

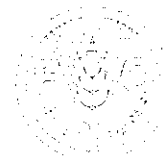
# Forest tree improvement

FAO  
FOREST  
PAPER

20



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AGRICULTURE  
ORGANIZATION  
OF THE  
UNITED NATIONS

# Forest tree improvement

Report on the  
FAO/DANIDA Training Course  
on Forest Tree Improvement  
Mérida, Venezuela  
January - February 1980

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ABSTRACT

The FAO/DANIDA Training Course on Forest Tree Improvement was held in Venezuela from 14 January to 2 February 1980. The Course was organized by the FAO Department of Forestry in collaboration with the Government of Venezuela, the University of the Andes, and the Instituto Latinoamericano de Investigación y Capacitación. The Course was financed with funds made available by the Danish International Development Agency (DANIDA). It was attended by 19 experts from 17 countries of Latin America: Argentina (1), Bolivia (1), Brazil (1), Chile (1), Colombia (1), Costa Rica (1), Cuba (1), Dominican Republic (1), Ecuador (1), Guatemala (1), Honduras (1), Nicaragua (1), Panama (1), Paraguay (1), Peru (1), Uruguay (1) and Venezuela (3).

The Course consisted of two weeks of lectures and practical demonstrations in Mérida and one week study trip to the states of Barinas and Monagas in western and eastern Venezuela respectively.

Lectures included the following topics: tree improvement in relation to national forest policy; elements and principles of genetics; conservation and rational use of forest genetic resources; collection and handling of forest seeds; storage, testing and certification of forest seeds; experimental designs; statistical interpretation of test results; species and provenance trials; selection and management of seed stands; selection of forest trees; vegetative propagation methods; controlled crossing systems and designs; establishment and management of seed orchards; progeny trials; genotype/environment interaction; breeding for disease resistance; strategies for tree development programmes; economic considerations of forest tree breeding programmes.

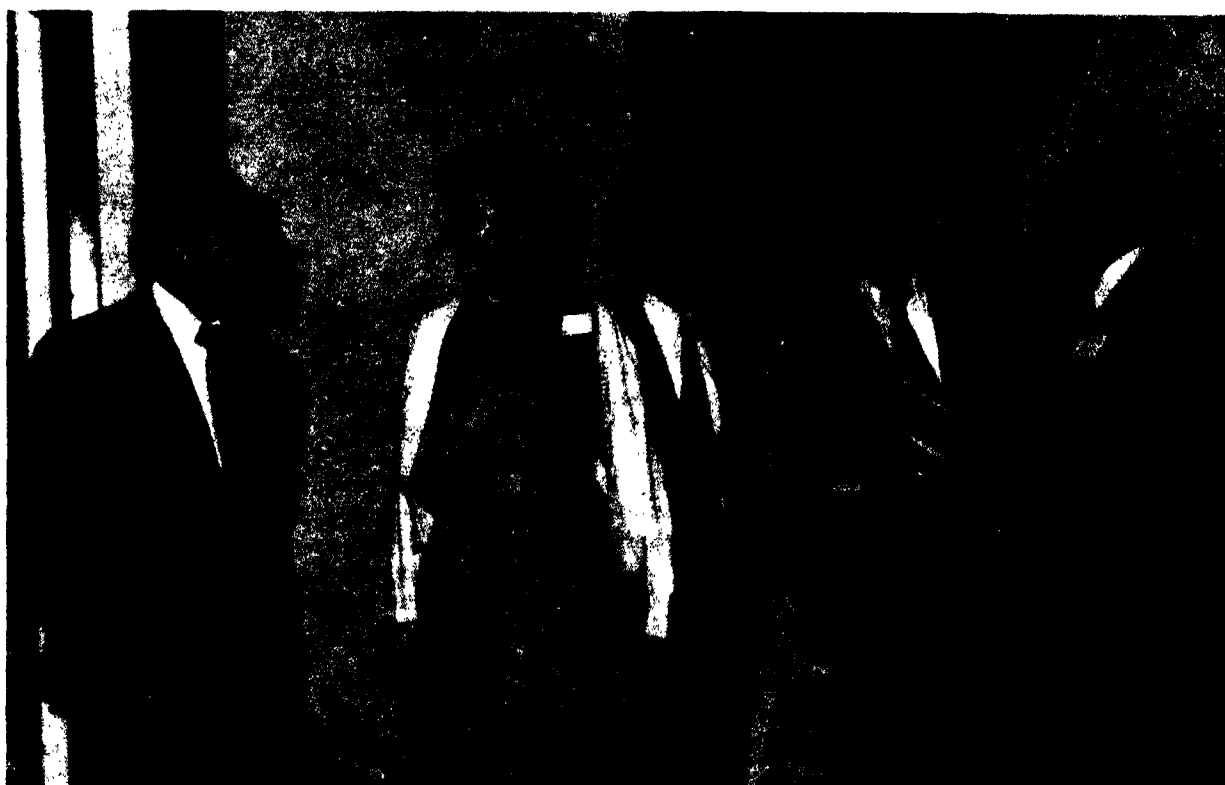
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Opening of the course. Dr. R. Chalbaud Zerpa (Governor of the State of Mérida); C. Palmberg (FAO Co-Director of the course); B. Ditlevsen (DANIDA Co-Director of the course); A. Luna Lugo (ULA); and W.H.G. Barrett (International Director of the course).

## 1. INTRODUCTION

The FAO/DANIDA Course on Forest Tree Improvement was held in Venezuela from 14 January to 2 February 1980, at the kind invitation of the Government of Venezuela. The Course was organized by the Department of Forestry of FAO with funds made available by the Danish International Development Agency (DANIDA). With the technical collaboration of the University of the Andes in Mérida and the support of the Instituto Latinoamericano de Investigación y Capacitación, IFLAIC.

The training course was one in a series as part of the FAO programme for forest tree improvement. Earlier courses in the series were held in Denmark in 1966, in Kenya in 1973 and in Thailand in 1976.

The objective of the course held in the Latin American region, and which was intended for professional foresters, was to provide participants with a theoretical and practical background in present-day forest tree improvement, and to promote contact between foresters and forestry institutions in the region.

Nineteen participants from 17 Latin American countries participated in the training course (see Appendix I).

Dr. W.H.G. Barrett of Argentina was the International Director of the course. Dr. M. Quijada R. of the Institute of Silviculture, University of the Andes, acted as national Co-Director. Dr. B. Ditlevsen of Denmark acted as the DANIDA Co-Director and C. Palmberg was the FAO Co-Director.

## 2. ORGANIZATION AND CONDUCT OF THE TRAINING COURSE

The first two weeks of the course covered both theoretical and practical aspects of forest tree improvement. The third week was devoted to a study trip to the states of Barinas and Monagas in western and eastern Venezuela respectively.

Appendixes II and III list the detailed programme of the course.

This training course benefitted from the experience of earlier courses.

With respect to earlier courses, this training course placed heavier emphasis on experimental designs and statistical evaluation of trials. Tropical hardwood tree improvement techniques were also included where possible.

The close relationship between national forestry policy and tree improvement programmes was stressed throughout the training course. An attempt was made to give participants a broad perspective of the tree improvement issue. The various prerequisites of justifying a new tree improvement programme such as available land and a solid reforestation programme were also stressed.

Before the course the instructors prepared written lecture notes which were distributed to participants on their arrival in Mérida. Participants also received certain publications and papers of fundamental importance of general interest. The lectures are found in Appendix IV. A bibliography, including the publications distributed to participants, is found in Appendix VII.

Before their arrival in Mérida, participants filled out a questionnaire on the current plantation and forest tree improvement situation in their respective countries. This information formed the basis of the brief talk by each participant based on the "Country Reports" in Appendix VI.

## 3. CONCLUSIONS

The course offered expertise which will be applied and extended by participants upon their return to their respective countries. This aspect of the course should certainly not be under-rated, but the opportunity for 19 participants representing 17



countries to meet and exchange information and experiences and discuss common problems with experts from other countries was also, and unquestionably, a unique and valuable opportunity.

This was a particularly opportune moment for a course of this type because most of the Latin American countries are intensifying plantation activities with an eye to meeting their wood and fuelwood requirements, and are including the introduction of exotic species and selection and improvement programmes in their activities.

The study trip at the end of the course was highly important and very valuable. Participants were given the opportunity to see problems which can occur in real life situations and to discuss possible compromises and ways of solving these problems.

It should be stressed that the success of the course was largely due to the interest shown by participants. This made it possible to overcome certain difficulties which arose at the outset, such as the range of technical expertise met at the meeting. The camaraderie and good humour which were a permanent feature of the workshop helped create a propitious, inspiring atmosphere for the activities of the course.

#### 4. ACKNOWLEDGEMENTS

FAO wishes to express its appreciation to the Government of Denmark, who sponsored the course through the Danish International Development Agency, and to the Government of Venezuela who offered to host the course. In addition, thanks are due to the Department of Forestry Sciences of the University of the Andes, Mérida, for its very valuable administrative and professional support and to the Consejo de Desarrollo Científico Humanístico (CDCH) for its financial support; the Instituto Latinoamericano de Investigación y Capacitación, IFLAIC, which made its lecture rooms and libraries available to the course; the Corporación Venezolana de Guayana, CVG, and the Compañía Nacional de Reforestación, CONARE, through whose cooperation the study trip was made possible; the Laboratorio Nacional de Productos Forestales, LABONAC, and the Training Centre of the University of the Andes for their collaboration throughout the course.

Special thanks are due to the Governor of the State of Mérida, Dr. Reinaldo Chalbaud Zerpa, who contributed substantially to the success of the course through his personal interest, ensuring that participants were thoroughly briefed on the traditions and customs of Venezuela and of Mérida.

Finally FAO wishes to thank all lecturing and support staff and expresses its appreciation for the interest of participants and also extends thanks to all those who, through their interests and efforts, helped to make this a successful training course.



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1st Row, left to right: M.E. Quinteros (Paraguay); J.A. Enricci (Argentina);  
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Appendix I

FAO/DANIDA  
TRAINING COURSE  
ON FOREST TREE IMPROVEMENT

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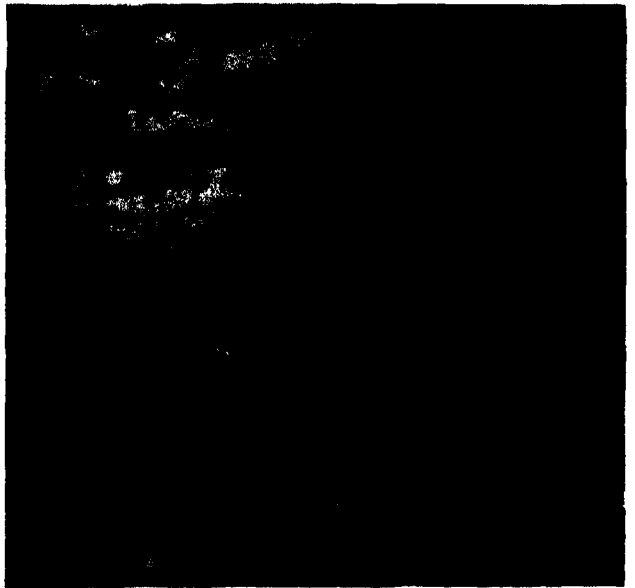
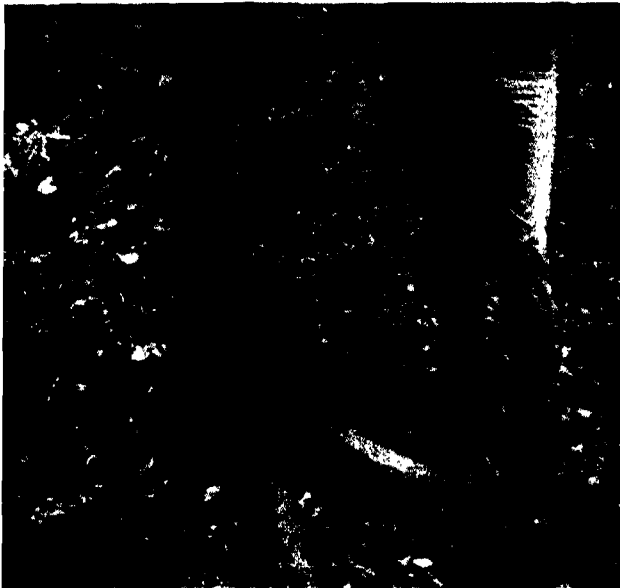
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Bombacopsis quinata, genetic variation in the occurrence of buttresses.

## Appendix II

## FAO/DANIDA TRAINING COURSE ON FOREST TREE IMPROVEMENT

PROGRAMME OF COURSE  
(theory)

Time	Monday 14.1.80	Tuesday 15.1.80	Wednesday 16.1.80	Thursday 17.1.80	Friday 18.1.80
8.30	9.30 Official opening of course	Conservation and rational use of forest genetic resources (C. Palmberg)	Experimental designs (B. Ditlevsen)	Species and provenance trials (W.H.G. Barrett)	
10.15					
10.30	Tree improvement in relation to national forestry policy (W.H.G. Barrett) 1/	Collection and handling of forest seeds (B. Ditlevsen)	Statistical interpretation of test results (B. Ditlevsen)	Selection and management of seed stands (M. Quijada)	Visit to la Carbonera experimental forest (H. Finol U.)
12.00					
13.30	Elements and principles of genetics (W.H.G. Barrett)	Storing, testing and certification of forest seeds (B. Ditlevsen)	Visit to computer centre and CDCH. Visit to	Selection of forest trees (M. Quijada)	Visit to Jaji, a typical Venezuelan village
15.15					
15.30	Visit to Institute of Silviculture, Library of the Dpt. of Forestry Sciences and the Instituto Forestal Latinoamericano de Investigación y Capacitación	Visit to the forest seed laboratory. Demonstration of seed treatment, storage and testing	NABONAC	Country reports (Argentina, Bolivia, Cuba, Guatemala)	
17.00					
20.00		The life zones of Venezuela (L. Rodriguez Poveda)			
21.30					
Time	Monday 21.1.80	Tuesday 22.1.80	Wednesday 23.1.80	Thursday 24.1.80	Friday 25.1.80
8.30	Quantitative genetics: general principles and practical application in forest tree improvement (B. Ditlevsen)	Controlled crossing systems and designs (B. Ditlevsen)	Progeny trials: principles and application of results in practical improvement programmes (M. Quijada)	Economic considerations of the forest tree breeding programmes. (B. Ditlevsen)	Specific examples: Example I - Genetic Improvement programme in a sub-tropical region (W.H.G. Barrett)
10.15					
10.30	Methods of vegetative propagation (M. Quijada)	Designs and establishment of seed orchards (W.H.G. Barrett)	Genotype/environment interaction (M. Quijada)	Planning and strategies for forest tree breeding programmes (C. Palmberg)	Specific examples: Examples II - Programme of genetic improvement of tropical hardwoods (M. Quijada)
12.00					
13.30	Working parties	Management of seed orchards (W.H.G. Barrett)	Working parties	Disease problems in the tropics (O. Holmqvist)	Closure of the first part of the course
15.15					
15.30	Country reports (Costa Rica, Dominican Rep., Panama, Paraguay, Uruguay)	Country reports (Colombia, Nicaragua, Peru)	Country reports (Chile, Venezuela)	Country reports (Brazil, Ecuador, Honduras)	

Appendix III

COURSE PROGRAMME

(Study trips)

- 27 January Trip by bus to Barrancas. "El Irel" experimental station. Controlled pollination demonstration on Bombacopsis Quinata.
- 28 January Caemital experimental forest: trials at "El Irel station".
- 29 January Trip to Puerto Ordaz, "El Mereí" forestry site.
- 30 January Visit to CVG plantations, nursery and trials in Uverito.
- 31 January Visit to CONARE plantations, nursery and trials in Chaguaramas.
- 1 February Trip to Puerto Ordaz, visit to "La Llovizna" park and SIDOR plant (Siderúrgica del Orinoco).
- 2 February End of course.



"Perils" during the study trip



Appendix IV

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Tree Improvement in Relation to  
National Forest Policy and Forest Management

R.L. Willan  
FAO

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INTRODUCTION

The justification of any national programme of tree improvement and the amount of resources devoted to it should be largely determined by the forest policy of the country (Keiding 1974). Forest policy, in turn, must be related to national development plans.

Basic questions which need to be asked are (1) How significant is forest in the nation's economy? and (2) How significant is plantation forestry in the forestry sector as a whole? At one extreme is the case of a small, highly populated country in which there is no room for extensive forestry, and therefore no place for tree improvement. Singapore and Malta are examples. At the other extreme are countries with low population density and large areas of natural forest capable of being naturally regenerated and of providing the country's needs in the foreseeable future. Gabon and, until recently, Kalimantan and Indonesia may be examples. In such countries there is a case for a simple silvicultural technique designed to retain a proportion of the best trees as seed-bearers and, without doubt, for the establishment and protection of strict natural reserves within the forest, but not for a long-term programme of tree breeding. In regions where the crucial protective function of the forest in steep topography precludes commercial harvesting and hence reforestation, there is likewise no scope for tree breeding.

Few countries can now afford to rely entirely on natural forests. In most the pressure on land is becoming steadily greater and, if the requisite raw materials can be produced from a much smaller area or in a shorter period by using intensive high-yielding plantation methods, foresters have a responsibility to employ these methods. Concentrated plantations lead to indirect economic and social benefits through the development of forest industries and opportunities for employment. Accordingly, plantations are being established on an increasing scale throughout the world. In practice the roles of natural and man-made forests should be considered as complementary, with natural forests fulfilling essential protective and cultural functions and providing certain special categories of wood, such as high quality material for cabinet making or veneering, while plantations supply an increasing proportion of requirements for constructional timber, utility sawn wood, wood based panels and pulp (Hughes and Willan 1976).

Generally speaking, the prerequisite for a tree improvement programme is plantation forestry. As soon as seed is collected, plants raised and artificially cultivated, there is a chance to select and improve. Thus, it will be convenient to start the consideration of tree improvement in relation to afforestation and reforestation programmes (Keiding 1974). This is why country statements which participants have been requested to complete set the information on national tree improvement programmes in the context of the national environment, the national forest policy and national programmes on afforestation and reforestation.

## PREREQUISITES FOR A TREE IMPROVEMENT PROGRAMME

Prima facie Even though there may be a case for plantation forestry and tree breeding in a country, expenditure of funds and effort demands certain prerequisites:-

### A. The planting programme

(1) Availability and control of land. The large investment involved in plantation forestry can be justified only if there is an assurance that forestry will remain the object of land management for at least one rotation. Even with "fast-growing species" this is likely to extend for one or more decades. And the managerial authority must have full control of the land throughout the period. Excellent security of tenure may exist if the plantations are on government-owned forest land included in a national land usage plan by which continuity of management is promised for some years ahead. Land which is fragmented among numerous small private owners is usually unsuitable for plantation forestry. On the other hand, tree breeding may have a part to play in the provision of trees for diffuse planting in agrisilviculture, provided that the farmer is convinced of the value of the product and of the need to protect and manage the trees.

(2) Scale of operations. No matter how great the gains to be derived from tree-breeding, the basic minimum costs of a small research unit need to be spread over an adequate area if they are to pay for themselves. For example a unit costing \$100 000 a year and producing improved seed capable of yielding an increase in discounted product value of \$100 per ha per year, would more than pay for itself on a 10 000 ha a year programme but could not be justified for a 100 ha a year programme.

(3) Availability of markets. There needs to be reasonable assurance of markets for plantation produce, either within the country or through export. Not only must the markets exist, but they must be within economic distance. Plantations, even on high-yielding sites, may be uneconomic if transport costs are crippling.

### B. The tree improvement programme

(4) There must be reasonable assurance, e.g. in a written policy statement by the financing authority, that staff and funds will be provided to the tree improvement programme on a continuing basis. As Zobel (1969) has stated: "Will I have the backing in funds, facilities and manpower to do a decent job? If not, then don't start! A half-hearted programme, poorly done, will only sour people on forestry and its potentials." If a trained tree breeder is not already available from within the country, provision to train one must be made from the start.

(5) Assessment of technical information available from elsewhere. Results of research in other countries with similar environments may reduce, if not eliminate, the need to start a national tree improvement programme de novo. For small countries with modest planting programmes, a regional research unit may provide the same results as several national programmes and at a lower cost. Examples of regional tree improvement programmes are those which operated in East Africa during the 1960s and '70s and CATIE now operating for Central America. Even where a country's planting programme is large and is carried out on a unique range of sites, international exchange of information and of genetic material can do much to avoid duplication and concentrate research on solving the most important problems or exploiting the most promising opportunities.

## DEFINING OBJECTIVES

Having established that the basis for a national tree improvement programme exists, the policy maker needs to define its objective as clearly as possible. There are often good reasons for specifying more than one objective. In view of the long-term nature of forest crops and, in comparison, the speed with which technological preferences and markets can change, there is often a strong case for maintaining the maximum flexibility in the objectives. Flexibility is especially important with rotations longer than 15 years (Hughes and Willan 1976). However, there are limits to the flexibility of programmes and species which should be recognized from the start. A high density eucalypt is likely to be superior to a low density eucalypt for fuelwood but inferior for short-fibre pulpwood. In the southern USA separate seed orchards are planted for high-density and

low-density wood in pines. Thus different purposes may sometimes be served best by growing separate crops using separate selection criteria rather than by attempting to grow a "multi-purpose" crop which serves neither purpose adequately. If more than one objective is specified and in case resources prove inadequate to achieve all objectives - which is almost inevitable - it is important to assign relative priorities.

The objectives defined must be based upon immediate, short term and long term requirements of the relevant afforestation programme. Constraints on the achievement of objectives also must be taken into account at the time of definition, and should indicate the limits of the resources (staff, facilities and finance) within which the project will be required to operate (Hughes and Willan 1976).

#### CONSTRAINTS

Tree improvement objectives can only be achieved within existing biological human and financial constraints. In some cases these are so limiting that the objectives are impossible of attainment and it becomes the duty of the tree breeder to convince the policy maker to set more realistic objectives. Examples in which limiting conditions could force a change in the objectives might be:-

- (1) Attempts to grow high-yielding plantations in semi-arid conditions. Species of provenances may be fast-growing or drought-resistant, but rarely both. Any improvement from tree breeding is likely to be small and slow. More impressive improvement may be obtained by shifting the afforestation scheme to a more humid zone or by introducing irrigation.
- (2) Attempts to start a tree improvement programme in an introduced species, using small plantations of narrow or unknown genetic base. In such cases further introductions and provenance trials are more urgent than individual selection in the existing plantations.
- (3) Attempts to use an exotic species of which foreign seed supplies are inadequate and which fails to produce a seed crop in the new environment.
- (4) Attempts to improve traits which are known to have very low heritabilities.
- (5) The time-scale imposed by the period taken from germination to seed production in forest trees is often a serious constraint. If somewhat improved seed is needed in five years and the species takes 10 years to produce seed in a seed orchard, then establishment of a seed orchard now cannot achieve the objective. Alternatives, such as heavy improvement fellings in commercial stands, or a change of strategy, such as development of vegetative propagation methods, must be considered.

#### TREE IMPROVEMENT IN RELATION TO MANAGEMENT

Tree improvement is simply one tool available to forest management and cannot be considered in isolation. Research on tree improvement should therefore be closely integrated with other research, e.g. on soils and site assessment, on establishment techniques, on spacing and thinning and on wood quality. National forest policy must therefore include provision for the integration of all sectors of forest research and for the rapid multiplication and introduction into forestry practice of improved material.

Tree improvement results may modify forest management. For example better trees, more uniform and more disease resistant, make possible a wider initial spacing which reduces costs while still achieving the desired final stocking (Zobel 1969). Breeders can produce genotypes which respond well to intensive site preparation and fertilization and other genotypes which will tolerate poor soils and no fertilizers. Within a single country there are likely to be a number of different site types to be planted and the tree breeder therefore needs to develop a range of genotypes adapted to the various sites. Technological developments may alter breeding priorities, e.g. the invention of a new pruning device leading to a major reduction in pruning costs may reduce the need to breed for small branches and early self-pruning, or a revolutionary new pulping process might reduce the importance of wood quality or wood uniformity.

### SUMMARY

(1) Tree improvement programmes must be closely related to the objectives and priorities of national afforestation programmes and hence to the national forest and development policy of the country.

(2) A number of prerequisites, e.g. availability of land and a substantial scale of afforestation, are prerequisites to justify the initiation of a tree improvement programme

(3) If a tree improvement programme is to be started and is to have a good chance of success, it must have clearly defined objectives and priorities, and some assurance of continuing provision of adequate resources to achieve them. As far as possible objectives should be unequivocal and quantitative.

(4) The tree breeder must examine objectives closely in the light of biological, human or financial constraints and, if necessary, he must convince policy makers to change the objectives. Only after realistic objectives have been set and accepted can the tree breeder start to plan his strategies and programme as described in another lecture.

(5) Tree improvement interacts with other aspects of research and management, e.g. site assessment and preparation, spacing and thinning. So tree improvement research must be closely integrated with other sectors of the national forest research programme.

(6) Tree improvement programmes should be flexible and provision should be made for regular revision. National economic priorities change and may call for changes in tree improvement objectives. Equally, successes and failures in tree improvement research may suggest changes in forest management and afforestation policy (change of species, ability to afforest new sites hitherto considered uneconomic to plant). Communication between policy and research must be two way.

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ELEMENTS AND PRINCIPLES OF GENETICS 1/

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DEFINITIONS

Genetics is the study of the similarities and differences between individuals, or, in other words, of variation and inheritance in living things and consequently their evolutionary process. A distinction may be made between conventional or Mendelian (or transmission) genetics, and population genetics (the specific effects of genes on living things). Genetic improvement is the application of the science of genetics for the good of humanity.

This article describes some basic concepts of genetics, which are applicable both to animals and plants. Some examples are given of their application to tree species.

CHROMOSOME STRUCTURE

All living cells are made up of an outer cell wall, cytoplasm and nucleus. Within the nucleus are the chromosomes, which are the carriers of genetic information and are responsible for transmitting this information to the other cells. They are constant in number for each species. Thus, for example, willow and poplar species have  $n=19$  chromosomes, pines  $n=12$ , eucalyptus  $n=11$ , etc. Cell size varies according to the species, usually small with angiosperms (which are only a few microns long) and larger with gymnosperms.

1/ This paper is based on:

- Wright, J.W. (1962). Genetics of Forest Tree Improvement. Forestry and Forest Products studies No. 16, FAO, Rome;
- Wright, J.W. (1976). Introduction to Forest Genetics. Academic Press.

The chromosome is a long thread-like structure consisting of deoxyribonucleic acid (DNA) and a protein sheath. DNA, the active genetic material, is a long molecule composed of two spiral strands. Each strand is composed of four organic bases (cytosine, guanine, adenine and thymine) and attached sugar radicals; the two strands are joined together by phosphate radicals. This group generates a molecule from a nucleotide. The two strands are held together more loosely by hydrogen atoms forming molecules of nucleic acid.

The ability of DNA to replicate itself makes it possible for the chromosomes to transmit genetic information from one generation to the next. This is a consequence of the double-strand nature of the molecule and of the properties of the four protein bases. Adenine and thymine (purines with two rings) are joined together by two hydrogen bonds, and guanine and cytosine (pyrimidines with one ring) by three hydrogen bonds. For this reason, guanine will always be linked with cytosine, and thymine with adenine. At the time of chromosome division the two strands unravel, and are replicated, and pair off in such a way that each protein base is linked with its complementary base (adenine with thymine and guanine with cytosine). To give an idea of dimensions the distance covered by ten nucleotides on one strand is 34 Å. The bases are arranged linearly along a single strand in groups of three, and, as there are four bases, there are 64 combinations. In other words, they are like a four-letter alphabet with 64 three-letter words, which are organized in special sequences or paragraphs which direct growth processes. The sequences responsible for the formation of some amino-acids and for the activity of certain enzymes governing protein synthesis are known for some one-celled plants. The molecular weight of the DNA molecule is very heavy. It has been estimated that a single pine cell contains some 50 000 000 000 nucleotide pairs. If each nucleotide is considered a letter of the alphabet, some 2 500 000 pages could be written.

The control of growth processes of a cell is accomplished by a substance similar to DNA called ribonucleic acid (RNA), which differs structurally from DNA inasmuch as it is single-stranded. RNA sugars have one more oxygen atom (ribose) and uracil replaces thymine. RNA performs the function of carrying messages between the DNA and the other parts of the cell, and regulates and participates in the synthesis of amino-acids, and in the synthesis of proteins from amino-acids.

#### GENE STRUCTURE

From a structural point of view, a gene is defined as a sequence of triplets along a DNA molecule. However, so far it has not been possible to isolate and study the structure of a gene. A gene can also be defined as that part of a chromosome responsible for the development of a particular trait. Thus we may speak of genes for rapid growth, resistance to cold, leaf, length, etc. The gene is considered as the ultimate hereditary unit, although we know it is of large molecular size. The number of genes in an individual cell is unknown, although there are estimates for some plants, such as, for example, the Pinus banksiana, in which there are said to be 13 000 000 genes. In some agricultural crops it has been found that individuals of the same species can differ by 500 genes. For an improvement programme, a few dozen genes could be used. The genes can have large or small effects. For example, growth rate is usually governed by many genes with small individual effects. On the other hand, the colour of eyes in human beings is governed by a single pair of genes with relatively large effects. Some genes may act independently; some, however, may act only when others are present.

Genes are arranged linearly on the chromosomes. For this reason, the genes of one chromosome belong to the same linkage group. However, this linkage is not perfect. At meiosis, when homologous chromosomes pair, they break and exchange parts. When this happens, it is said that there has been a "cross-over", giving rise to new genetic combinations. Usually there are one or more cross-overs per chromosome. Logically, the probability that two linked genes will separate from each other is proportionate to the distance between them on the same chromosome. This fact is used to prepare chromosome maps, where the distance between genes is defined in terms of frequency of new combinations; one cross-over unit is equal to 1 percent new combinations. Despite the fact that gene linkage has not yet been measured in trees, a knowledge of it is important for tree breeding. For example, in pines there are 12 pairs of chromosomes and therefore 12 linkage groups. When selecting for any one character, there are apt to be changes in the frequency of other, closely linked genes.

Genes occupying the same locus in a pair of chromosomes are called "alleles" or "allelomorphs" and are denoted by a single letter. Dominant allelic genes cause a characteristic to be expressed even when the tree is heterozygous, whereas recessive genes only have a visible effect if the tree is homozygous for them. This type of dominance is complete. It is partial or incomplete when the characteristic is intermediary in expression. This is what happens with red flowers (AA), white flowers and pink flowers (Aa). When dominance occurs between non-allelic genes it is called epistasis.

Genes are called additive when they enhance each other's effects in a cumulative manner. They are genes with small effects, that govern a single trait.

### MUTATIONS

An error in the replicating process of chromosomes produces changes which are called mutations. These usually occur at the level of the genes; they can cause a gross change in chromosomes, either in number, structure, inversion, addition or reduction in size or replication, etc. This produces large effects, usually abnormalities most of which are harmful.

The frequency of gene mutations is estimated at between 1 in 10 000 and 1 in 100 000 000. The majority of these mutations are harmful and recessive. Despite that, it is a beneficial process, since it is the principal source of variation of living things. These changes, because they are recessive, are incapable of expressing themselves. However, genes which may be detrimental in one environment may be beneficial in another environment. Gene mutation can be increased artificially through the use of X-rays, chemical substances, etc. These chemical substances can act directly on the DNA, producing chemical changes which, during replication, produce mutant offspring. This happens with nitrous acid or ethanosulphonate ethyl. On the other hand, other substances, like 5-bromo uracil, only act during the DNA synthesis. By analogy of bases, it resembles and replaces thymine in replication. During replication this base can occasionally be coupled with guanine instead of adenine, producing a different triplet.

### NON-GENIC INHERITANCE

Cytoplasmic or maternal inheritance has not yet been observed in trees, although it has in herbaceous plants. In maize a plant was found which did not produce masculine flowers and was therefore sterile, due to a cytoplasmic factor. This trait was considered very useful for the production of hybrid maize. Later it was discovered that the same clone was very susceptible to disease, and it was therefore rejected.

There have been cases of paternal inheritance with a Japanese conifer, Cryptomeria japonica.

### GENOTYPE AND PHENOTYPE

Genotype is defined as the genetic constitution of an individual or groups of individuals with a similar gene make-up as compared with specific genes.

Phenotype is the external appearance, partially controlled by the genotype. However, there are recessive genes that are expressed due to the presence of dominant genes, though they do exist in the genotype. There are also genes with small effects, or modifying genes, that are not manifest in the phenotype. Phenotype is also partly determined by the environment. A genotype can contain many genes for rapid growth, without this being apparent, because it is on poor soil or in an adverse climate. Or it may have genes susceptible to a disease, and appear resistant because the disease is not found at that site. However, some characteristics of the genotype may be deduced from a careful study of the phenotype. Of course, much more information will be obtained from studying a tree's offspring and the relationships between the characteristics of the parents and those of the offspring.



### CELL DIVISION AND NEW GENE COMBINATIONS

The cell division that occurs in the cambium, root, tips, leaves and other growth meristems, is called mitosis. The regular constitution of the cells ( $2n$ =diploid) is maintained by replicating each chromosome constituting two identical new chromosomes. Here there is no difference between the chromosomes, apart from possible mutations.

Conversely, in meiosis, there is a reduction in the chromosome number from  $2n$  in vegetative cells (diploids) to  $1n$  (haploid) in the gametes. During meiosis, the two sets of homologous chromosomes come together in the centre of the mother cell, and pair there. This is where cross-overs occur. Segments of each pair of chromosomes are interchanged, producing new gene combinations. Meiosis is a two-stage process, in which there are two successive nuclear divisions that end by forming four gametes.

### FERTILIZATION AND SEED DEVELOPMENT

In fertilization, the male gamete ( $n$ ) comes together with the female gamete ( $n$ ), to produce the egg cell ( $2n$ ) which through successive divisions forms the embryo, the seed and later the tree. During this process, chromosomes from the male gamete are introduced into the nucleus of the egg cell. Meiosis and fertilization are the mechanisms whereby genetic variability makes it possible for individuals to segregate and recombine and produce offspring genetically different from the parents.

Angiosperms are characterized by dual fertilization; i.e. one nucleus of the male gamete fertilizes two polar nuclei making up the endosperm. As a result, various genetically different tissues may be found in the seeds of the angiosperms.

<u>Tissues</u>	<u>Number of chromosomes</u>	<u>Origin</u>
Seed Coat	$2n$	maternal
Embryo	$2n$	maternal and paternal
Endosperm	$3n$	2/3 maternal 1/3 paternal

In gymnosperms, however, the endosperm is haploid and of maternal origin.

### ENDOGAMY

Endogamy of inbreeding is the crossing of related individuals with loss of heterozygosity. The extreme case is "selfing", or the crossing of a tree with itself. There are all gradations from this extreme, for example, back-crossing with one of the parents, crossing between siblings, cousins, etc., or among members of small isolated populations.

Wild populations (forests where there has been no human activity) usually carry a large "genetic load" with a considerable number of recessive genes. Since the individuals cross with each other, and not all of them have the same recessives, these recessive traits do not appear in their offspring. However, if the tree is selfed, for each heterozygous character 25 percent of individuals among the offspring will show the effect of this recessive gene.  $Aa \times Aa = 25\% AA + 50\% Aa + 25\% aa$ . It can happen that the effects of these harmful recessive genes are small and not visibly obvious, but if the selfed parent contains 100 recessive genes their cumulative effect on the offspring can be important. Experiments made with Pinus taeda in the United States showed a loss of vigour among offspring of selfed trees as compared with open-pollinated offspring of the same trees. With other forest species, selfed seedlings have often grown less than 50 percent as fast as normal seedlings.

However, selfing does not always bring with it a loss of vigour. Some autogamous plants, such as tomato and wheat, have flower structures that promote selfing. These plants may have contained, or acquired through mutations, harmful genes, which have been eliminated by thousands of generations of selfing. As far as may be discovered, loss of vigour is not due to selfing or to inbreeding per se, but to accumulations of harmful recessive genes. A tree free of these recessive genes could be selfed without loss of vigour.

Allogamous plants can have mechanisms that inhibit self-pollination, a factor that leads to a reduction in the quantity of seed. One of these mechanisms is the existence of genes for self-sterility, like the multiple alleles  $S_1, S_2, S_3, S_4$  etc., where neither  $S_1$  nor  $S_2$  pollen can germinate a style with the genotype  $S_1 S_2$  etc. There are 40 known alleles in red clover. However, it can happen that the pollen fertilizes the egg, but the recessive genes act against the embryo, thus producing a sterile seed.

There is a wealth of literature on the effects of selfing on tree species. J.W. Wright quotes examples of loss of vigour and reduction in seed fertility in eucalyptus, pine, elms, larches, etc., and others with variable results, ranging from vigorous to weak offspring and from high to low seed fertility.

This extreme endogamy selfing produces individuals or lines scarcely or not at all adapted to the surrounding environment. Without reaching this extreme, when the crossing occurs between a few trees, some random gene fixations take place producing uniform individuals little adapted to the environment.

To sum up, the general effects of endogamy, fixation of characters, decline in fertility, size and vigour, are due to an increase in homozygosity.

Measuring endogamy: In the special case of selfing, heterozygosity is lost at the rate of 50 percent in each generation;  $F$  is the endogamy coefficient used to measure the loss of heterozygosity or increase of homozygosity. The symbol  $\Delta F$  is used to express the per generation change in amount of inbreeding.

$$\Delta F = \frac{1}{2N} \quad N \text{ being } = \text{ number of individuals}$$

In this case  $N$  is the total number of individuals where each tree is used both as male and female parent. When they are different, the formula to be used is:

$$\Delta F = \frac{N(\sigma) + N(\varphi)}{8(N\sigma \times N\varphi)}$$

To calculate inbreeding over a number of generations, it is better to work with the heterozygosity coefficient,  $H = 1 - F$ .

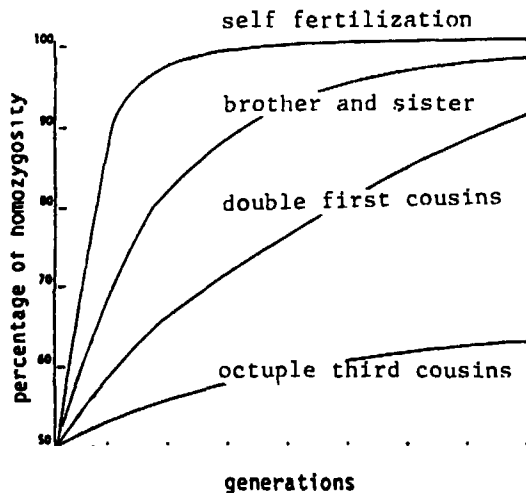


Figure 1. Percentage of homozygosity in successive generations under inbreeding various systems (from S. Wright, 1921. Systems of Mating, Genetics 6: 167).

To calculate  $H_n$ ,  $n$  being the number of generations,  $H_n = (H)^n$ ; and  $H$  = the heterozygosity per generation. As numerical example, assume that  $N = 5$  and  $\Delta F = \frac{1}{10}$ :

$$H \text{ (per generation)} = \frac{9}{10}; \quad H_2 = \frac{(9)^2}{(10)} = 0.810; \quad H_3 = \frac{(9)^3}{(10)} = 0.729$$

After three generations, 72.9 percent of the original heterozygosity remains in the population, and the inbreeding rate is:

$$F_3 = 1 - H_3 = 1 - 0.729 = 0.271$$

Inbreeding coefficients of populations maintained as sites of  $N = 50$  to  $250$  for 10 or 100 generations.

<u>Population</u>	<u>Coefficient F</u>	
N	n = 10	n = 100
5	0.651	0.999
10	0.401	0.994
25	0.182	0.86
50	0.095	0.63
100	0.0489	0.39
250	0.0198	0.18

(extract from J.W. Wright, 1976)

In tree breeding it is assumed that the loss of vigour through unbreeding is proportionate to the loss of heterozygosity as estimated by the coefficient F. In annual plants, on the contrary, it is easy to take five individuals and reproduce them over successive generations and measure the results.

There are mechanisms in plants that encourage or prevent autogamy. Annual plants usually have perfect hermaphrodite flowers and have developed mechanisms suitable for selfing. This is not generally the way with trees, except (according to J.W. Wright, 1976) for tropical trees constituting mixed forests with hundreds of species per hectare, where the possibility of crossing is remote and there is therefore a high probability of selfing or at least a high percentage of endogamy. There must therefore be mechanisms to prevent this damaging the species. Unfortunately we have no experimental data on this subject.

In temperate or cold climates, however, where tree species tend to grow in stands which are pure, or composed of a few species only, there are mechanisms inhibiting selfing. In these cases a greater variability is necessary since there are great fluctuations in rainfall, temperature, exposure to fire, glaciation, etc. One of these mechanisms is the dioecious character of the plants, e.g. male and female flowers are produced on different trees. This happens with poplars, willows, junipers, Araucaria araucana, A. angustifolia, etc. Monoecism also performs this function, e.g. male and female flowers appear on the same tree, as with oaks, Aesculus, and most conifers. In the latter group the masculine flowers are produced on the lower branches, and the female flowers on the higher ones. As pollination is wind-borne, this stratification inhibits selfing to a large extent, since the male pollen would have to rise.

There are mechanisms like dichogamy, whether in hermaphrodite or in diclinous flowers, where the male flower is receptive at a different time than the female; for example, the hazel tree with diclinous flowers (protandry) and the tulip tree (Liriodendron) with hermaphrodite flowers (protogyny).

A simple method has been developed by forest geneticists to determine the percentage of selfing in natural populations of different forest species. It consists in counting the number of abnormal seedlings from open pollinated seed, in the nurseries and multiplying the figure by 5. In various pine species between 2 and 7 percent of selfing has been recorded.

"Selfing plus later crossing" has been used to improve herbaceous plants, but it lacks practical possibilities when applied to trees.

The random fixation of genes in small populations is called genetic drift. If inbreeding is continued over a long geological period, the result is a uniform population which has developed non-adaptive traits. The isolation of small pine populations in the mountains of Mexico has produced a great diversity of forms, which is probably due to random gene fixation. Although this is more frequent in mountain areas, it has also been

observed in existing islands, or regions that were under water in different geological periods. This is the case of Pinus elliottii var. densa which has highly differentiated morphological and adaptive variations, irrespective of distance, in the absence of clonal gradients. One may observe on one island key, for instance, a population which has fascicules with two relatively short leaves and, on a neighbouring key, fascicules with three long leaves.

J.W. Wright (1976) observed similar examples in species of Picea, noting that many of these populations which have not adapted to the environment in which they live are on the point of extinction.

#### HYBRID VIGOUR

Hybrid vigour or heterosis refers to the exceptional yield of a hybrid when compared with its parents. To explain this phenomenon, four explanations have been suggested, which are: dominance, over dominance, additive and hybrid habitat hypotheses.

According to the dominance hypothesis, hybrid vigour is due to the absence of depression caused by endogamy. The homozygosity produced by inbreeding leads to the appearance of recessive genes which are harmful to the plant, producing a depression which would otherwise be "covered" by dominant genes from heterozygous individuals.

The overdominance hypothesis maintains that the heterozygous gene combination produces effects impossible to achieve with homozygous genes.

The additive hypothesis holds that the trait is governed by various genes which hybrids accumulate, the effect being thereby greater.

In the "hybrid habitat" hypothesis, vigour derives from a "hybrid" environment, where the parents show less capacity for adaptation than the hybrid.

If the first hypothesis, of dominance, is true, it should be possible to select against recessive genes in subsequent generations and thus fix hybrid vigour. If it is due to overdominance, vigour will be greater in the first generation and decrease in successive ones. If it is due to additive effects, it should be possible to select the best genes governing the components of this vigour, and to obtain a greater effect in successive generations. Lastly, if the hybrid habitat hypothesis is true, hybrid vigour will be equal in the generations following the F<sub>1</sub> generation.

A case of extensive utilization of hybrid vigour was the crossing of Pinus rigida with P. taeda in South Korea, where performance was excellent in F<sub>1</sub> and even better in F<sub>2</sub>.

The breeding method depends on the type of inheritance of the trait to be bred for. If greater productivity is due to dominance or additive effects, selection should exclude selfing. If, on the other hand, vigour is due to over dominance "selfing and later crossing" is the best method.

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Participants in class.

PRINCIPLES AND STRATEGIES FOR THE IMPROVED USE OF FOREST GENETIC RESOURCES

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## INTRODUCTION

Increase in the world's population, together with higher standards of living, result in continuous pressure to transfer areas previously under forest to agricultural or other uses (Willan 1973). The resulting large-scale disappearance of natural forests is leading to an accelerated loss of valuable or potentially valuable germplasm. This loss is of particular concern in those areas in which botanical and genealogical exploration has not been systematically carried out, and in which species composition as well as inter- and intra-specific variation therefore are not known sufficiently well to enable timely and adequate conservation measures.

In addition to the fact that large areas of forests are being partially or fully destroyed, areas destined to remain as forest are often being brought under more intensive forms of management which may endanger certain species and change the genetic composition of others (Kemp *et. al.* 1976). Even where the central part of the range of a species is unaffected, particular sub-population or provenances at the limits of the species range may be in critical danger; it is often these marginal or isolated populations which have developed, through natural selection, specific characteristics such as tolerance to drought or other adverse environmental conditions, and which may be of great potential value for sites with a similar selection pressure.

The continuous pressure for land mentioned above coupled with an increasing demand for wood and wood products has tended to shift the emphasis from utilization of the often complex natural forests to plantations of species relatively easy to manage and capable of producing large quantities of wood per unit area (Willan 1973). Although the creation of plantations to a certain extent will relieve the pressure on the natural forests and the genetic material they contain, their establishment may raise problems. The use of plantations gives the forester an opportunity to exercise much stricter control not only over site characteristics but also over the genetic quality of his forests (Willan and Palmberg 1974). This leads to a development from the use of 'wild' to the use of more 'advanced' populations, in which gene frequencies have been changed to meet specific requirements. In these new populations, selected and bred for uniformity, high yield and other short-term objectives, the genetic base is often narrowed down to very low levels by restricting the genepool from which parental material is drawn and by subsequently rejecting, through selection in given conditions, a great proportion of the original population. While adaptation of these new populations to specific plantation conditions is increased, their genetic flexibility and their potential for future adaptive change to meet often unforeseen or unforeseeable environmental changes such as a shift in the average site quality of plantations, the emergence of new or genetically adapted pests and diseases, or increased levels of industrial pollution, is gradually decreased. The narrowing of the genetic base in populations used for the production of seed for future plantations does not, as such, necessarily have negative effects, as long as the genetic diversity of the species and the provenances is safeguarded through conservation measures in situ or through the establishment of genetic reserves, conservation stands and/or widely-based breeding or base populations, from which material to meet new requirements can be drawn.

## PRINCIPLES OF CONSERVATION AND UTILIZATION OF GENETIC RESOURCES OF FOREST TREES

Conceptually, the issues of genetic conservation are similar whether dealing with annuals or long-lived trees, domesticates or wild plants; needs, strategies and methods differ in detail, but not in principle (Frankel 1978).

The exact strategy of conservation depends on the nature of the material and the objective and scope of conservation. The nature of the material is defined by the length of the life cycle, the mode of reproduction, and the ecological status of the individuals (wild, domesticated); the objective could be research, static or evolutionary conservation (see below), selection and breeding, etc.; the scope refers to timescale and area considered. (Frankel 1970).

Activities commonly recognized as essential steps to maintenance of genetic diversity within individual species and to the fuller use of existing genetic resources are (i) exploration; (ii) collection; (iii) evaluation; (iv) conservation and (v) utilization. (FAO, 1975a - See Annexes 1 and 2).

### EXPLORATION

Efficient use of existing genetic resources can only be achieved if sufficient information is available on their extent, structure and composition (Brazier *et. al.* 1976; Snee & Hendrikson 1979; Lamprey 1975). For a large number of tree species, especially for species growing in the tropics, there is a great lack of knowledge on the ecology and biology, as well as on their potential as plantation species and the potential use of non-wood products derived from them. Even for species of proven value, their variation throughout their natural range has often been explored inadequately. This lack of information is well illustrated by the fact that every one of the tropical/sub-tropical forest tree species explored and collected during the present decade in a programme coordinated by FAO has, as a consequence of the exploration, been found to be in danger of depletion, extinction or contamination of its genetic resources in at least parts of its natural range; where the gene pool is not thought to be in danger of extinction, the population has often been so heavily reduced that supplies of seed are very limited and may deplete further in future (Keiding and Kemp 1978).

For practical purposes, the field activities in the fundamental step of exploration can be divided into (i) botanical and (ii) genecological exploration. Botanical exploration includes the correct taxonomic identification of species and knowledge of the limits of their distribution, with particular reference to isolated occurrences. For some forest tree species adequate information has been available well before the start of genecological exploration, for others it may be necessary to combine the two operations together. Botanical exploration logically leads to species trials.

Through genecological exploration patterns of ecological and phenotypic variation within the natural range of species are studied, leading to provenance seed collections and provenance evaluation (FAO 1975).

### COLLECTION FOR EVALUATION

Collection for evaluation consists in collecting relatively small samples of seed from a relatively large number of seed sources, covering the whole natural range of the species. In the initial stage, collections thus comprise range-wide sampling on a fairly coarse grid; in some cases a second stage, sampling a limited part of the range on a finer network, may be called for after the results of first stage provenance trials are available. In these second-stage collections seed is often kept separate by mother trees to enable the evaluation of genetic variation within, as well as between, provenances. The gene pools included in the collections may be indigenous, or introduced. In forestry, these latter so-called 'land races' (i.e. exotic plantations which to various degrees have adapted to local conditions as a response to natural and sometimes artificial selection), are potentially of great importance as sources of seed, and should be included in the collections (FAO 1975a, Turnbull 1978).

To determine the number and location of populations to be sampled, environmental gradients are generally followed; sampling within each population could be done at random or selectively. Although the latter option is often used in within population sampling it should be remembered that phenotypic superiority is no guarantee of genetic superiority, specially in cases in which the past history of the population is unknown (Barner 1974; Bennett 1970).

### EVALUATION

Collection of range-wide samples should be followed by the establishment of provenance trials aimed at revealing potentially useful variability, degree of adaptation to a range of environmental conditions, and economic or social value of the species/provenances under test. The evaluation should be carried out on as many potential sites as possible and, whenever feasible, be centrally coordinated.



## CONSERVATION

The development of the concept of genetic conservation in the 1950s was mainly due to the realization that the primitive cultivars of traditional agriculture were rapidly disappearing, and the genetic diversity accumulated in them over many centuries substituted by varieties selected and bred to meet short-term needs. The importance of maintaining genetic diversity and gene pools from which new genes can be introduced into existing varieties in order to improve adaptation, yield and resistance to diseases and adverse conditions, has clearly been brought into focus by some major outbreaks of diseases, especially in food crops (Frankel 1978, Snee and Hendriksen 1979). Not only should variability within species of known value be conserved, but maximum diversity should also be maintained on a species level, including as yet unknown and untested material, thus keeping future options open (Whitmore 1975a).

Conservation, used in its proper sense, embraces both preservation and utilization; conservation is, in fact, an aspect of resource management which ensures that utilization of the resource is sustainable, at the same time safeguarding genetic diversity essential for its maintenance.

A compromise between biological, technical, economic and administrative factors is often unavoidable when choosing long-term strategies for the conservation and utilization of genetic resources. The final objective must be to choose methods which minimize losses and maximize gains in terms of usefulness, knowledge and integrity (Frankel 1970a).

Current problems in genetic conservation are often so severe that it is tempting to concentrate on them alone. However, strategies for action should include preventive measures through the inclusion of conservation aspect in long-term planning at the policy-making, the organizational as well as the technical level (Anon 1980).

The main strategies for conservation have been outlined as follows (Burley and Styles 1976):

1. Conservation of ecosystems. Such conservation of carefully selected areas of adequate size and with suitable management policies would preserve not only forest trees but also other elements of the ecosystem (plants, mammals, birds, etc.), as well as other potentially valuable products such as extrativas, fruits, etc.
2. Preservation of rare species and species threatened with extinction. This goal could often be achieved under general ecosystem conservation, if carried out competently.
3. Prevention of "genetic erosion", i.e. depletion of genetic variability. In this field it is not enough to conserve a species as such; we must make certain to conserve a broad spectrum of genetic variability to act as a reserve for present and future needs (adequate seed sources, wide genetic variability as a base for tree breeding, etc.). Such material can be conserved in in situ reserves, or can be sampled by means of seed, pollen or vegetative material, in such a way that the conservation of the major part of the genetic variability is insured. Seed, pollen or other material can either be stored as such, or be used for the establishment of conservation stands ex situ.

## IN SITU CONSERVATION

Conservation in situ, i.e. conservation of species/provenances as part of a viable, existing ecosystem, is generally the most desirable method of conserving forest genetic resources, provided that the area can be given full protection and provided the genetic material conserved is made available for use both within and outside the country of origin (FAO 1975; Whitmore 1975a, b; Lamprey 1975; IUCN 1978). For many species, e.g. for a vast number of rainforest species which are not fast-growing pioneers, which occur as individuals rather than stands, and for which knowledge on ecology and genetics is scarce or lacking, in situ is the only method of conservation available to us at our present level of knowledge (Kempt 1978).

In situ conservation of forest genetic resources will often for practical reasons have to be combined with other environmental, scientific or socio-economic purposes, this generally means that a compromise must be made between various objectives of the reserve.

Genepool conservation frequently deals with genetic differences which cannot be directly identified but only surmised. It is concerned with population samples, possibly along latitudinal or altitudinal transects, often over extensive areas, to include a spectrum of ecological variability to provide a corresponding spectrum of genetic variability. The efficiency of ecosystem conservation (e.g. biosphere reserves, national parks) to adequately meet the needs of genepool conservation is closely related to the size, number, distribution and location of these reserves.

There is a general consensus that the conservation of representative samples of most ecosystems will require an area within the range of 100 to 1 000 ha, the exact size depending on the heterogeneity of the area as well as on its species composition (Ashton 1976). If conservation of genetic resources is a major objective of ecosystem conservation, the inclusion within the reserve of the minimum number of interbreeding individuals needed for a viable genepool (i.e. a population which is able to retain its self-renewing capacity), must be considered rather than the total area of the reserve per se (Roche 1975).

Considering genetic resources at a species level, Ashton (1976) working with rain-forest species in Borneo made a theoretical estimation of the area of forest needed for conservation, arbitrarily assuming that 200 mature individuals will form a viable population; by this criterion an area of at least 2 000 ha of unmodified virgin forest would have been needed to conserve the tree species of two areas examined, while only 60% of the species would have been safeguarded in 1 000 ha. At the intra-specific level Dyson (1974), studying numbers of individuals quoted for effective breeding populations in animals, estimates that 200 individuals will constitute a minimum "safe" population for forest trees for maintaining genetic variability, provided that sampling is done from at least three parts of the range. Up to 25 000 individuals are recommended by Marshal (quoted in Kemp 1978) 'for maintaining a given level of heterozygosity in populations in a diffusely outbreeding tree species'. However, as discussed below, the conservation of a mythic heterozygosity (Namkoong 1979a) by conserving specific genotypes is neither desirable nor possible.

Theories as to the relative merits of one large as opposed to several smaller, separate reserves, have been extensively discussed. The answer will depend on the exact objectives of conservation, the amount of inter- and intra-specific variation to be considered, and the distribution of gene frequencies. From a purely managerial point of view, one or very few large areas would be preferable, as a large number of scattered reserves are difficult to manage and protect. However, especially in the case of areas with a complex species composition, and in the case of conserving the intra-specific variation of widely distributed species, a series of reserves, strategically placed to sample the full range of ecological variation is called for. It is particularly important to include extreme environments and marginal populations, in which selection effects may have created varieties or ecotypes of particular potential value, and in which gene frequencies may differ from those in the main population, giving us bigger chances to capture 'rare genes' (Namkoong 1979a, b).

#### EX SITU CONSERVATION

Although conservation in situ in theory may be the most effective strategy it may, in reality, face enormous difficulties which often are social, political or financial rather than technical in nature (Sastrapradja et al. 1978; Kemp et al. 1976). The alternative way of conservation is ex situ. Ex situ conservation is especially useful when dealing with certain species or genera with a combination of biological characteristics which make them amenable to this approach; through knowledge of the breeding system and biology of the species, as well as of the methodology for growing them in plantation condition and/or storing their seed, are prerequisites for using this strategy. Many of the species which during recent years have attracted the attention of foresters for their use in high-yielding plantations fall into this category.

Sometimes, especially in the case of economically valuable plantation species extensive genetic modification of native stands caused by man may occur (Libby 1978). This situation arises if non-native populations of a species are used for seed procurement and the subsequent establishment of plantations close to existing native stands. Clouds of

pollen from the plantations will repeatedly be dispersed over the native stands, resulting in offspring which will be increasingly contaminated by genes from the foreign populations, gradually leading to a loss of the original genepool. In these cases, in situ conservation will not be feasible and the only way to conserve the original population will be by ex situ conservation.

#### COLLECTION FOR EX SITU CONSERVATION

Where the exploration phase has shown that certain populations are endangered but that conservation in situ is not feasible, early collection is necessary of substantial quantities of seed or other propagating material of endangered provenances either for temporary storage or for immediate establishment of ex situ conservation stands on new sites (FAO 1975). Sampling for variation (i.e. random rather than selective sampling) is essential for conserving the integrity of allele frequencies (Frankel 1970b).

Methods of sampling for gene conservation purposes and theoretical number of individuals needed to maintain intraspecific allelic variation are discussed by Namkoong (1979a), who gives probability levels for losing specific alleles occurring at given frequencies, using different sampling intensities within and among populations.

It is not possible to lay down general rules and guidelines for sampling, as many factors, both interrelated and independent, affect the intraspecific variation we are trying to capture (heterogeneity and size of the natural range, ecology, breeding system and population structure of the species, etc.). However, as no system of sampling and collection as likely to achieve the objective of saving all allelic combinations present in a species, sampling is generally aimed at saving as many of the existing alleles as possible for future recombination and use (Namkoong 1979a). We should thus aim at conserving and evaluating genes rather than genotypes.

#### STORAGE AS SEED OR OTHER REPRODUCTIVE MATERIALS

In addition to being a means of conservation per se, storage of seed is often an essential link between collection and later field operations. Meticulous handling of the seed during all phases of the work is essential. For many species particularly in the tropics, there is inadequate knowledge of practical methods of both long-term storage, and additional research is urgently needed.

Conservation of forest trees is generally done as conservation stands in situ or ex situ, rather than as seed, as is often the case in agricultural crop species. This difference in approach is mainly due to practical difficulties: plant gene banks should regenerate their seed collections whenever the viability falls by, at most, fifteen percent below the initial value at which the seed was stored (Wang 1976; IBPGR 1976). With the long vegetative period that most tree species have before they produce viable seed, seed regeneration by growing a crop and re-collecting will be a prolonged and expensive procedure; in addition, natural selection during this prolonged period is likely to have greater effects on genetic composition than in the case of species which produce seed within a short period of time after sowing.

With present-day knowledge of the physiology and biochemistry of pollen and tissue culture, conservation of forest genetic resources in these forms seems unlikely to become more than a useful supplement to other forms of conservation. Although pollen storage is a valuable means for short or intermediate-term conservation storage time of pollen, when using known drying and storing techniques, is generally shorter and less reliable than that of seed. Likewise, and with the possible exception of vegetatively propagated species, the conservation of forest genetic resources by means of tissue culture is generally not considered likely to become of great importance (Wang 1978; Frankel 1978).

#### EX SITU CONSERVATION STANDS

Conservation stands ex situ are expensive to establish and to maintain, and therefore they are normally confined to species of proven or evident potential value (FAO 1975). Danger of extinction, economic potential and difficulty in procurement of seed should be the main criteria in forming priority list of species and provenances for ex situ conservation.

Guldager (1978) lists four conservation objectives which may be met by the establishment of ex situ conservation stands:

(1) Static conservation, in which the genotype frequencies of the original population are maintained. As discussed above, this method is not practicable for most forest tree species.

(2) Static conservation, in which the gene (allele) frequencies of the original population are maintained. No genetic information is lost and any genotype found in the original population could in principle be reproduced although genotype frequencies in the ex situ stands might be different than in the original population.

(3) Evolutionary conservation, in which gene frequencies in the stand are allowed to change according to natural selection pressures.

(4) Selective conservation, in which gene frequencies in the stand are deliberately changed by man in order to capture characteristics important for plantation economy in a region, and at the same time eliminate undesirable characteristics. To avoid a decrease of the genetic potential for future plantation establishment in environments different from the environment in which this type of stand is established, replication is necessary in each potential plantation area. In the long term, selective conservation faces the same problem as met in long term breeding programmes. (i.e. maintenance of genetic variation, avoidance of inbreeding).

The ex situ conservation stands known to have been established to date fall under categories (3) and (4). The level of maintenance of genetic integrity in these stands will be dependent on three main factors (Guldager 1976): (i) sampling in the original population; (ii) survival and growth ex situ of sampled genotypes (i.e. adaptation to new selection pressures); (iii) mating patterns ex situ between the sampled genotypes.

(i) Sampling for conservation has been discussed above. Even the most rigorous efforts to maintain original gene frequencies through careful management in a series of conservation stands ex situ will be of little avail from the point of view of species/provenance conservation if the gene frequencies have already been considerably changed during initial sampling. Sampling is thus of critical importance. Long term storage or maltreatment of seed are other factors that may critically influence gene frequencies even before the stands are established.

(ii) For most plantation species it is possible to combine the selection of suitable sites with efficient nursery and plantation techniques so as to ensure almost 100% survival in the field. Initial competition between genotypes can be minimized by wide spacing. The question of mechanical versus silvicultural thinning in the stands will depend both on the ultimate objective of conservation and on practical possibilities. However, if the stands are established over a wide range of sites in which environmental pressures vary, a great proportion of the genetic variation is likely to be maintained even if thinning is carried out in favour of desirable phenotypes. As a compromise, a proportion of the trees to be left (say, 1%) may be phenotypically selected before carrying out a systematic thinning for the rest of the stand. This approach will be adapted in the case of the international conservation stands mentioned below.

(iii) Our possibilities to accurately pass on genetic information from the first generation ex situ conservation stand to the next depends on mating within the stand (synchronization of flowering, proportion of actual random mating, etc.), size of population (influencing genetic drift and inbreeding coefficient), and migration in terms of pollen contamination. To help overcome these problems, location (near optimum or optimum for flowering and seed production), size (recommended size is 10-30 ha FAO 1975, 1977) and isolation (300 m or more between hybridizing species/provenances; FAO 1977), should be carefully considered. In addition to careful siting, the conservation stands require meticulous standards of site preparation, planting and tending (FAO 1975). An imperative condition for their establishment in a region is thus that sufficient technical expertise as well as organizational stability is available, to ensure a high standard of long term management. Interest in the provenances concerned from a plantation point of view, is likely to increase the benefit as well as the security of the scheme (Guldager 1978).

Detailed recommended prescriptions for the establishment and management of ex situ conservation stands have been published in Annex 7 of the Report of the 4th Session of the FAO Panel of Experts on Forest Gene Resources (FAO 1977).

Besides the long-term benefits of conserving species/provenances of known genetic characteristics, conservation stands have valuable possibilities for short-term utilization, providing seed and other genetic material for immediate use. In cases where international finance has been provided, agreements have therefore been drawn up to ensure that the stands benefit all countries interested in the species/provenances (see FAO 1977, Appendix 7).

#### DISSEMINATION OF INFORMATION

Another aspect of conservation is the preservation and dissemination of information. It is important to preserve not only the areas, units, populations or individuals, but also the relevant data on them. This data must be carefully recorded, safeguarded and disseminated (Frankel 1970a).

#### UTILIZATION

Utilization is the ultimate objective of all activities concerned with forest genetic resources. It comprises both the use of bulk supplies of seed or other propagating material for large-scale plantation schemes, and the breeding of better adapted and more desirable genotypes.

As information becomes available from provenance trials as to the most suitable seed sources, emphasis will gradually switch from evaluation to the utilization of bulk supplies of seed or sometimes other propagating material of populations found well-adapted to given conditions. The supply of bulk quantities of propagating material should be the responsibility of Government Forest Services or commercial seed merchants, although agreements both within and between countries on common standards of genetic and physiological quality of the material are essential (FAO, 1975a).

Individual selection and breeding within locally adapted provenances provide a method of achieving additional improvement in selected characteristics. In the case of introduced species, an important interim stage between successful provenance trials and large-scale afforestation with the best-adapted provenances may be the establishment of one or more substantial blocks (5 ha or more) of these provenances to act as seed stands and as a basis for local selection and breeding. The same stands may combine the purpose of ex situ conservation.

#### NEED FOR INTERNATIONAL ACTION

When the urgency of conservation and the massive efforts needed are jointly considered, it becomes evident that conservation of the world's genetic resources requires the cooperation of all nations.

Although progress in development of improved forest genetic resources will remain largely dependent on the active efforts of individual countries or research institutes, these can only be fully effective in an international framework (FAO 1975). Maintenance of the genetic diversity of species either in situ or ex situ may have to be spread over many environments in a number of countries, collection of seed cannot be confined within national borders; research coordinated to give information of species/provenance performance over the maximum range of sites possible will be of great mutual benefit to cooperating institutes and nations; safety and permanence for irreplaceable collections of genetic material, either in situ or ex situ should be secured for perpetuity by agreements under international supervision.

Many countries which contain forest genetic resources of great but sometimes unexplored potential value are at an early stage in their economic development. There is often a severe shortage of funds and skilled staff in the forestry sector and those available are, logically, channeled to meet immediate national needs when e.g. drawing up species priorities. It is therefore highly desirable that international resources should be made available to help in the development of strategies and to safeguard material invaluable to many nations.

There is another aspect to conservation, and that is the conservation and dissemination of information. It is not only important to conserve areas, communities, populations and individuals, it is also important that information related to them is adequately recorded, safeguarded and made available (Frankel 1970).

The best way of ensuring efficient coordination in the wide field of forest genetic resources is by the adoption of a global programme such as that proposed by the FAO Panel of Experts on Forest Gene Resources (FAO 1975a). Such a program should ensure the integration of conservation measures with the equally important activities of exploration, collection and utilization. At the same time it should improve efficiency through coordinating the efforts not only of the many countries but also of the several international agencies concerned with genetic resources (Roche 1978).

Progress in the conservation of forest gene resources in the last ten years is outlined in Annex 3.

#### CONCLUDING REMARKS

In the rapidly advancing field of forest genetics we have answered many questions in recent years, but these answers have often led to new and more difficult questions. We have learned enough techniques to be certain that we can develop new breeds to more accurately meet present-day needs. We have also come to realize more fully that the original gene pools will be lost unless positive action is taken to conserve them. Now we need to decide how to organize breeding and gene management strategies that will meet both immediate needs and long-term requirements (Namkoong 1978).

It should not be difficult to conduct tree improvement programmes which include short-term and long-term objectives side by side, provided that those responsible for planning and finance realize that the long-term programme is no less important and no less deserving of funds than the short-term one, and that the greater the genetic diversity we can maintain and save now, the wider will be our options for finding suitable genotypes to meet future needs (Namkoong 1979).

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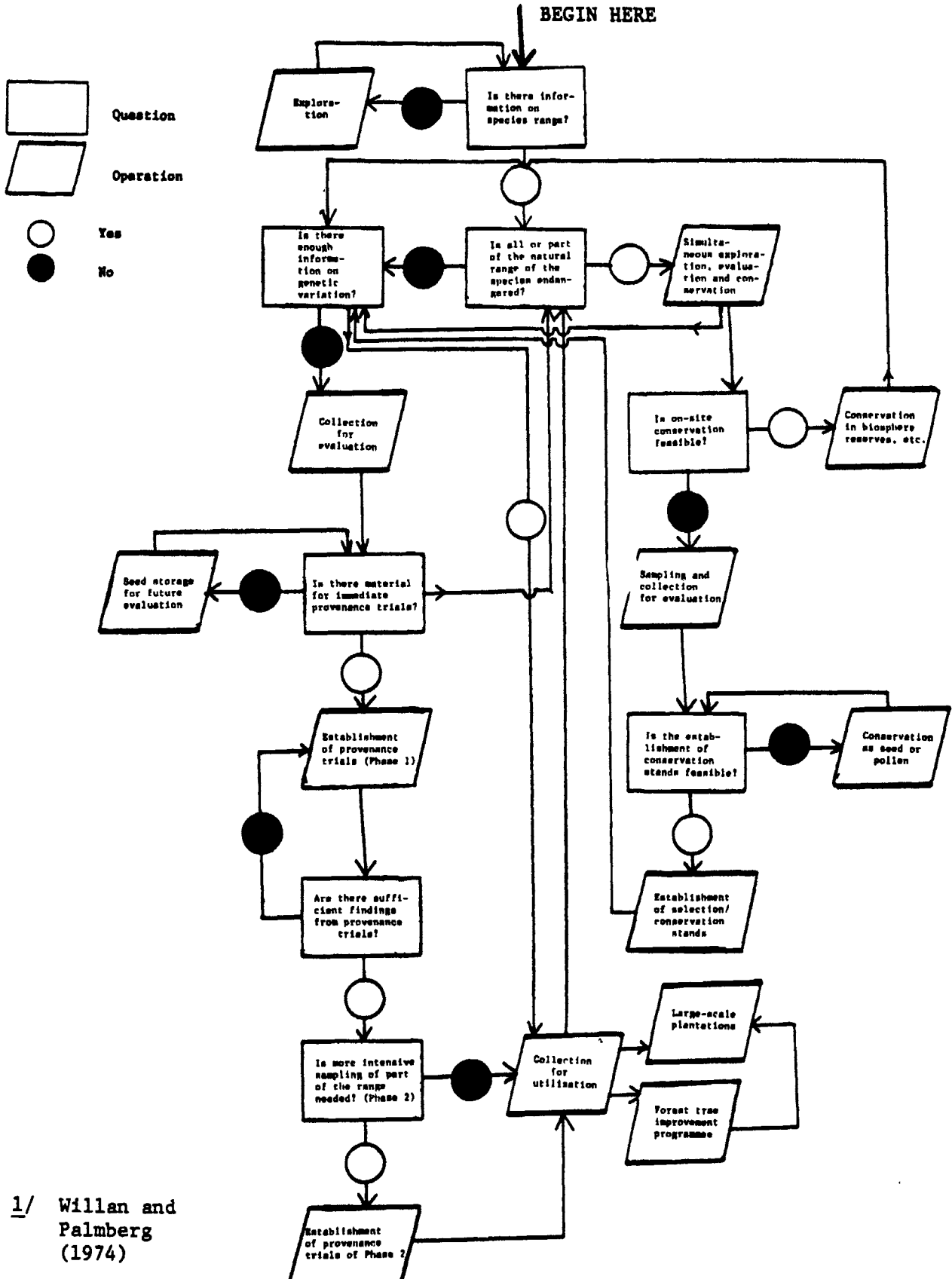
Grafting of Pinus Caribaea var. hondurensis

(CONARE, Chaguaramas)

ANNEX 1

FOREST TREE GENETIC RESOURCES

Phases and Operations 1/

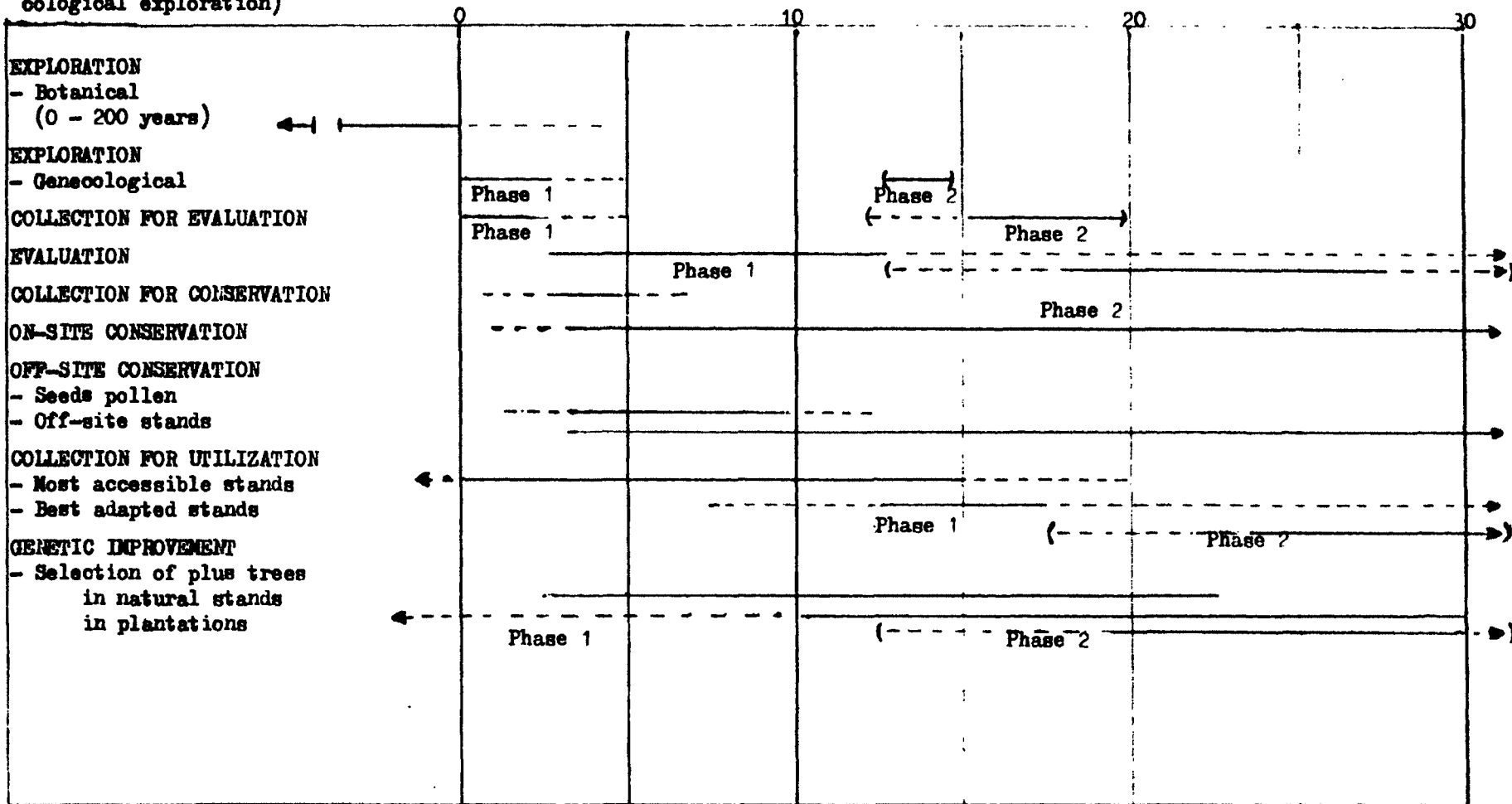


1/ Willan and Palmberg (1974)

FOREST TREE GENETIC RESOURCES

Duration of necessary phases; hypothetical example for a tropical pine <sup>1/</sup>

YEAR  
(Year 0 = beginning of gene-  
cological exploration)



<sup>1/</sup> on of he dix in an & Palmberg 974

Annex 3

PROGRESS IN THE CONSERVATION AND UTILIZATION OF  
FOREST TREE GENETIC RESOURCES

Concern over the loss of genetic diversity has grown rapidly since early fifties, and has spurred increasing national and international action.

Some national institutes had already begun systematic forest tree seed collections for international use at that time, but the present picture has spurred international and national exploration, collection, conservation and research efforts in forest tree genetic resources. These efforts have created world awareness of the need to conserve these resources, mobilizing national and international funds for experimental plans, pilot studies and practical activities in this field.

The panel has met four times. FAO has published information on these meetings, indicating progress, past and present trends, and recommendations for future action (FAO, 1969, 1972, 1975b and 1977). So far, the funds recommended by the panel for programmes coordinated by the FAO Forestry Department have been mainly earmarked for the exploration and collection phases to fund certain organizations working in these fields. FAO cooperates not only with national institutes, but with other international agencies such as Unesco <sup>1/</sup>, IUCN <sup>2/</sup>, and UNEP <sup>3/</sup>, and collaborates actively with the competent IUFRO <sup>4/</sup> working parties. Recently some funds have been received from the International Board of Plant Genetic Resources (IBPGR), an auxiliary body of the Consultancy Group on International Agricultural Research (CGIAR), for the purpose of mobilizing long-term financial support to close the gaps in agricultural research in the developing countries.

Through the Panel, priorities have been established by region and by species for each phase of a programme on forest tree genetic resources (FAO, 1977, Appendix 8). These priorities, which are periodically reviewed in the light of the most recent discoveries and measures adopted, are based on the extent to which genetic resources of species are endangered, and their potential or actual socio-economic importance. However, as it is only in the course of exploration that exact information will be obtained on the conservation status of a species, the priorities indicated and species included in the list reflect to a certain extent the quantity and quality of the information available to the Panel to adopt its decisions, and not only the real situation (Keiding and Kemp, 1978).

Based on the orders of priority indicated by the Panel so far, full-spectrum exploration and collection activities have been carried out, followed by the establishment of centrally coordinated international provenance trials for 12 tropical species. Considerable progress has also been made in the exploration, collection, distribution and evaluation of various genera, including Tectona, Populus, Pinus, Pseudotsuga, Araucaria, and Eucalyptus. Among the genera most recently included in the Programme are Acacia, Prosopis, Terminalia and Aucoumea. FAO has published abstracts of the most important collections (FAO 1975b; FAO 1977). The reader may also consult the FAO review "Information of Forest Tree Genetic Resources".

Although many of the species trials based on range-wide collections carried out in recent years are too new to supply precise data, many already indicate the existence of major provenance differences and clear interactions between provenance and environment, confirming that research on provenance is as important for tropical species as it is for temperate species. The findings of many of these trials have been published in summary form by species and countries in the proceedings of the joint IUFRO Working Parties S2.02.08 and S2.03.02, held in 1971, 1973 and 1977 (Burley and Nikles, 1972, 1973a, 1973b; Nikles, Burley and Barnes, 1978).

1/ United Nations Educational, Scientific and Cultural Organization.

2/ International Union for the Conservation of Nature and Natural Resources.

3/ United Nations Environment Programme.

4/ International Union of Forestry Research Organizations.

Table

EX SITU CONSERVATION  
FAO/UNEP PROGRAMME 1108-75-05

Species	Pinus caribaea var. hondurensis			Pinus oocarpa			Eucalyptus tereticornis		Eucalyptus camaldulensis		
Provenance	Alamicamba	Los Limones	Poptun	Mountain Pine Ridge	Kukul	Bonete	Cooktown	Mt. Garnet	Petford	Katherine	Gibb River
Country	Area ha										
CONGO	20	20	10	10	20	20	10	10			
IVORY COAST	10		10	10	10						
KENYA		10									
NIGERIA	20	20		30	30				10	10	
ZAMBIA				20	10	20	10	10			
THAILAND	20	30	10	30	30				30		20
TOTAL PRO- JECTED AREA	70	80	30	100	100	40	20	20	40	10	20
TOTAL ESTAB- LISHED AREA as of 31/12/ 1979	36.1	46.9	30	79.6	92.1	58.4	20	20	13.1	1.4	10.8

In 1975, with financial support from UNEP, FAO carried out a pilot study which gave rise to the publication "Methodology of the Conservation of Forest Tree Genetic Resources" (Roche, 1978a). Based on the technical recommendations of this study and on the early findings of the exploration and international provenance trials mentioned above, in 1975/76 an FAO/UNEP project was launched for the conservation of genetic resources of certain species and provenance. This experimental project, which includes elements of both on-site and off-site conservation, is now drawing to a close, and a report on its achievements and conclusions is now being prepared.

The off-site component of the above FAO/UNEP project has performed as expected. Over the last four years, 33 international ex situ conservation/selection stands, each 10 ha in size, have been established in five African countries and one Asian country, with a total of 11 provenances of four different species (see Table 1). In addition to the international stand funded by UNEP and FAO, many of the countries participating in the project, as well as some neighbouring countries, have established national ex situ selection/conservation stands. In Appendices 7/1 to 7/4 of the report of the Fourth Session of FAO Panel of Experts on Forest Genetic Resources (FAO, 1977) include the reasons for the selection of the species/provenance for the project, the agreement between FAO and the participating countries, some recommendations on the establishment, management and handling of stands, and cost estimates. Succinctly, the agreement calls for international financing to foot the bill for seed costs, plus the projected cost of the first two years of the establishment phase. The host government pledges to supervise the establishment, maintenance and management of the stands, and to make 50 percent of the seeds, or other reproductive material collected, available to other countries at cost price.

DANIDA (Danish International Development Agency) began a complementary project in 1979 on off-site conservation.

It has proven difficult to reach agreements on in situ conservation. The FAO/UNEP project only provided funds for two botanical reserves in Zambia for the in situ conservation of Baikiaea plurijuga (Zambia Sequoia) or Zambesi Redwood. The main reasons why identifying proper zones for on-site conservation is a problem are listed below:

- 1) On-site conservation in the tropics generally has to contend with heterogeneous ecosystems, of which economically valuable species are only a small part. When funds are scarce, national priorities for expenditures and efforts tend to centre on other sectors and on other species;
- 2) Tropical ecosystems are complicated and not enough is known about them, unlike ex situ conservation stands (even-maturing monocrops). They are also difficult to manage;
- 3) It is difficult to predict when the first substantial benefits from in situ conservation will be produced at the national level;
- 4) It is often difficult to identify which specific vital operations or phases of in situ conservation might be suitable for international, short-term financing;
- 5) The establishment of ex situ conservation stands is a specialized type of reforestation, and, as such, is clearly within the sphere of competence of the forestry service of the country involved. However conservation of the ecosystem (and therefore in situ conservation) is often under some other authority such as departments responsible for flora and fauna, national parks, etc.

There has been no let-up in action to overcome these difficulties.

Among the progress achieved in the dissemination of information on forest tree genetic resources in recent years we may list such meetings as: (i) the three FAO/IUFRO World Consultations on Forest Tree Improvement (Stockholm, 1963; Washington, 1969; Canberra, 1977), which viewed existing data on the scientific principles of forest tree improvement and forest genetics; practical advantages and progress in tree improvement; and problems and prospects for the utilization and conservation of forest tree genetic resources; (ii) the three meetings of the IUFRO working parties S2.02.08 and S2.03.01 already mentioned in this paper; (iii) the Eighth World Forestry Congress (Indonesia, 1978), which acknowledged the fundamental importance of genetic conservation, devoting a session to this item on its agenda. A series of training courses have also been held on tree improvement.

These were financed by UNDP and DANIDA and organized and implemented by the FAO Forestry Department (Denmark, 1966; U/S/A/, 1969; Hungary, 1971; Kenya, 1973; Thailand, 1975). A training course on tree improvement organized by the Forest Research Division of the Commonwealth Scientific and Industrial Research Organization, Canberra, and financed by the Australian Government, was held in Australia in 1977. The International Seed Trials Association, ISTA, has organized various seminars on the processing and analysis of forest seeds.

The FAO publication "Information on Forest Tree Genetic Resources" (FAO 1973-79) launched in 1973 publishes three issues in the biennium. The review features periodic reports on these and other meetings, seed collections, provenances and the exploration, evaluation, utilization and conservation of forest tree genetic resources.

SAMPLING IN SEED COLLECTION

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INTRODUCTION

In any seed collection, sampling will ultimately determine the proportion of the genetic variation present that we will capture. Errors or carelessness in sampling, i.e. in the selection of the populations and the trees from which seed is collected, cannot be remedied at the planting stage, no matter how careful and sophisticated our experimental design is or however carefully we establish our plantations.

In broad terms, sampling is done at two levels, the population level (provenance and stand), and the individual level. The choice of the exact method and intensity of sampling will depend on the specific objectives of the seed collection.

The main objectives of seed collection are:

- (i) Evaluation
- (ii) Conservation
- (iii) Utilization (large-scale afforestation).

COLLECTION FOR EVALUATION

Evaluation, in this context, generally refers to the establishment of species and provenance trials in which the range and type of variation is assessed and the adaptation of the various species/provenances to potential plantation sites is evaluated.

The two main questions to be answered when planning a specific seed collection mission is how to allocate, in practice, the available time and funds between the frequency (how many sites?) compared with the intensity (how many trees per site?).



### SAMPLING AT THE POPULATION LEVEL

Initially, sampling is done throughout the range of the species (Barner 1974; Turnbull 1975). If adequate information is not available on the distribution of the species, searches of literature and herbaria, and contact with foresters, amateur botanists, and others living in or close to the species range may help define its boundaries. Aerial photographs, if available, can sometimes be used to save time in picking out possible collection sites in unknown country or in difficult terrain (Turnbull 1975).

Ideally, taxonomic and botanic exploration should precede collection, as efficient sampling schemes can only be devised based on knowledge of the distribution and ecology of the species. Sometimes, however, the activities of exploration and preliminary collection will have to be combined. This kind of a single, combined expedition cannot be expected to furnish all answers, and a series of reconnaissance and seed collection missions are necessary.

The number of seed sources (provenances 1/) to be sampled will depend on the extent and the heterogeneity of the distribution range and on the genetic diversity of the species. As little will be known about variation patterns of the species in first-stage studies, sampling can be done on a fairly coarse grid, collecting at rather widely separated intervals following environmental gradients.

Genetic diversity is generally largest in areas which are optimal for the development of the species in question. However, at the limits of the ecological range, outlying populations of a species may be exposed to extremes of temperature, rainfall or edaphic conditions. Such provenances may possess morphological and physiological characteristics which will be of great potential for particular environments. For this reason it is particularly important that these marginal sites are included in the collections (Turnbull, 1975).

When promising, broad general regions have been located through first-stage provenance trials, second-stage provenance collections should be concentrated on these, through sampling on a finer network (more collection points in a more limited area). Examples of sampling schemes used for some specific species are discussed by Turnbull (1975).

The specific stands from which seed is collected will have to meet certain criteria. A stand has been defined as a sufficiently large population of trees possessing sufficient uniformity in composition, constitution and arrangement to be distinguished from adjacent crops (OECD 1971). In practice, the main consideration should be to select a population which is large enough to allow for sufficient cross-pollination between a large number of trees and which is isolated from related species to minimize risks of hybridization (Turnbull 1975; Melchior and Venegas Tovar 1978). The application of such criteria to some tropical species which are found as isolated trees in mixed forest may be difficult. In such instances, individual tree lots may be kept separate or combined with others covering a considerable area to represent 'a stand' (Turnbull 1975).

Melchior and Venegas Tovar (1978), referring to Eucalyptus globulus plantations in Colombia, consider 300 individuals a minimum number for a stand suitable for seed collection purposes.

Stands should be of such an age that seed is produced in quantity, due to practical as well as genetic considerations.

In the case of introduced species, seed should whenever possible be collected from stands of known origin 2/. The general history of the stand is relevant in the case of both indigenous and introduced species. Any treatment which may have altered the distribution of the phenotypes should be noted and stands which have been selectively thinned to remove the best phenotypes should be avoided (Turnbull 1975).

1/ Provenance: The place in which any stand of trees is growing. The stand may be indigenous or non-indigenous (OECD 1971).

2/ Origin: For an indigenous stand the origin is the place in which the trees are growing; for a non-indigenous stand the origin is the place from which the seed or plants were originally introduced (OECD) 1971.

### SAMPLING AT THE INDIVIDUAL LEVEL

In selecting trees for sampling for provenance studies the aim is to take a sample which is as representative as possible of the population. The main considerations in sampling are the number of trees, the type of tree and the distance between trees to be sampled. In order to give maximum flexibility in selection it is desirable that seed collections take place when there is a good seed crop on the majority of trees (Turnbull 1975). Good seed years will also furnish a seed sample which more fully represents the population genetically.

Sampling at the individual level can be done either for variability or for superiority in specific characteristics. Provenance studies are designed to expose genetic differences between populations and to indicate the best localities for seed collections. Such research can be done as well, if not better, with seed from random trees as with seed from carefully selected phenotypically superior individuals. IUFRO standards suggest selecting 'average or not less than average' trees of dominant or co-dominant status in 'normal' as compared with 'plus' stands.

In sampling trees for provenance trials from natural stands, the question of spacing between sample trees is important because of the need to avoid trees which are closely related genetically (half-sibs) or trees which have an abnormally high incidence of self-pollination. Although recommendations vary, it is generally considered that seed trees should be between 100 and 300 m from each other to avoid narrowing down the variation sampled due to relatedness or inbreeding (Turnbull 1975; FAO 1975; Melchior and Venegas Tovar 1978). Adjacent trees in plantations are usually not closely related because the seed has been bulked and so there need be no restrictions on sampling from adjacent trees (Turnbull 1975).

The number of trees sampled per stand will vary according to the species and its breeding system. Ten to twenty-five trees can be considered a minimum in species which are found in stands (Barnar 1974); possible solutions in dealing with tropical species which occur as individuals rather than as stands have been discussed above.

The number of seed required per tree for provenance trials need not be large: 10 000 seeds per tree would be sufficient for each experiment, provided seeds are picked out one per container or individually sown in seedbeds.

### COLLECTION FOR CONSERVATION

The main consideration when sampling for conservation ex situ is the maintenance of maximum allelic diversity. Strategies are discussed in the lecture 'Principles and Strategies for the Improved Use of Forest Genetic Resources'.

### COLLECTION FOR UTILIZATION

### SAMPLING AT THE POPULATION LEVEL

Collection for utilization is generally done from a limited part of the range, from populations which have been found through provenance trials to be well-adapted to the environmental conditions of the planting site. However, as many countries will start their planting programmes before sufficient information is available on provenance performance, climatic and edaphic matching is often done to select the most likely seed sources. As most species and provenances have some degree of plasticity (i.e. capacity to adapt to environmental conditions which differ somewhat from the natural ones) (Willan 1979), this can be an acceptable temporary measure provided that full-scale evaluation trials are started in parallel. Systematic evaluation is always necessary, as other factors than climate and soil in the present environment will determine the genetic make-up of trees, making the performance of new introductions in a matching environment unpredictable.

If collection is carried out in plantations or in even-aged, homogeneous stands, the genetic quality of the seed can generally be somewhat improved by sampling for superiority of stands as well as of individual trees (Turnbull 1975). However, it should be noted that in the case of uneven-aged natural stands and stands in which past history is

not known, phenotypic performance is no guarantee of genetic superiority: the probability of superiority being due to purely environmental causes is, in fact, 50% (Melchior 1977; Barner 1974).

#### SAMPLING AT THE INDIVIDUAL LEVEL

The lowest acceptable standard of collection at the individual level, often used, by necessity, to meet the needs for substantial quantities of seed for large-scale afforestation programmes, involves the collection of seed from all trees of a particular provenance or provenances, except from those of notably inferior phenotype (Turnbull 1977). Ideally, the trees sampled within a stand should be dominants, free of pests and diseases and in the case of plantations, of better than average form.

In stands regenerated by natural seed fall, collecting from trees growing closely together may result in plantations with a narrow genetic base, thus responding in a uniform manner to environmental pressures such as diseases or unforeseen adverse conditions, and generally having less flexibility to adapt to the requirements of a new site. In addition, if seed stands are subsequently established in these stands or seed is collected from them, severe inbreeding effects may occur in the resultant second generation stands. In natural stands, the distance between trees collected should, as in collections for evaluation, ideally be 100-300 m and as a minimum requirement, trees should be selected at an interval that exceeds normal seed fall (Turnbull 1975).

When collecting bulk quantities of seed there is no upper limit for the amount of seed collected per tree, provided that the number of trees collected is large. When collecting from standing trees, the lower limit of seed per tree would be set by economic considerations.

#### GENERAL REMARKS

Practical limitations and economic possibilities often modify the ideal sampling strategies outlined above. Factors such as accessibility of stands and yearly fluctuations in the seed crop at the provenance as well as at the individual level also influence decisions on sampling. If, however, the genetic and biological principles on which recommended sampling methodologies and intensity are based are known, these modifications can often be accommodated without too wide-ranging adverse consequences. Detailed recording of sampling procedures used and number of provenances, stands and individual trees collected from, as well as selection criteria in each instance, are of fundamental importance and cannot be over stressed.

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COLLECTION AND HANDLING OF FOREST SEEDS

C. Palmberg <sup>1/</sup> and G.H. Melchior <sup>2/</sup>

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## INTRODUCTION

A foremost constraint of large-scale planting of native or exotic species in Latin America, as in other parts of the world, is the lack of available information on basic theory and practical methods of harvesting, handling and treating forest seeds. Lack of contacts with the outside and especially lack of foreign exchange mean that the seed gap often cannot be closed by purchases abroad.

Since the Latin American countries still have relatively extensive forested areas, domestic requirements for seeds of native species could be met by collections in local stands. There is an urgent need to establish seed areas or plantations to produce exotic seeds so that natural self-reliance in seeds can be achieved as soon as possible.

Forest seeds may be collected to:

- ensure the continuous short and long-term supply of reproductive material for plantation programmes. Seed collection to be determined by the demand for final products within the country;
- guarantee the reproductive material needed for scientific trials;
- supply the reproduction material for the establishment of ex situ gene banks, and for the establishment and expansion of arboretums, botanical gardens and other collections of tree species;
- supply reproductive material for beautification of landscapes, recreational sites, cities, highways and the like.

Reproductive material collection methods vary in accordance with the above-mentioned objectives and will depend on the species in question, the sites to be re-afforested, the type of reproductive material to use, and so forth.

## BIOLOGICAL PRE-CONDITIONS FOR FLOWERING AND FRUITING

Detailed discussions of the formation of gametes and zygotes in conifer and hardwood tree species can be found in the Mittak manual (1978) and in various biology texts. This lecture will therefore be confined to pointing out certain biological aspects of particular importance for the development of forest seeds.

## THE JUVENILE - ADULT PHASE

The zygote, seed and sporophyte are formed through the union of masculine and feminine gametes. A diploid individual is produced by mitotic cell division. This individual can be defined in terms of its specific morphological and physiological features such as: the position of the needles, shape of the leaves and duration of the juvenile period.

The characteristic feature of the juvenile period is that the individual is incapable of sexual reproduction. The length of the period is further influenced, in addition to hereditary factors, by environmental circumstances. The duration of the period can range from 2 to over 50 years, depending on the species. Cordia alliodora in lowland areas for instance, matures in 4-6 years, Podocarpus in mountain areas requires 30 years or more, and Quercus in the temperate zone over 50 years.

When the tree reaches maturity its morphological characters change. The initiation of flowering and fruit setting is one criterion closely related to the degree of maturity of the tree. Unfortunately we know very little about phenological variation among and within tropical forest species and about the genetic and environmental influence. But it is known that individual trees within a specific stand or forest usually vary as to age at first flowering and the regularity of flowering and fruit setting, especially when young. One result of this variation, aggravated by the typically great distances between individual trees or groups of individuals of the same species in tropical forests, is the birth of subpopulations which all flower at the same time. If these subpopulations are small there

is a grave danger of selfing among them with all the adverse effects of inbreeding for the next generation: instability, low resistance to biotic and abiotic factors, and reduced vigour. This is why it is absolutely necessary to resist the temptation to collect seeds in very young stands, despite the fact that collection would often be easier and less expensive in such stands than in mature ones. