of e.g. 12 percent means that the benefits of 4 units of some amenity received by the population today is more important than the alternative benefit of 1,000 units of the same amenity received by the population in 50 years! (The discounting factor is (1/(1+0.12)50) = 0.0035). The question of selecting the appropriate rate of interest is discussed in detail by Pearce and Nash (1981).

In this study we assume that a rate of 5 percent may be suitable in many situations, considering the long time span of the investment. All calculations are performed at 3, 5, 8 and 12 percent in order to reveal the economics at different interest rates.

4.3 Present value of gains from the increased value produetion

The increased value production from using improved planting stock can be calculated based on the above assumptions. The flow of gains in value from using improved planting stock is shown in Table 2. The total gain over a fifty year rotation is estimated at 35,787 US $. The average yearly gain is thus 716 US $ per ha.

Table 2. Gain from increase in future volume production of teak.

Year	Harvest (cub.m./ha)	Value (US$/cub.m.)	Total value (US$)	Gain from Tree Improvement (US $)
0-10	O	90		
11-20	O	99		
21-30	50	109	5,490	549
31-40	50	121	6,070	607
41-50	50	134	6,700	670
50	350	970	339,690	33,969
Total	500		357,870	35,787

The gain in terms of the *Present Value of Gains* (PVG) is calculated below by multiplying each yearly gain with the discounting factor D,

$$D(\text{year } j) = (1 + i/100)^{-j}$$

where i is the interest rate and j is the number of years from planting. PVG based on interest rates of 3, 5, 8 and 12 percent are presented below. The results referring to 5 percent are typed in bold face, as this interest rate could apply to many plantation programmes in tropical countries:

PVG (3 percent): 8,506 DS $/ha.
PVG (5 percent): 3,404 US $/ha.
PVG (8 percent): 933 DS $/ha.
PVG (12 percent): 202 DS $/ha.

The PVG is the value of the future benefits discounted back to the time of planting. One ha of newly established plantation of improved teak will be worth 3,404 US $ more than the same ha cultivated with seedlings of an unimproved seed source (assuming i = 5 percent). This difference can be broken down to a per-seedling value (extra value) assuming 1,110 seedlings used per ha).

Extra value (3 percent): 7.65 DS $/Seedling.
Extra value (5 percent): 3.06 US $/Seedling.
Extra value (8 percent): 0.84 DS $/Seedling.
Extra value (12 percent): 0.18 DS $/Seedling.

One can say that the PVG calculated above is the money that the tree planter loses by using non-improved planting stock, if both improved and un-improved seed sources are available at the same price. Of course, improvement and propagation cost money, and these costs should therefore also be considered.

4.4 Costs of propagation

4.4.1 The costs of propagation by means of seeds

One hectare of seed orchard is required for every 30 ha of annual planting. The orchards are estimated to cost 3,000 US $ per ha in establishment and 150 US $ per year in maintenance. How much will these costs increase the costs of using an improved planting stock compared to unimproved? Again this will depend on the interest rate, because the costs of establishment must be paid ten years before the first seed is produced in the seed orchard. For example, if the money for establishment is borrowed in a bank, then one should also include the interest (less inflation) paid during the ten year time lag from establishment to the initiation of seed production. A newly started private enterprise can include the actual costs involved in borrowing money from a bank and investing it in a given seed orchard programme. Self financing enterprises, or governments, must select an appropriate interest rate as in the case of PVG above, but in this case the cost of seed orchards should be compounded rather than discounted. Each payment should thus be multiplied with a factor I,

$$I(\text{year } j) = (1 + i/100)^{(10-j)}$$

where i is the interest rate and 10-j is the numbers of years until year 10. For example, the establishment cost should be multiplied with $I(0) = (1 + 0.05)^{(10-0)} = 1.65$ in order to calculate the correct value year 10. The total investment in one hectare of seed orchard (i.e. costs from year 0 to year 10) is calculated below:

Value (at age ten) of costs from year 0 to 10:

PVC (3 percent):	5,601	US $/ha
PVC (5 percent):	**6,623**	**US $/ha**
PVC (8 percent):	8,499	US $/ha
PVC (12 percent):	11,800	US $/ha

The seed orchards are assumed to give a yearly production of 180 kg per ha in their twenty year life span. This is a total of 3,600 kg per ha - sufficient for 600 ha new plantings, or 667,000 seedlings assuming a spacing of 3 x 3 m. How much are the costs increased because of the seed orchard cost? Consider the situation the first year with flowering in the seed orchard. The total »investment« in the seed orchard (year 0 to 10) has so far been 6,623 US$ per ha. This investment should be depreciated during the following 20 years, and interest should be paid for the invested money. An easy way to handle this cost within the framework of standard economics is to calculate the annual payment which can »amortise« the »invested« money over 20 years (please refer to standard economic textbook for details on calculations).

