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PLANNING BREEDING PROGRAMME FOR TROPICAL HARDWOOD

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SUMMARY

The importance of a tree breeding programme for tropical forestry has been pointed out. The guidelines for establishing and developing operational tree improvement programmes based on modern plant breeding theory and practice have been presented. General considerations on choosing the species, securing immediate seed supplies, selection of plus trees, establishing seed orchards and long term research programmes have been reviewed and discussed extensively. Planning operational breeding programmes for tropical hardwoods have been proposed using teak as the illustrations for three restricted conditions. Finally the importance of intra- and international cooperation has been stressed.

Introduction

Tropical forests make up more than half of the world's forests (BAWA and STETTLER, 1969). The productivity of these forests can be markedly increased by the cultivation of high-yielding varieties of native species from known or improved genetic stock. It is in this context that protection and conservation in general and tree improvement work in particular assumes significance. The attempt should, therefore, be made toward setting up the operational breeding programme in order to obtain improved seed for artificial reforestation. Tree improvement has already had a major effect on forest management in temperate regions where forestry is intensively practiced. It should make an even greater contribution in most of the tropical countries where forestry is now becoming more important. Valid guidelines for establishing and developing long term operation of tree improvement programmes, based on modern plant breeding theory and practice, are needed for foresters in the tropics. This paper intends to provide these by discussing the decisions

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which have to be made in planning a breeding programme and the way in which selection theory and quantitative genetics should be applied. The idea is confined to the tree improvement of tropical hardwood species and is illustrated by proposed planning programmes for teak *(Tectona grandis* L.*)* improvement.

Basic Requirements for Initiating a Breeding Programme

The tree improver faces many questions that must be answered before a programme can be started. He must know the market potential and kind of product needed, the growth potential and size of area where the programme is to be operated. Put another way, the important requirement for a viable tree improvement programme to be initiated is an active plantation programme with a suitable species, that is, one that has been adequately evaluated over a full rotation (at least in experimental plots). Further requirements are a definite commitment to a continued and economically viable plantation programme and sufficient backing in funds, facilities and man power to do the improvement work.

Choosing the Species

It is recommended to choose a few fast-growing species to concentrate on, and to make sure that the best provenance of the species is to be used. Fast-growing hardwoods have the advantage of yielding quick results and relatively early decisions can be made about the species. Besides growth habit, wood quality also must be considered. It is important to know the kind of wood that will be produced. Examples exist where several countries have hundreds of thousands of acres of beautiful plantations now at a merchantable age, but they don't know what to do with the wood because of its poor quality (ZOBEL, 1969); such situations must be avoided. Other important information necessary for initiating tree improvement programmes is related to the biology of the species, such as floral function, pollinating agents and reproduction system which affect breeding mechanism. The key to success of any tree improvement programme is to know the species.

Securing and Genetically Improving Immediate Seed Supplies

Obtaining regular supplies of improved seed is frequently a problem in the planting programme in the tropics, as elsewhere. Fortunately, local seed bearing stands and mature plantations available at present provide the possibility for securing early improvement:

1. Seed may be collected from the best individuals selected throughout the stands and plantations.

2. Seed may be obtained from seed production areas which can be established in plus stands or plantations from which phenotypically inferior trees will be removed to about $\frac{1}{10}$th of the original stand stocking. The area should be isolated to prevent an influx of foreign pollens.

The advantage of the first method is that the seed trees can be intensively selected, although only female parents are selected and the male parents are random, appreciable genetic improvement can be obtained by this approach. This can be practiced and continued until the time that seed orchards become productive.

The seed production areas, on the other hand, are more convenient for collecting large number of seeds as well as easier for cultural practices to increase seed production. Provided the thinning is truely selective (not just for spacing) and the area is sufficiently isolated from other unimproved stands, improvement in growth and form of progeny can be expected. The seed production area, however, is more prone to suffer from a single disaster, and from initial errors in selection.

Offspring from *Pinus taeda* L. seed stands have given rather disappointing results in southeastern U.S.A. This is thought to be the result of inbreeding, since trees selected in a small area of natural stands are likely to be offspring of only a few parents. This should not happen in the tropical hardwood plantations where the family structure is broken during seed handling, in the nursery and during planting.

