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Experience from Tree Improvement of Teak (*Tectona Grandis*) in Thailand

by
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DANIDA FOREST SEED CENTRE

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Experience from Tree Improvement of Teak (*Tectona Grandis*) in Thailand

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1. INTRODUCTION

Teak is one of the most important species for plantations in the tropics. It has its natural distribution in parts of India, Myanmar, Thailand, Laos and Indonesia. In Thailand it occurs naturally in the northern parts of the country (Kaosa-ard, 1981). The first plantations in Thailand were established in 1906. Large scale plantation programmes were initiated in 1943 by Royal Forest Department (RFD), and in 1968 by the state owned Forest Industries Organisation (FlO) (Kaosa-ard, 1996). In recent years the majority of teak planting has however been on private land (RFD 1995; RFD 1996).

Teak was early recognised in Thailand as being interesting from a tree improvement point of view: (i) teak is used on a large scale, (ii) the timber has high value, and (iii) it is easily established in plantation regimes, which allows introduction of improved genetic material. However, obstacles for tree improvement of teak have also been identified:

(i) low seed yield per tree (causing problems in relation to progeny testing and especially mass seed production in seed orchards),
(ii) low germination percentage yielding a low number of seedlings per sown seed in nursery production (increasing the problems of low seed production) and
(iii) difficulties in performing controlled pollination (Kaosa-ard, 1996}.

2. LARGE SEED REQUIREMENT

Teak is planted on a large scale in Thailand and a large amount of seed is therefore required. The annual plantation area established by Royal Forest Department and Forest Industries Organisations during 1982-1986 was on average 16,000 ha, but recently this figure has been decreasing to approximately 8,500 ha. Teak plantings in the private sector have increased considerably during the past few years due to government incentives and as a result of an increasing private recognition of high economic returns from investment in teak plantations. The total area established by the private sector in 1994 and 1995 was 63,700 ha and 45,538 ha respectively (RFD, 1995).

The majority of teak planting in these two years has thus been on private land. The rate of planting was extraordinarily high in 1994/95, and the rate is expected to decrease in the future. Lack of available land may become a severe limitation.

In present nursery practice in Thailand, only 5 seedlings of appropriate size are obtained from 100 seeds sown. This is mainly due to the low germination percent and sporadic germination behaviour of teak seed. Wellendorf and Kaosa-ard (1988) find that one ton of seed only produces 92,000 seedlings by the present techniques. Typical planting practice requires 1,100 seedlings per ha, and one hectare of teak plantation thus requires about 12 kg of seed. The total use of teak seedlings in Thailand is at least 22 million seedlings per year (Kjaer and Suangtho, 1997). This requires almost 240 tons of seed to be procured per year.

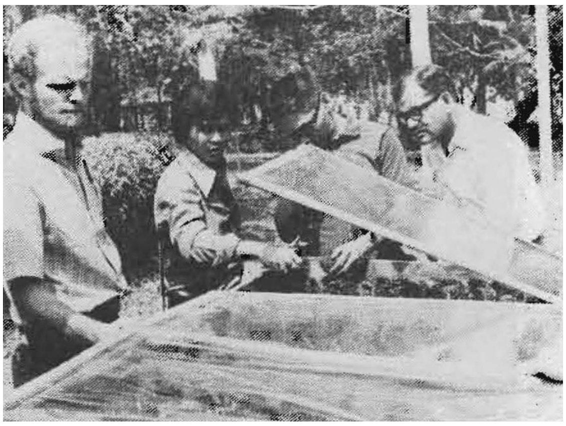
Germination of teak provenances in connection with the international series of teak provenance trials, showing sporadic germination of teak seed.

The productivity of seed in clonal seed orchards (CSOs) is not high in Thailand. Studies have shown that production is very variable. On a good site, production capacity can be 70-100 kg per ha (Meekaew, 1992; Kittibanpacha, 1996), but an average of 50 kg per ha (from age 15) is more realistic (Wellendorf and Kao-sa-ard, 1988).

The large demand for improved seed and limited productivity of the CSOs make seed procurement a difficult business. At present, a large part of the used seed is, therefore, collected from easily accessible seed sources, e.g. road sides and urban areas.