The annual payment to amortise the »investment« in one hectare of clonal seed orchard (e.g. 6,623 US$, i=5 %, 20 years) can be calculated to be 531 US $/year. The cost for maintenance (150 US $ per ha) shall also be added in order to calculate the annual cost.

This cost can then be divided between the 180 kg seed - or between the 30 ha plantings - or between the 33,330 seedlings. The cost per hectare and per seedling is shown in Table 3[1].

[1] e.g. for i = 5%

$$\frac{531 + 150}{30} = 22.7 \text{ US\$} \qquad \frac{531 + 150}{33{,}330} = 0.020 \text{ US\$/seedling}$$

This cost can be considered as the additional production cost of one seedling due to costs of establishing and maintaining seed orchards.

4.4.2 The costs of propagation by means of tissue culture

Improved material cannot be introduced until ten years after planting because of the late flowering of the seed orchard. An alternative to clonal seed orchards (CSO) is vegetative mass propagation by means of tissue culture. This technique has been developed on a commercial scale in teak (see e.g. Kaosa-ard 1990). Tissue culture requires intensive capital investment, but has the advantage of saving time and avoiding the problem of unreliable seed supply. The improved genetic material can be introduced faster into the plantations, as one does not have to wait ten years for flowering. The genetic superiority of this improved material will however depend on the efficiency of the plus tree selection. The clonal trials (for genetic testing) must grow for five to ten years before they can contribute with important information. The assumed gain will therefore be less than ten percent in the initial phase.

The propagation cost involved in tissue culturing has been estimated by Kaosa-ard (1990) to be approximately 0.03-0.06 US$ per plant (assuming 12 percent interest charged on 30 percent of fixed assets). Lining out results in a little less survival of the plant than traditional seedlings and the total additional cost may be in the neighbourhood of .06 - .08 US$ per plant. This is higher than the CSO costs shown in Table 3, when the applied interest rate is below 12 percent. At 12 percent the costs of tissue culture is close to the costs of CSO propagation.

Table 3. Gain from using improved teak planting stock compared to the propagation cost

Interest rate	Gain from using improved material (US$/ha)	Extra costs due to CSO costs		Profit before R&D (research and development) costs (US $ /ha)
		US$/ha	US$/seedling	
3 percent	8506	17.6	0.016	8488
5 percent	**3404**	**22.7**	**0.020**	**3381**
8 percent	933	33.9	0.031	899
12 percent	202	57.7	0.052	144

The comparison between CSO and tissue cultured clones is only applicable after the CSOs start flowering, i.e. after 10 years. *Before that starting point tissue culturing (or other means of vegetative propagation) is the only way to introduce improved material.* The »time gap« between the tissue propagated clones and CSO will of course be maintained, and improved material from a second breeding cycle will therefore also be introduced to the forests approximately ten years before the seedlings from CSO. The result, that CSO are the most economical way of mass propagating the improved material once CSO seeds become available, is only valid under the assumption of equal gain from the two methods. A small percentage additional genetic gain due to the tissue cultured method (clonal selection yields somewhat higher gain) will make the tissue cultured plants competitive provided there is a substantial annual planting programme. It is important to notice that the propagation costs, *CSO or tissue culture*, are small compared to the possible gains from using improved planting stock.

The question of tissue culture versus clonal seed orchard is also a question of seedling forestry versus clonal forestry . This has many other aspects than the simple costs and expected gains.

4.5 Comparison of propagation cost with the possible gain: The value of maintaining a tree improvement programme

The extra costs involved in mass propagating improved seedlings for one ha of teak plantation can now be compared directly with the additional gain achieved by using this improved stock instead of a cheaper unimproved material (Table 3).

The profit before research and development (R&D), multiplied by the total annual planting area gives the value of having identified superior genotypes for mass propagation. For example, if 500 ha are planted every year, then annual value will be 1,690,500 US$, for i=5%.