Implementing a Breeding Programme

Any intensive programme of intrapopulation improvement involves the following elements:

1. Selecting trees from the unimproved population.

2. Producing seed in some form of orchard, from seedlings or from vegetative propagules of these phenotypic selections.

3. Testing and evaluating offspring of the first generation's selection to improve the genetic quality of seed from the first generation orchard by removing poor clones, and/or to provide selected trees for the second generation with which to establish new orchards. Testing is also most important to validate the success of the selection programme, so that support must be continued.

Phenotypic Selection of Plus Trees

Observation indicates that tropical hardwoods such as teak, eucalyptus and other species exhibit a large amount of phenotypic variability. Base on the quantitative genetics theory of the metric characters, it can be assumed that the inheritance of most economically important traits is controlled by complex, multiple gene combinations. The evidence from various crop and tree improvement programmes has shown that the additive component of variance is large enough to provide the basis for effective mass selection.

Phenotypic selection is the basic for genetic improvement, and selection of plus trees is the first operation in initiating a breeding programme. Some undrestanding of the mathematical basis of selection for a single character can be of considerable help to the breeder in allocating his resources to best advantages.

Theoretically, genetic gain depends on the proportion of the trees selected, the variability of the trait and it's heritability. Of these the only one over which the breeder has direct control is the proportion selected. He can thus control the selection differential within the limits of variation of the trait in the population. How much of this selection differential he later realizes as genetic gain will depend on the extent to which the trait is passed from parents to offsprings, a situation over which he has no control. Thus once the characters to be selected are chosen, the proportion of the population selected is the key factor in this plus tree selection.

Recently, two schools of thought have developed on the question of optimum proportion of the population to select. One group favours a low selection intensity with a large number of initial selections. For example, BURDON & SHELBOURNE (1970) proposed several improvement programmes for radiata pine in New Zealand, for which the initial selections were very large (800 trees) and the proportion selected was about 1:1000. The idea behind these proposals is that the selection differential increases curvi-linearly with the proportion of the individuals selected such that the increase in selection differential drops off rapidly in relation to additional efforts of increasing the proportion selected. The other group believes that the selection differential must be very high (select only 1:50,000 or 1:100,000) and initial selections of 30-100 trees would be sufficient to initiate a breeding programme (RAWLING, 1970 and KITZMILLER, 1971).

The main point to be concluded here is that it is more practical to work with smaller initial selections than the larger one in terms of testing areas, measuring, record keeping, tending and expense. The costs of progeny testing a given selection is generally several hundreds times the cost per initial selections (NAMKOONG, 1970). Economic analysis of tree improvement programmes indicate that the relative cost of a rigorous selection phase (1:50,000) was only 0.5% of the total cost while progeny testing contributed over half of the total cost (DAVIS, 1967). On the basis of linear functions of gain/cost/selection unit for two stage selection NAMKOONG (1970) concluded that greater expense and effort in the field selection would probably yield greater benefits than would additional progeny testing and that progeny testing is often justified only on the population data it yields. Although, I do not advocate elimination of progeny testing, the idea of having rigorous selection which will result in having an initial selections of about 50-100 selected trees to start from, to my opinion, is practically and economically well-suited for initiating tropical hardwood improvement programmes.

In practice, several avenues are opened to tree breeders for increasing the efficiency of individual tree selection. In tropical hardwood tree breeding programmes, selection must be made in natural stands and plantations growing under variable environmental conditions.

Therefore, it is important to utilize any measure that will minimize the differential effects of environment. Some methods to increase the efficiency of selection are the following:

1. Choose the best stands for making selections. In most natural forests or plantations there is variation among stands in genetic composition. By restricting selection to stands with the better phenotypes advantage can be taken of any between stands genetic variation that exists.

2. Make selection only in stands that are relatively uniform with respect to age, spacing and microsite, if possible.

3. Use comparison trees as a basis of selection. The use of carefully chosen comparison trees is necessary to adjust for environmental differences among and within stands.

4. Restrict selection to a few traits that are of major importance.

Establishment of Seed Orchard

The major objective of a seed orchard is to produce mass quantities of genetically improved seed. The procedure by which this is accomplished is to bring together phenotypically superior clones (or progenies from those clones) and establish them according to a specific design to lessen cross pollination between related individuals. There are two basic types of seed orchards, clonal and seedling orchards. The advantages and disadvantages of both types have been well documented (TODA, 1964 and LIBBY, 1969) and will be mentioned here only in brief. In some cases, however, these basic types can be modified for a particular purpose. A few examples will be reviewed and evaluated.

1. Untested clonal orchard (without roguing). Grafts or cuttings of 25 or more of the phenotypically best parent trees available are planted at normal orchard stockings of 50-100 stems per acre (123-246 per ha.). Whatever the genetic composition of this type of orchard, it is not designed to be changed materially during its working life. The advantage of using this method is that rapid establishment of a large acreage of orchard is possible where a large number of selected trees is available. Elimination of progeny tests reduces the costs and considerable genetic gains can be expected theoretically if the heritability of desirable traits are relatively high. On the other hand, disadvantages of this method are that genotypes of trees within the orchard are unidentified and that the information of general combining ability of trees for use in future improvement work will never be available. Costly mistakes which may be made in initial selection will not be removed. Most important is that the extra genetic gain possible from proper use of progeny test results is completely ignored in this method. In large scale commercial planting, utilization of only a small amount of this extra gain can cover the whole cost of research and improvement activities in the programme including costs of progeny tests. (David, 1967). For tropical hardwood improvement programme in particular, the information on inheritance of growth characteristics and wood properties of important species is scarcely available at present. It is, therefore, unsafe to adopt this type of orchard and I do not advocate using it particularly, for initiating programme.

2. *Rogued clonal orchard.* Grafts or cuttings of selected trees can be established at closer than normal orchard spacing to allow the removal of up to 4 genotypes out of 5 on the basis of progeny test results. Provided the capacity of producing large numbers of propagules exists, such an approach will allow considerable extra genetic gain to be realised from the first generation orchard. In the absence of reliable genetic information in most of the tropical hardwood species, this method is a conservative approach which, to my opinion, is most warranted at the present time.

3. *1.5 Generation orchard,*[1] When progeny test results are available, new clonal orchard can be established from the genotypes with the best general combining ability (best progeny mean) for the important traits. The method is useful for further improvement when first generation orchards are completed or almost completed. Determination on the use of this method must await the collection of more basic data and observation from the first generation orchard performance. This method is not to be used for initiating tropical hardwood improvement programme but may be considered useful in the future when a programme has been

1) This term has been coined by Dr. B.J. Zobel, Director of the N.C. State-Industry Cooperative Tree Improvement Programme.

developed to certain extent that the requirement for extra gain is stressed.

4. Seedling seed orchard. It serious vegetative propagation difficulties are encountered, use of seedlings from controlled crossing between phenotypically selected trees provides an alternative means of packaging the genes for the seed orchard, to vegetative ramets of different clones (LIBBY, 1969). The advantage of this method is combining progeny test with seed production. This procedure is effective if desired characteristics are expressed at a young age and/or the species flower regularly at young age. Two cycles of selection are completed in one generation. With tropical hardwoods, however, economically important traits such as diametre growth, height growth and volume production are expressed at advanced age, so costly mistakes may be made by roguing before valid comparison can be performed. Many important species flower late in life. Additionally, the disadvantages of this method are that progeny evaluation and seed production are difficult to obtain simultaneously; that cultural practices desired for seed production are often not desirable for evaluating progeny tests; and that there is danger of related mating half- and fullsib relatives in the seedling orchard.

A low cost but relatively low gain option is afforded by open pollinated seedling seed orchard, thinned on combined family and individual performances. If about 5% of the original stand is retained, genetic improvement from seed of the survivors is predicted to be about the same as for an unrogued clonal orchard (NAMKOONG et. al., 1966). The inbreeding from an open-pollinated thinned seedling orchard is likely to be lower than the control-pollinated type because related matings (excluding selfing), that occur, will be at most between members of the same halfsib family. The more families involved, the lower the possibility will be of inbreeding in products of the orchard. This type of orchard is well-suited only when dealing with a relatively small scale planting programme where substantial investment for establishment of clonal orchard is not economically justified.

In summary, the seed orchard is the production unit of the breeding programme. It is important to investigate and solve the practical problems which may stand in the way of this function. The important point to be made is that if the technical problems of making vegetatively propagules normally by grafting have been solved, if graft incompatability is not a serious problem, and if there are no barriers to seed production, the clonal seed orchard is probably the most effective means of seed production that will result in seed of substantial genetic improvement becoming avilable relatively quickly.

The Long Term Approach

Seed from a seed orchard will provide seedlings suitable to grow under certain environments and to produce a desired product for a period of time. The production orchard, however, will not serve as a sole base for future improvement. It is, therefore, necessary to have available additional genetic material from which new orchards can be developed. This can be maintained in tree banks ready for use in a seed orchard as needed. New production orchards established from tree banks will yield good genetic gain, since there has been time to breed and select and test more intensively perhaps through several generations, a process not possible for the first production orchards (ZOBEL & McELWEE, 1964). Considerable imagination and prediction is required on the part of the researcher to estimate future management practices and product requirements when testing tree banks for possible future use. Genetic material from which new production orchards will be established can be drawn from the following sources:

1. Progeny test material. The approach followed in the first generation, including number of selections, type of orchard, and mating design, will greatly affect progress in the generation to follow. If individuals are to be chosen from progeny tests, caution must be exercised to restrict the use of trees having a common ancestor, since high levels of inbreeding are known to be deleterious (FRANKLIN, 1969).

2. Plantation from seed of the production orchard. These trees will have undergone more than one selection cycle, and provided that they do well under the new conditions, should give considerable genetic improvement depending on the quality and characteristics of the original production seed.

3. Established tree banks. In many cases trees with specific characteristics will be used and trees that may be highly desirable in all but one characteristic will be rejected. Instead of discarding those trees, the "temporary rejects" could be retained in tree banks and progeny tested with the expectation that in the future the rejected characteristic might be desired.

4. Exchanged material. Tree improvement programmes for important hardwood species such as teak have been or very soon will be started in many tropical countries. Selected trees are growing under widely differing conditions. Crosses among these trees hopefully will yield many new and potentially useful genetic combinations.

Besides consideration on the next generation material, the research to solve specific orchard establishment and management problems must be incorporated in operational programme. Information on irrigation and fertilization to increase and stabilize seed production is greatly important. Damage caused by insects and pathogens could be very destructive, therefore, research work into the biology and control of these pests is also necessary.

Implication of General Considerations for Teak Breeding Programme

The discussion to this point has dealt wholly with the general aspects. Most of the ideas and information are obtained from the more advanced pine breeding programmes in the southeastern U.S.A. Tree breeding programmes for tropical hardwood species have been virtually untouched, but this is as it should be. Despite a large number of economically important hardwood species available in the tropical regions, information on artificial regeneration and management of many species is not extensively known. Furthermore, breeding systems of only few species have been investigated up to the present. Developing a tree breeding programme for any species without knowing how this species complex is to be regenerated, managed or harvested cannot be justified.

Teak is an exception. Regeneration by artificial plantations has been adopted for over 50 years in many tropical countries such as India, Burma, Indonesia and Thailand. Information on provenance, site studies, growing techniques and cultural practices are extensively known. Accumulation of genetic information of the species up to the present time can enable, though not perfectly, the tree breeder to make justified decisions about developing a breeding programme. A most important foundation is the large active planting programmes developed in many countries aiming to produce large quantities of veneer timber. Every year millions of seedlings are planted in the field. The productivity of these plantings can be greatly increased by the cultivation of genetically improved seed, made possible through active tree breeding programmes.

Initiating a teak improvement programme is justified. However, to obtain sufficient and consistent financial support may be a major problem in some areas where economic situation forces the forest owners (mostly governments) to be extremely carefull on any investment, especially when the investment seems to be very large. It is very likely, however, that the tree breeder will obtain certain facilities, certain areas of land, co-workers, some money and time. He will have to use these effectively in order to obtain maximum gain per unit of time and effort spent. For these very reasons, three possibilities are proposed for the following conditions:

1. When a programme recieves little support.
2. When a programme recieves moderate support, and
3. When a programme recieves considerable support.

It is very difficult and subjected to risk of generalization to delineate specifically in term of absolute value for the proposed conditions, since the amount of work differs from location to location, from species to species. The cost and expense vary greatly from one country to another and so on. Examples in the N.C. State-Industry Cooperative Tree Improvement Programme reveal that establishment of loblolly pine clonal seed orchards will cost $ 4,800–7,600 per acre (Davis, 1967). It should be far less than that if similar activities are conducted in tropical countries with teak, because the labour cost will be greatly reduced.

In actual practices, the problem of choosing the proposed programmes will not be so difficult because the activities to be performed are described with diagrammatic illustrations. The tree breeder, after careful consideration on amount of work to be done in relation to the amount of financial support available, will finally be able to decide which of these proposals will suit his condition best.

A specific type of seed orchard is proposed for each condition. Orchard size will depend upon the quantities of seed required. In full production, for a guideline, an average of 60,000 seeds per tree can be expected. Allowing for bad seed years, unsound seed and nursery losses a conservative estimate of 15,000 plantable seedlings per tree (750,000 seedlings per acre) is a reasonable guide for computing orchard size.

1. A breeding programme with little support. Under this condition, clonal seed orchard is considered unaffordable. To obtain genetically improved seed on a mass basis the following breeding procedure should be followed:

1.1. Select rigorously (1:50,000) about 100 fast growing superior trees. Height, volume, straightness and small uniform limbs should be selection criteria.

1.2. From these, collect seed and mix seed in approximately equal amounts from each tree to sow in the nursery as a unit.

1.3. Select about 5% of seedlings and transplant to well prepared site at spacing 6′×6′ (1210 trees/acre).

1.4. After final evaluation select the best trees from this plantation, remove all other. Leave about 50 trees per acre. Seed production will begin after 10 years.

If further improvement becomes desirable the following activities can be performed:

1.5. When trees in seed orchard flower extensively at around age 8–10 years, collect open-pollinated seed and grow them in nursery seperately by family.

1.6. Transplant seedlings to well prepared site in 12-tree family row at 6′×6′ spacing. There will be approximately 100 row/acre. Rows of the same family must be kept far apart.

1.7. Evaluate and reject the whole rows that are inferior in average performance. Also, remove all but one tree per family in the superior rows. As much as 25 families (50 rows) can be removed in an acre and only 50 trees per acre will be left for seed production.

Diagrammatic representation for this method is given in Fig. 1.

2. A breeding programme with moderate support. Under this condition, a clonal seed orchard can be established and open-pollinated progeny test of selected parents can be done. The following breeding procedures are proposed with diagrammatic illustration (Fig. 2).

2.1. Select rigorously (1:50,000) about 100 fast growing superior trees. Collect open-pollinated seed from these and then progeny test.

2.2. Establish clonal seed orchard and clone banks.

2.3. Evaluate families and individuals within families then rogue the clonal seed orchard.

2.4. Second generation seed orchard can be established by selecting material from the improved breeding population.

The programme will be opened for new selections. After progeny tests, proven clones will be incorporated into breeding population for next generation.

3. A breeding programme with considerable support. Under this condition, control-pollinated progeny test of selected parents is proposed to be employed. The breeding procedure is illustrated in Fig. 3 and will be described as the following:

3.1. Select very rigorously about 50 plus trees.

3.2. Establish clonal seed orchard and clone banks.

3.3. Clones will start flowering approximately around year 5; then make control pollination in clone bank using subdivided modified dialell as illustrated in Fig. 4. There will be 108 crosses per subdivision or totally 216 crosses; then progeny test thereafter.

3.4. Evaluate families and individual within families and use the information involving general combining ability of each clone as a guideline to rogue clonal seed orchard.

3.5. Further genetic improvement can be achieved by establishment of second generation seed orchard from proven material as indicated in the diagrammatic representation. Inbreeding can be avoided by using pedigree records available through this procedure.

The programme will be opened for new selections or exchanged material. Factorial 4 tester of proven parents will be employed and progeny will be evaluated. Proven clones, finally, will be incorporated into the breeding population for next generation.

Roles of Cooperation in Tree Improvement Work

Forest tree improvement is concerned with various aspects of biological science. Although actual breeding may claim most of the activities, tropical hardwood improvement work will invariably overlap other fields of research such as silviculture, statistics, pathology, soil science, plant physiology and etc. The work will often need discussion and advice from specialists in these fields, on the other hand the tree material will offer new opportunities for investigations and experiments.

The same principles of exchange both of knowledge and material will of course apply to tree breeding stations in many countries. Also here the benefit will be mutual. From breeding stations of long establishment in the temperate regions many experiences have been accumulated, from which the foresters in the tropics may learn and thus get off to a better and quicker start. The relative fast growth of tropical tree species in turn may soon yield results of interest to breeding stations in other regions.

Finally, all the information mentioned previously point to the fact that cooperation in different directions and at different levels is beneficial. The tropical hardwood improvement station should consider it as part of its obligation to make actual practical cooperation by all possible means.

Fig. 1. Diagrammatic representation of a teak breeding programme with little support.

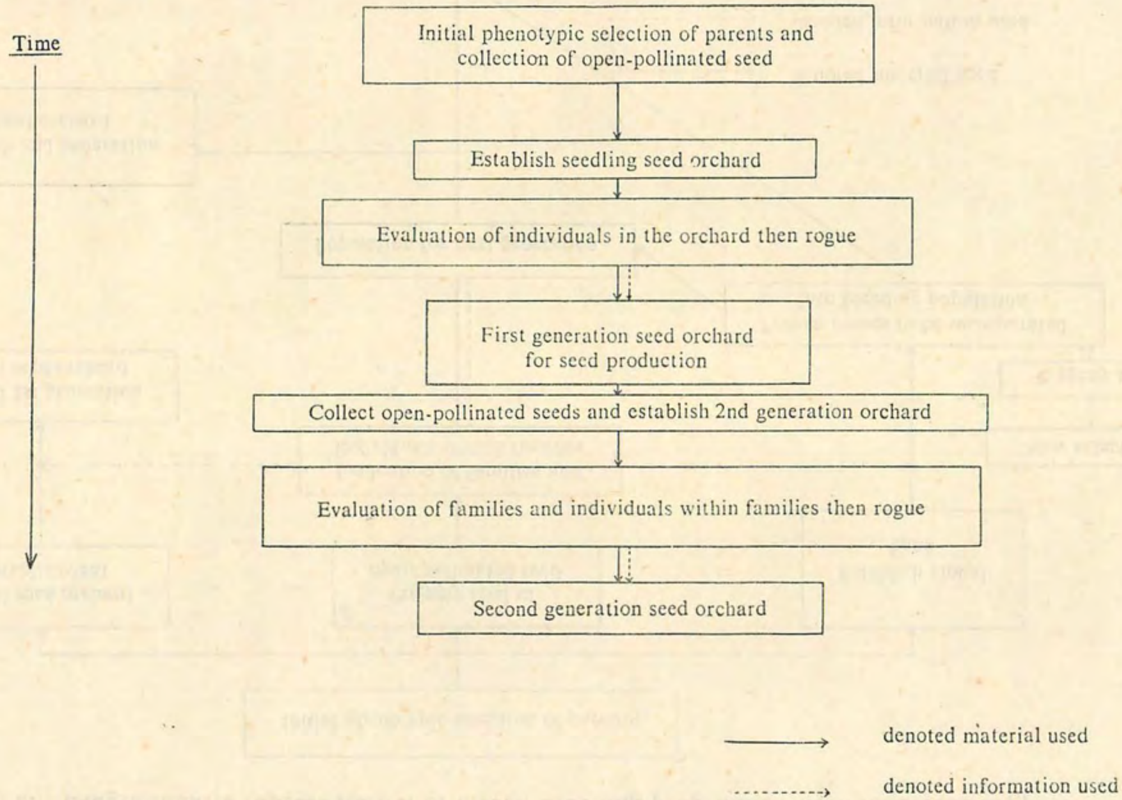

Fig. 2. Diagrammatic representation of a teak breeding programme with moderate support.

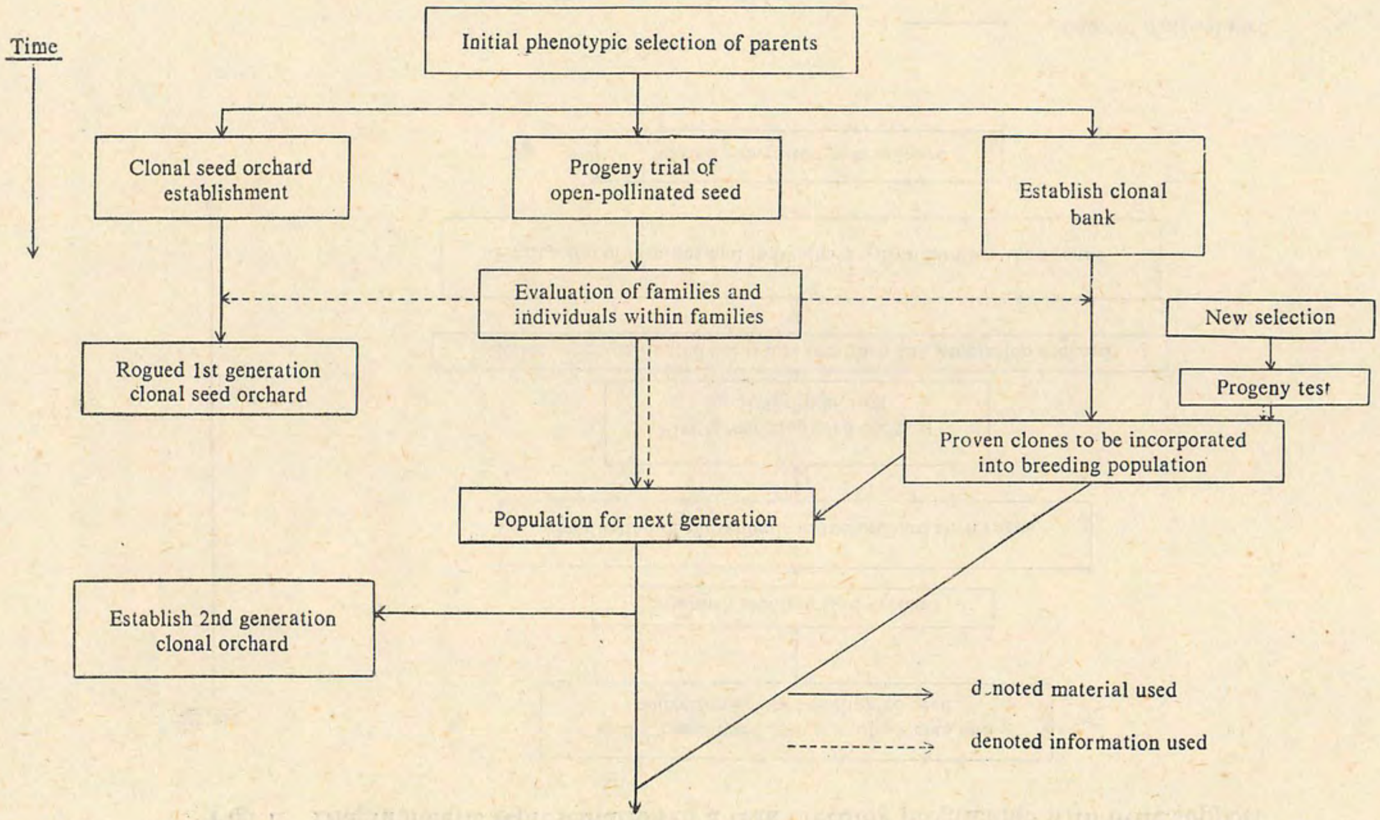

Fig. 3. Diagrammatic representation of a teak breeding programme with considerable support.