Low number of seedlings produced per kg of seed is a general feature for teak (see e.g. Srimathi and Emmanuel, 1986, experience of India), but fortunately much can be gained from improved nursery techniques. Studies on pre-treatment have shown that heating at 80°C for 48 hours can increase both germination percent and germination speed substantially, thus increasing the number of seedlings produced per kilo sown seed (Suangtho, 1980). Storing the seed for 72 hours in heat traps, or simply sowing the seed four weeks prior to the beginning of the wet season, have also given good results.

Other parts of nursery production may also be optimised, and improved nursery practices should therefore be part of a sound seed procurement strategy. For example a 50% increase in the number of seedlings produced per kilo will reduce seed requirement with one third.



For many years trays with polythene lids have been used for extraction of pine seed by sun-heal. 'Heat traps' like these have been used successfully for pre-treatment of teak seed. Pine Improvement Center.

3. GENETIC VARIATION AND POSSIBLE GAIN

Tree improvement activities are initiated in order to obtain gains in selected characters. The large differences in growth conditions within the natural range of teak indicate the existence of genetic differences between origins. Provenance differences have been investigated in an international network of provenance trials (Keiding *et al.* 1986, Kjaer *et al.* 1995), which together with the studies by Bingchao *et al.* (1986) probably provides the best available information on provenance variation. These trials reveal genetic variation between a number of provenances tested at locations within and outside the natural distribution For Thailand, the international trials indicate that suitable local seed sources should be used. A provenance trial comparing 30 Thai provenances was established in the early phase of the teak tree improvement programme in Thailand, and data based on assessment after 15 years is now available (Kaosa-ard, in prep.) However, little is known of the variation within provenances, as most clonal and progeny trials are still young. The available data does, however, reveal genetic variation in both growth and stem form (Wellendorf and Kaosa-ard 1988, Wellendorf, unpublished). Wellendorf and Kaosa-ard (1988) estimated the possible gain from using the best seed sources (seed production areas, SPA) to be 5-12% in volume production. The additional gain from using seed from clonal seed orchards (originating from the initial plus-tree selection) rather than from SPAs was not included in this estimate. However, for stem form it will probably be significant. Genetic thinning in the seed orchards was estimated by Kjaer and Suangtho (1997) using data from Kittibanpacha (1995) - to yield an additional 5-10% gain in volume production.

Based on the above, Kjaer and Suangtho (1997) estimated that seedlings from classified seed stands are expected to have at least 8 % higher value production than seedlings from unclassified seed (this increased value production originates from both improved volume production and better stem form). CSOs are expected to be at least 4 % better than classified seed sources because they consist of selected clones from the best seed sources (effect from plus-tree selection). This means a total of at least 12 % (8 % + 4 %) higher value production from CSO-progeny compared to seedlings from unclassified seed sources. An additional 5 % can be gained from collecting seed exclusively from the best clones in the CSOs, and multiplying these seedlings by vegetative propagation, i.e. a total gain of 17 % (in value production) compared to planting stock from unclassified seed sources.

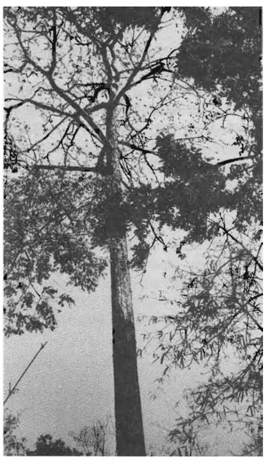
Based on an estimated 10% gain from using seeds from CSOs, Kjaer and Foster (1996) calculated the absolute value of using improved planting stock. They estimated the gain to be approximately 36,000 US $ per ha during a 50 year rotation, i.e. 3,600 US $ per ha for each percent the improved planting stock is better than the unimproved. The present value of these future gains will be less than these figures, because the gains shall be discounted in order to achieve present value. The result will depend on the rate of interest as discussed in more detail in Kjaer and Foster (1996). They suggest that 3,400 US $ per ha will be a realistic estimate for the present value under most conditions in tropical countries, i.e. 340 US $ per ha for each percentage the improved planting stock is better than the unimproved. A gain of 17 % obtained from using highly improved material, as mentioned above, will thus correspond to an increased value of 17 % x 3,600 US$ = 61,200 US$ per ha established plantation over a 50 year rotation (present value of 17 % x 340 US$/ha = 5,780 US$/ha).