4.6 Costs involved in research and development

The initial cost for selecting superior trees, harvesting seeds from plus trees, establishing progeny trials, assessing the performance, analysing the data and other breeding activities has not been entered into the calculation so far. It is obvious that an afforestation of some magnitude is necessary in order to finance these activities. If one assumes that these activities cost 200,000 US $ per year for ten years, then the total cost of tree improvement will be 2,000,000 US $. These costs precede the introduction of the improved planting stock by up to ten years just like the costs for seed orchards described above. Therefore, they must be compounded to year 10 in the same way.

PVC (3 percent) =	2,362,000 US$
PVC (5 percent) =	**2,642,000 US$**
PVC (8 percent) =	3,130,000 US$
PVC (12 percent)=	3,930,000 US$

These costs refer to a substantial breeding programme. Smaller plantation programmes may be located in fairly homogeneous conditions (only one breeding zone) and smaller testing regimes could be sufficient. This will reduce the costs and, undoubtedly, excellent breeding programmes can be set up for less money in many situations. The costs are, however, so different from country to country, so the high costs are chosen as a standard assumption. The figures can be discussed separately in country/region.

4.7 Will tree improvement be profitable on the national level ?

The value of the costs of a breeding programme is for example 2,642,000 US$ for i=5 %. This means that the total costs of the research and development activities can be financed from the increased productivity of 800 ha (2,642,000 US$/ 3,381 US$/ha = 781 ha) teak forest planted with the improved material. If 500 ha teak are planted every year, then the increased future productivity can be said to pay back the research and development costs in only two years. The gains from establishing stands with improved material in future years will then make the tree improvement activities highly profitable.