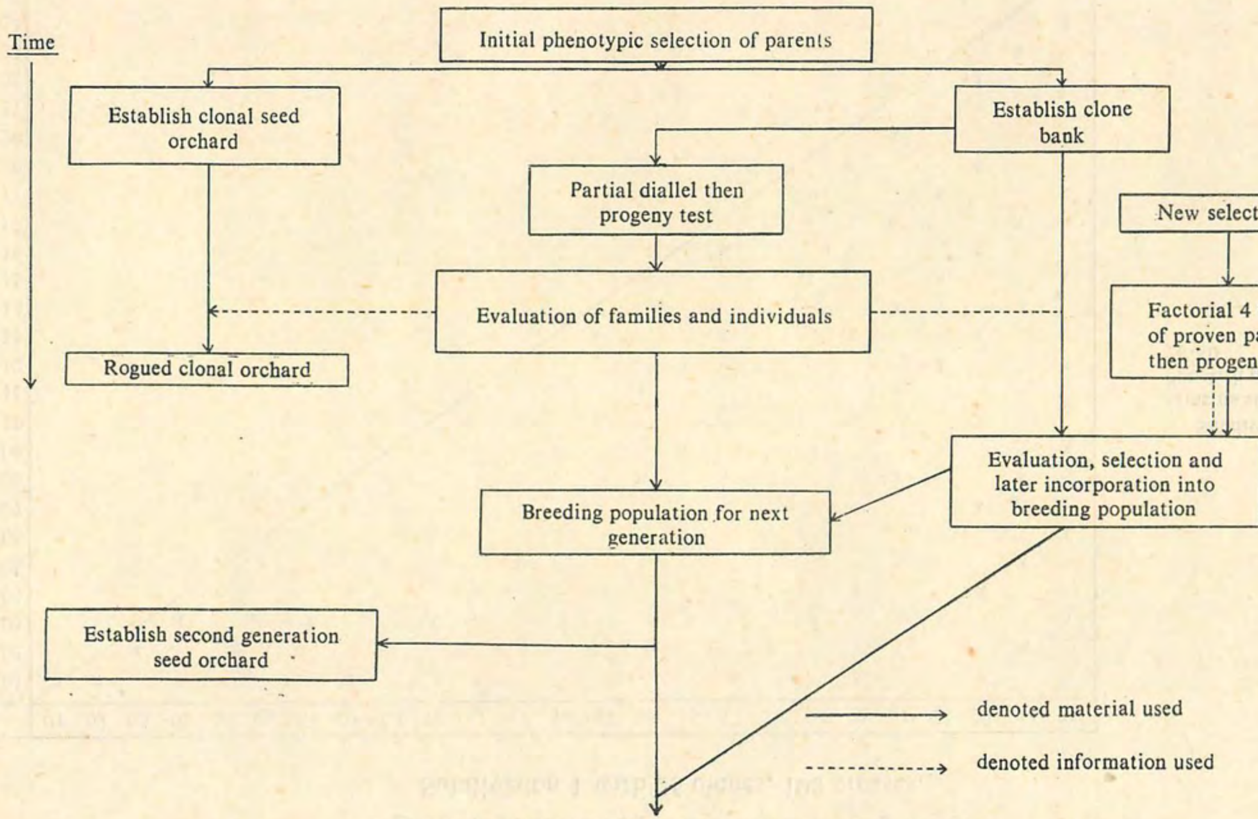

Fig. 4. A subdivided partial diallel mating design.
Subdivision 1 with 25 clones, 108 crosses.

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
01		x			x			x			x			x			x			x			x		
02			x			x			x			x			x			x			x			x	
03				x			x			x			x			x			x			x			x
04					x			x			x			x			x			x			x		
05						x			x			x			x			x			x			x	
06							x			x			x			x			x			x			x
07								x			x			x			x			x			x		
08									x			x			x			x			x			x	
09										x			x			x			x			x			x
10											x			x			x			x			x		
11												x			x			x			x			x	
12													x			x			x			x			x
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24																									x
25																									

Subdivision 2
same as subdivision 1
but with clone #
26-50

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