4. TEAK IMPROVEMENT ACTIVITIES IN THAILAND

Tree improvement activities were initiated in Thailand in the early 1960s (Boonkird 1964; Keiding 1966), and intensified through establishment of the Teak Improvement Center (TIC) at Ngao, Lampang province, in 1965. During the last 30 years, TIC has been involved in establishment of provenance trials, selection of plus trees for tree breeding, development of vegetative propagation techniques (grafting, budding, cuttings and tissue-culture), establishment of seed production areas, clonal banks and CSOs, clonal trials and supportive research mainly into reproductive biology (TIC, 1994).

4.1 Selection of plus trees and establishment of clonal seed orchards

The teak improvement strategy for Thailand is described in detail by Wellendorf and Kaosa-ard (1988), and Kaosa-ard (1996). A review of the latest development is presented by Kjaer and Suangtho (1997). Two rounds of plus-tree selection have been carried out. 100 clones were selected during the first years of tree improvement.



A plus tree near the Ngao-Lampang highway. 1965

Approximately 60 of these clones have been propagated by budding on a large scale, and a total of 1,830 ha CSOs have been established. The majority (91%) of CSOs has been established by RFD at five regional CSO-centres, the rest mainly by FIO. An additional 300 clones have been selected in a second round of selection and included in the long-term breeding population. Clone banks have been established at TIC as well as at the five regional CSO-centres. The first of three new breeding seed orchards (BSOs), each containing 100 clones, has been established. All four BSOs will be replicated at four locations.

Seed supply from the CSOs has turned out to be much lower than initially expected. Three major reasons for this can be identified. First, the seed set per flower in teak is generally very low in the South and South East Asian regions resulting in low seed production. Recent studies on the reproduction biology of teak have increased the understanding of the reproductive process (Kertadikara and Prat 1995, Kjaer and Suangtho 1995, Nagarajan *et al.* 1996, Palupi and Owens 1996, Tangmitcharoen and Owens 1996). According to these studies, teak flowers can easily be self-fertilised by insects in the crown of the individual tree, because apparently no selection works against self pollination.

However, the selfed embryos tend to abort soon after fertilisation, and the final result is low rate of selfing in the progeny and low seed setting in general. The low fruit production in these regions may therefore be caused by lack of efficient pollinators combined with late acting gametophytic self-incompatibility in form of postzygotic abortion (= the flowers are to a large extent self-pollinated, and in most cases these selfed embryos fail to develop into seed). Lack of pollinators capable of mediating cross-pollination can thus result in a situation where most flowers are selfed and seeds subsequently aborted. Artificial introduction of efficient pollinators (e.g. honey bees) and/or improved CSO designs that could make them more attractive to the pollinators should be tested.

A second reason for the low seed production is that the CSOs established in Thailand include areas that are not teak sites. The orchards were to a large extent established in dry deciduous dipterocarp forests in order to avoid contamination from the teak forests. However, these soils are often not suited for teak, and parts of the CSOs have therefore developed far slower than expected, and are still not productive.

Thirdly, limited resources for maintenance of the large areas of the orchards have also been a problem for seed production. It has therefore in many cases not been possible to maintain regular weeding of the seed orchards, which, in combination with the wide spacing used of 10 x 10 → 12 x 12 m, has resulted in severe competition and fire damages reducing growth of ramets in the orchards. Obviously, the problem with weeds has also been an obstacle to the actual seed collection. To conclude, it has been difficult to find fully suitable areas, and subsequently to maintain the very large CSO area in good condition. As a result, it has been difficult to utilise the potential of the very valuable seed sources efficiently. However, the majority of the seed orchards are in good physiological condition and should therefore become more productive as soon as extra funds have been allocated to improve and manage the orchards in recent years. Kjaer and Suangtho (1997) have calculated that the extra cost for CSO improvement will be approximately 40,000 US $ (i.e. 1,500,000 Thai Baht) per year. The output from the orchards is estimated at 56 tons of improved seed per year which is equal to 7,700,000 seedlings per year (if 138 seedlings/kg is assumed). As a result, 7,000 ha of teak plantation can be established by using improved stock from the CSOs. A clear marketing effort for the improved seed is further required in order to attract the attention of the nurseries to the value of good seed sources.

Clonal trials, testing the majority of the 60 clones included in the 'old' breeding population, have been established at two locations as part of the breeding plan. One progeny trial has been established, but has had a fairly difficult start and is not in good condition. New progeny trials will be established and this work has high priority as there is still no information on the concordance between results from progeny trials and results from clonal trials.

4.2 Seed production areas

Identification of approximately 1,200 ha of the selected teak forests for establishment of seed production area (SPA) has also been an important part of the effort to procure a sufficient amount of seed of high genetic quality. However, only 3-400 ha of the SPAs are still in suitable condition for seed collection due to uncontrolled logging operation in the SPAs, where trees with good growth and stem form have been removed. The plan is to change this development. Plantations established since 1943, mostly in the north are therefore to be surveyed over a five year period to identify areas which are suitable for conversion to SPAs.

Conversion of plantations into SPAs requires relatively heavy thinning in order to remove inferior trees and to increase seed production capacity of remaining trees. This means deviation from the standard thinning practice that is applied in plantations primarily for growth and yield improvement. Since the introduction of logging ban policy in Thailand in 1988, one RFD policy is also to limit the thinning activities in the plantations. Classification of good and protected plantations or 'seed sources' for future seed collection is, however, compatible with this policy as long as the plantations are not thinned at an increased pace. Seed production in such lightly thinned seed sources will be lower than in the traditional SPAs - maybe only 10 kg per ha on average (Kaosa-ard 1979). Kjaer and Suangtho (1997) assume that at least 1,500 ha of good seed sources can be identified and used in order to reduce the use of unclassified seed sources for production of teak seedlings.

4.3 Development of vegetative propagation techniques

In Thailand, development of vegetative propagation has been given high priority in the past decade with great success. Tissue culture technique has been developed on a commercial scale (Kaosa-ard *et al.*, 1987; Kaosa-ard, 1990; Kaosa-ard, 1993), and teak planting stock based on this technique is being produced on a commercial basis. The price for this planting stock is approximately two to three times higher than the price for traditional seedlings and/or stumps. Different clones require slightly different culture media, and it is therefore difficult to handle a large number of clones in commercial tissue-culture programmes. Tissue culture is for these reasons only used on a small scale at present. However, the combination of tissue-culture and subsequent cutting of tissue-culture plantlets has proved to be both technically and economically feasible for large scale production of clonal planting material.

Vegetative propagation by means of cuttings from juvenile seedlings and tissue-culture plantlets has also been developed on a commercial scale. Under favourable rooting conditions, over 90 percent rooting of stem (nodal) cuttings can easily be obtained. Serial cuttings (cuttings from plants derived from cuttings) can also be made successfully. In this case, the 45-day old plants derived from cutting are used for propagation.


Teak may be propagated by serial cuttings. See text.

As a result, within one growing season 30-40 plants can be reproduced from one seedling through such serial cuttings (three cycles). Through this propagation technique, it is estimated that one kg of improved seed, e.g. seed from CSOs and SPAs, can produce 5,000-6,000 plants (Sirikul pers. com.). The extra cost compared to conventionally produced seedlings is approximately 50 %. This extra cost is easily outweighed by the increased production provided that the cuttings are produced from improved genetic material. Still, cutting production is only being used on a small scale due to the extra production costs. More details on technical aspects of vegetative propagation of teak are given by Goh and Monteuuis (1997) and Monteuuis *et al.* (1995).

Increased use of cuttings is planned in Thailand for two reasons. First of all, in order to fill the present large gap between available improved material and annual demand for planting stock, a gap that otherwise can only be filled by using seed from unclassified sources. Secondly, additional gain can be obtained compared to CSOs by exclusively using seed from the best families in the seed orchard for the propagation, e.g. seed collected from the best 15 clones in the CSO, bulked and the plantlets used for production of cuttings. Seed from families will be collected after open pollination and therefore the flowers may potentially be pollinated by any of the clones in the CSOs. This will ensure a fairly high level of genetic diversity in the material (Kjaer and Graudal, in prep.). The best families will be selected based on results from clonal trials.

In the initial phase, 2,000,000 cuttings per year are envisaged (propagation of seedlings from approximately 360 kg of seed per year). Based on the success of the programme in the first years, the production can gradually be increased later on to further reduce the use of unclassified seed sources. This decision will depend on the experiences gained in the first years. The final goal could be a production of 10,000,000 cuttings per year. A broadening of the genetic basis for the propagation may then be considered, because a larger proportion of all the Thai teak plantings then will originate from these selected families. A production of 10 million cuttings will of course require a fully developed distribution system in order to ensure that valuable cuttings are not lost due to bottlenecks in distribution or poor planning.

It is important that cutting production concentrates on propagation of seed with the best genetic quality, because the costs of propagation by means of cutting are higher than costs of seedling production. The cutting option is especially attractive in Thailand because the results from clonal trials allow matching of clone to site.

Only cuttings produced from juvenile seedlings and tissue-culture plantlets give high rooting percentage. At present, it is therefore not considered to be economically feasible to produce cuttings from older trees, although Monteuuis *et al.* (1995) obtained surprisingly good results from 15-year-old trees. Still, the cutting option is only interesting as far as genetically superior material has been identified, i.e. there must be some kind of tree improvement activities. The genetic quality of cuttings is no better than the seedlings, or tissue-culture plantlets from which they are propagated.

5. CONSERVATION OF GENETIC RESOURCES IN SITU AND EX SITU

The area of natural teak forests in Thailand has decreased rapidly during the past three decades and there is an urgent need for conservation measures (Graudal *et al.* 1998). The breeding population has a valuable *ex situ* conservation function, but additional *in situ* conservation is required. A programme for evolutionary *in situ* and *ex situ* gene resource conservation has therefore been formulated (Graudal *et al.* 1998).

The natural distribution pattern of teak in Thailand has been divided into five genecological zones based on climatic variation, topography, soil conditions and results from provenance trials. The climate, in terms of the rainfall/temperature ratio, in general varies from high values in the north towards lower values in the south (Kaosa-ard, 1983). However, the natural teak forests are separated by mountain ridges going north-south, which may have functioned as partial barriers against pollen flow between subpopulations. Multivariate analysis of provenance trials supports a pattern of differentiation between east and west (Kjaer *et al.*, 1996), and genecological zones have therefore been suggested to be separated by both north-south and east west boundaries, Graudal *et al.* 1998, see Fig. 1. A total of 15 populations have been identified for gene resource conservation. Four of these are outside protected areas, and shall be conserved *ex situ* according to the 1998 plan.

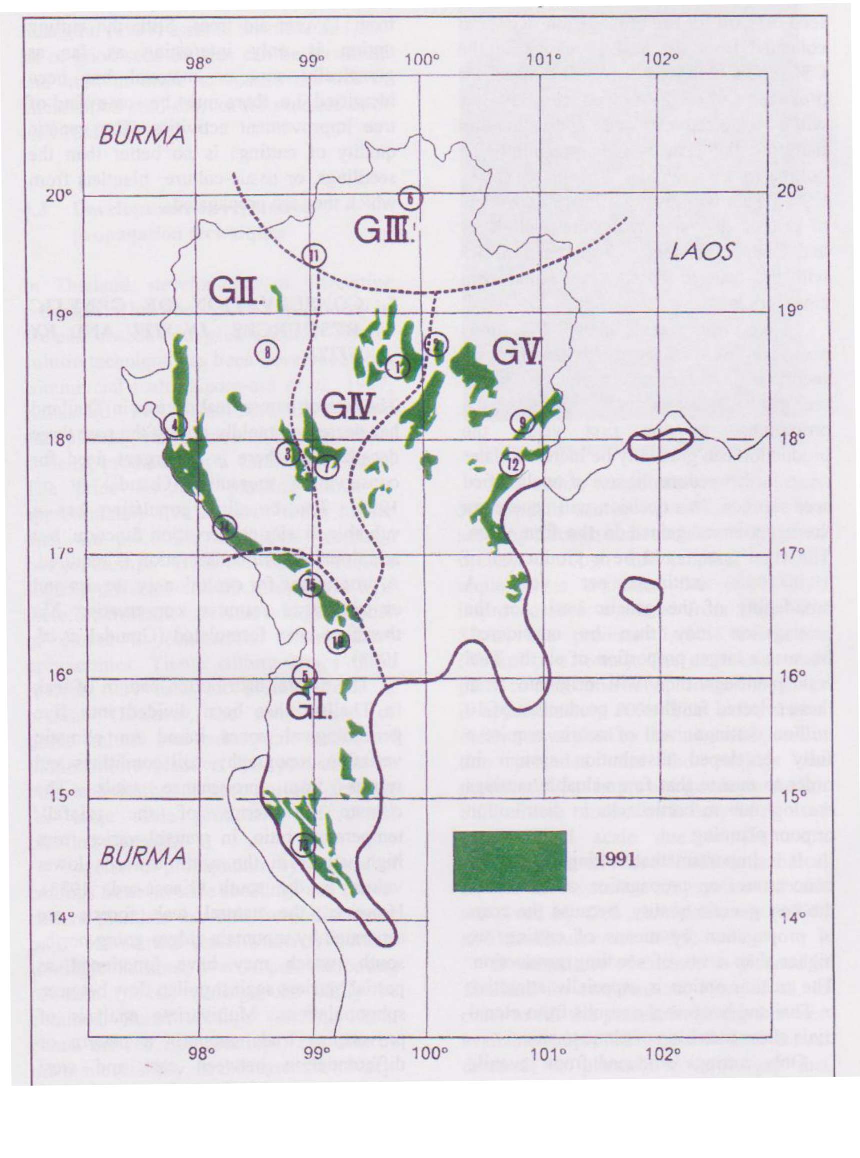


Figure 1. Genecological zones GI- GV and 15 areas prliminarily identified for conservation of the genetic resources of teak in Thailand. (Graudal. et al. 1997).

6. CONSIDERATIONS FOR THE FUTURE

FIO. ?

In Thailand, tree improvement of teak was initiated three decades ago. Several problems have been solved since then. Provenance trials have compared the relative performance of Thai and foreign seed sources. Budding/grafting has been developed for clonal propagation of mature selected trees. Techniques for seed pretreatment have been tested and an effective regime (80°C-treatment) has been developed. Reproduction biology has been intensively studied, and important knowledge gained. Plus trees have been selected and almost 2,000 ha CSOs established (one of the largest CSO areas for any single forest tree species in the world). Vegetative propagation techniques (cuttings and tissue culture) for large-scale plant production have been developed.

A 15 year-old clonal seed orchard of teak at Mae Gahr. Seed is being harvested from individual clones for progeny testing. 1981.

The establishment of the Teak Improvement Center (TIC) In Ngao, Lampang province has played an important role for the progress of the teak breeding programmes. Scientists and technical staff were gathered in this institution to work together on the teak project. A fruitful co-operation between TIC and the Chiang Mai University has been important in the development of tissue culture for commercial-scale plant production. Also, co-operation with other scientists from RFD has been valuable.

Transfer of tree improvement technology from Denmark to Thailand was important in the initial phase of the project, and is now followed up by large scale practical application in the FORGENMAP project as mentioned below. In the coming years, transfer of technology could take place from Thailand to countries that are initiating tree improvement programmes in teak.

Continuity and recognition of the importance of this work have been key factors in the success. Resources in terms of manpower and funds have been allocated to the project throughout the whole period, which has been an important prerequisite for the results achieved at TIC.

However, problems arose in the practical application of research results, and to date only few teak plantations have been established with the improved material. The institutional set-up - with all activities organised within the Silvicultural Research Division - has been effective in the initial phases as breeding activities require highly skilled staff. However, close co-operation with the Afforestation Divisions of RFD has turned out to be important in the later stages of the programme when the results were to be implemented in the plantation programmes, i.e. getting the improved seeds into commercial nursery production.

Research and development in tree improvement must be followed by implementation on a practical scale. Improved genetic material should be multiplied and introduced into the plantation programmes as soon as possible.

According to the experience from Thailand, it is very important to consider the organisational set-up carefully from the very start of the programme. Seed procurement must be closely linked to both the organisation in charge of CSOs and the organisation in charge of nursery production. Information must flow freely from one to the other. Seed procurement is an integrated part of seedling production, which again is a precondition for any planting programme. Funds required for seed procurement are often small compared to the total budget for plantation establishment. Costs for CSO maintenance and seed collection are only 1-2 % of the total plantation cost, but this activity is - as described above - of major importance for the long term results of the total investment in the plantations. It is therefore very important that sufficient funds are allocated for seed procurement. Still, it is not only a question of resources. Correct information concerning seed demand in terms of quality (genetic and physio-logical) and quantity (amounts and timing) is also very important for a successful integration of tree improvement and seed procurement in the total planting pro-gramme.

A project, FORGENMAP[4], has recently been initiated in Thailand to facilitate the link between seed procurement and planting programmes. Regional seed centres have been set up in order to cover the gap between research activities and practical implementation:

- Forest Genetic Resources Conservation and Management Project (FORGENMAP) is a project within Royal Forest Department. FORGENMAP focuses on development of integrated strategies for seed procurement, tree improvement and gene resource conservation for a number of species in Thailand. It is supported by the Danish Co-operation for Environment and Development (DANCED) plantation establishment. The Northern Tree Seed Centre in Lampang, which has teak as a priority species, will work closely together with both TIC and the afforestation units of RFD and FIO. and with the private sector. Special efforts are made to ensure that small scale private planters also have access to the improved seed.

The low seed production capacity makes the traditional CSO concept problematic for mass seed production. Large and expensive CSO areas have to be established until proper techniques have been developed for increased seed production. More work has to be conducted in this field as improved seed production will be of major importance. The site for establishment of CSOs should be carefully selected to secure high seed production and isolation from contaminating pollen sources. For practical purposes, it is necessary to increase the improved stock derived from CSO seed by means of juvenile cuttings. This can substantially reduce the required CSO area.

Progeny and clonal tests are important parts of the breeding activities in order to achieve gains in traits with low heritability (such as volume production). Such trials should be established soon after the initiation of the improvement programme, because it takes a long time (over 10 years) to obtain adequate results required for the evaluation of genetic quality of individual clones in the CSOs.

4. Forest Genetic Resources Conservation and Management Project (FORGENMAP) is a project within Royal Forest Department. FORGENMAP focuses on development of integrated strategies for seed procurement, tree improvement and gene resource conservation for a number of species in Thailand. It is supported by the Danish Co-operation for Environment and Development (DANCED)

The experience from Thailand highlights progeny testing as a weak point in the improvement activities. Many trials are required, and the establishment of these simultaneously with the CSO area will often cause bottleneck problems because of limited human and financial resources.

Breeding seed orchards (BSO) may be valuable in many situations because seed orchards and genetic tests here are combined. This concept will to some extent compromise the efficiency of the genetic tests. A detailed discussion pro/con this concept is given by Barnes (1995). For teak, this concept has been difficult to apply because of the low seed yield per plus tree (Wellendorf and Kaosa-ard, 1988).

6.1 Is teak unique compared to other species grown in the tropics?

Teak is different from many other broadleaved species in the tropics. It is an interesting species from a tree improvement point of view because: (1) it is used on a large scale, (2) the timber is of high value, and (3) it is mainly regenerated artificially, which allows introduction of improved genetic material. On the other hand, tree improvement of teak is complicated by poor fruit-setting capacity, low seed quality and poorly developed nursery techniques. This makes mass propagation very difficult compared to other species. The ability to handle mass-propagation activities may therefore be the key-factor in teak improvement programmes in contrast to e.g many coniferous species, where mass propagation is much easier. The slow growth of teak makes tree improvement activities a long-term investment. Ten to fifteen years may pass from the initiation of an improvement programme before improved seed is available, and another 40-50 years will then pass before the timber from the first rotation of improved planting stock is harvested.

However, the internal rate of return remains high in teak. The effect of discounting the gains over a long time span is more than counteracted by the high value of the timber (Kjaer and Foster, 1996). Still, the long rotation age causes problems for the breeder. Superior plus trees are selected at a mature stage, but their breeding value must be assessed from progeny tests, and these are evaluated at a young stage in order to save time. One must therefore rely on close correlation between juvenile performance and performance at harvesting age. Also, continuity in terms of funding and staff is especially important in breeding progranmmes for teak, because the time span for the breeding programme is relatively long. In species such as *Eucalyptus* sp. or *Gmelina arborea* gains can be realised much faster and progeny testing will be easier. The gain to be achieved from teak breeding is on the other hand very large compared to most fastgrowing species due to the high value of teak timber.

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