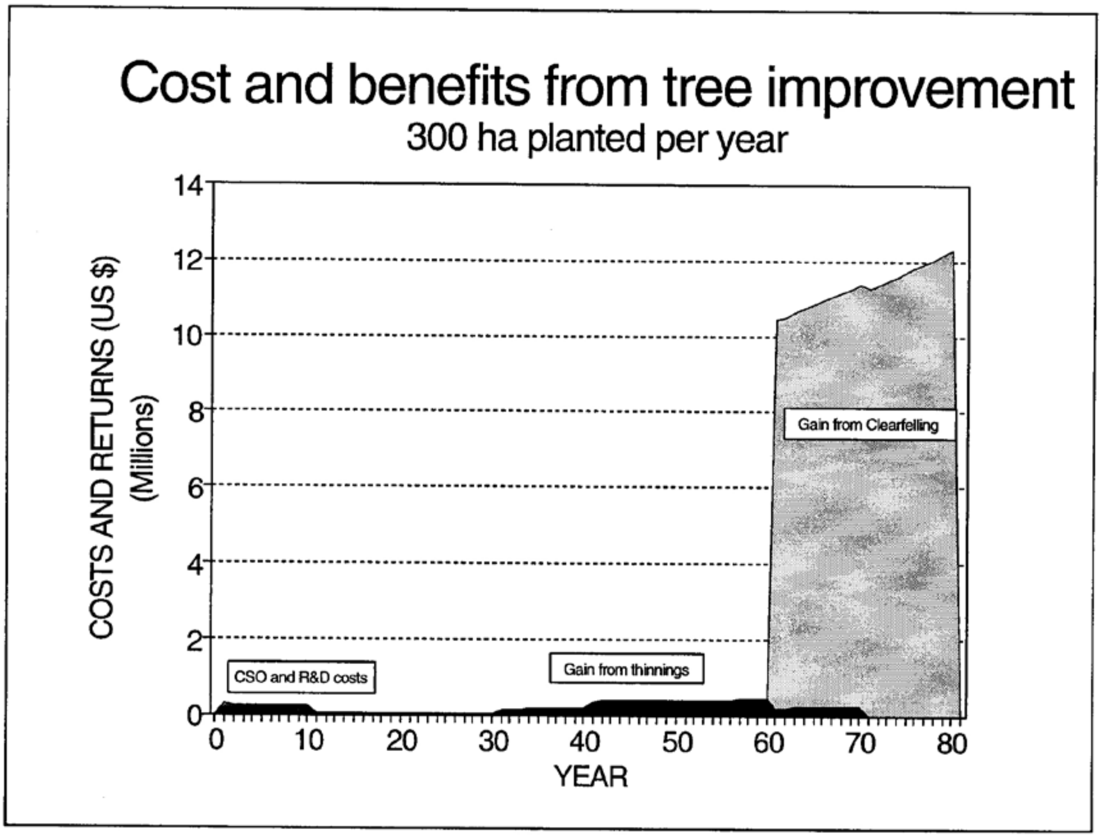

Figure 1. Flow of costs and benefits of a tree improvement programme

The actual return rate of the improvement activities seen as an investment has not been calculated so far. We can put together the different assumptions and calculate the internal rate of return (IRR). The yearly costs and benefits involved in a teak improvement programme are shown on a time scale in Figure 1. It is here assumed that 300 ha are planted every year. The seed orchards are expected to last twenty years, yielding seeds from year ten to thirty. Therefore, based on a 50 year rotation, the last payment will be achieved in year 80, fifty years after the last plantings are established from the seed orchards. The value of the timber is still assumed to increase by one percent per year in real terms and all other assumptions are unchanged. The IRR referring to 300 ha/year can be calculated from the cash flow presented in Figure 1 to be 8.0 percent. The IRR for other annual planting areas is presented in Table 4. The rate is calculated assuming R&D costs at two levels: (i) 200,000 US $/year (standard assumption) and (ii) 100,000 US $/year. The lower figure is more relevant for small plantation programmes.

These results show that improvement is indeed justified economically even for medium size planting programmes. An internal rate of return of ten percent for 1000 ha of annual planting area is a very impressive return.

Table 4. Internal rate of return from tree improvement of teak

Annual planting area	Internal rate of return (IRR)	
	R&D = 100,000 US$/year	R&D = 200,000 US$/year
100 ha	7.2 percent	-
200 ha	8.5 percent	-
400 ha	9.8 percent	8.5 percent
600 ha	10.5 percent	9.2 percent
800 ha	-	9.8 percent
1000 ha	-	10.2 percent

4.8 The economics of short rotation age, improved nursery techniques and long term development in timber prices

The above example of the economics of tree improvement of teak is based on several assumptions and is therefore only one case. Other assumptions may be more valid in other situations. We will end the economic evaluation by looking at the impact of reduced rotation age and improved nursery technique. The importance of the assumptions concerning long term development in prices of teak is also illustrated by evaluating the economics under two alternative assumptions.

The prospects of reduced rotation age have been discussed previously. The impact of short rotation age on the economics of this example is presented in Table 5. It is assumed that 350 cubic metres can be harvested over a 30 year rotation. The clear fellings are assumed to be sold at 475 S U$ per cub.m. rather than 600 US$ (1989-price, after 30 years this will be 640 US $ due to the annual increase of 1 percent). All other assumptions are unchanged.

Table 5. Economic return assuming short rotation age

Year	Harvest	Value	Total value	Gain from Tree Improvement
	(cub. m./ha)	(US$/cub.m.)	(US$)	(US $)
0-10	0			
11-20	50	110	5,500	550
20-30	300	640	192,000	19,200

Interest rate	Gain from using improved material	Extra costs due to CSO costs		Profit before R&D costs
	US$/ha	US$/ha	US$/seedling	US $/ha
3 percent	8215	17.6	0.016	8197
5 percent	4650	22.7	0.020	4627
8 percent	2026	33.9	0.031	1992
12 percent	698	57.7	0.052	640

A reduced rotation age improves the economics of improvement, especially for high interest rates. The smaller diameter and thereby heartwood percentage may have a decisive negative affect on price, and the calculation presented here may therefore »over-estimate« the possible gain from tree improvement in combination with short rotation age.

The economics will probably be best in combination with short rotation compared to long rotation as long as the applied internal rate of return is high. It is, however, in no way a prerequisite for good economics.

4.8.2 Improved nursery techniques

Improved nursery techniques will reduce the number of seeds used per seedling, and thus lower the costs for establishing seed orchards as well as the cost of commercial plantations. This will improve the economics, and the impact is easily calculated. In this analysis we have assumed that one ha of CSO can produce seeds for 33,000 seedlings. The cost per seedling will therefore simply be halved if the number of seedlings per kg sown seed is doubled. The assumption used in this analysis can be said to be optimistic compared to the present seed use in many nurseries world-wide, but we assume that increased care will be taken in handling the improved seed. If the opposite occur, and the seed consumption is doubled, then the CSO price per seedling will be doubled also. This does not change the basic results, that tree improvement will be profitable, but it will reduce the size of the gain. It may also influence the balance between the economics of propagating through tissue culture compared to CSO. A doubled seed consumption will thus increase the CSO cost per seedling to 0.08 US$ per seedling (for i=8 %), which is close to the cost of tissue cultured clones. At i=5 %, CSO propagation is still competitive.

4.8.3 Stable versus increasing prices of teak logs

It is assumed above that the price of teak is likely to increase with 1 percent per annum in real terms. Price relations are difficult to predict. Decrease in supply of tropical timber is likely to take place within the next decades, and increasing prices are therefore likely to be the result. The present value of the gain (PVG) from tree improvement under two alternative assumptions is calculated below: assuming (i) stable prices, and (ii) an increase of 2 % per annum.

The results in terms of PVG are calculated below (based on Table 6.a and Table 6.b).

Standard: Increase of 1 per cent per annum

PVG (3 percent):	8,506 US $/ha.
PVG (5 percent):	**3,404 US $/ha.**
PVG (8 percent):	933 US $/ha.
PVG (12 percent):	202 US $/ha.

Increase: O per cent per annum PVG (3 percent):

PVG (3 percent):	5,283 US $/ha.
PVG (5 percent):	**2,138 US $/ha.**
PVG (8 percent):	602 US $/ha.
PV G (12 percent):	138 US $/ha.

Increase: 2 per cent per annum PVG (3 percent):

PVG (3 percent):	13,689 US $/ha.
PVG (5 percent):	5,429 US $/ha.
PVG (8 percent):	1,455 US $/ha.
PVG (12 percent):	300 US $/ha.

The value of using improved material is reduced by approximately one third, if the price of teak wood is expected to be unchanged in real terms compared to the assumed situation with an increase of one percent per annum. Relatively high value gains thus remain if the teak prices are assumed to be stable. An increase in teak prices of 2 percent per annum increases the gains with approximately one half compared to the situation with the standard assumption.

Table 6a. Gain from increased future production (stable prices of teak wood)

Year	Harvest (cub.m./ha)	Value (US$/cub.m.)	Total value (US$)	Gain from Tree Improvement (US $)
0-10	0	90		
11-20	0	90		
21-30	50	90	4,500	450
31-40	50	90	4,500	450
41-50	50	90	4,500	450
50	350	590	206,500	20,650
Total	**500**		**220,000**	**22,000**

Table 6b. Gain from increased future production (prices of teak wood increase 2 percent per year).

Year	Harvest (cub.m./ha)	Value (US$/cub.m.)	Total value (US$)	Gain from Tree Improvement (US $)
0-10	O	90		
11-20	O	110		
21-30	50	134	6,686	669
31-40	50	163	8,151	815
41-50	50	199	9,336	934
50	350	1588	555,800	55,580
Total	**500**		**579,973**	**57,997**

5. CONCLUDING REMARKS

Any plantation situation is unique, but the general conclusion from this analysis must be that tree improvement is an important way to improve the productivity of teak plantations, and that the increased value production is likely to be able to finance both the breeding activities and mass propagation cost and still show a profit. The actual resources available are always limited, and the economics of improving teak should always be considered in connection with the possible economics of improving other species. In some countries other species may be even more attractive.

This paper has only focused on the economics of fairly simple, but on the other hand, widely applied tree improvement activities. The large gains available suggest that more sophisticated breeding activities may be profitable as well. The question of finding the economical optimum intensity can also be addressed in an economic evaluation. This is seldom done, however, probably because it is difficult to handle the numerous assumptions required for this. References can be found in Friedman (1992).

The gains estimated in this analysis only cover the increased value of the timber production in the forests. Many countries have imposed a policy of sawing and manufacturing the wood locally rather than exporting the logs. Increased flow of valuable teak timber from the plantations to the wood industry may therefore result in additional jobs and industrial production. The value added to the wood during processing is often several times the initial value of the logs. The socio-economic effects of an increased production from the teak plantations will depend on the amount of available socio-economic resources. For example, it will be increased if unemployed people can be employed at sawmills and wood manufacturers (see e.g. Pearce and Nash 1981 or FAO 1979). The effects are not discussed further in this paper because it must be based on local socio-economic considerations. However, the socio-economic effects may be as important as the simple value of the timber.

6. ACKNOWLEDGEMENT

Norman Jones, of the World Bank, originally suggested us to write this paper and he has contributed with ideas and comments. We will also like to thank R. L. Willan, E. B. Lauridsen, H. Wellendorf and M. Linddal for valuable comment on the paper. A. Kaosa-ard, V. Suantho, and B. Gua have contributed with important data and suggestions.

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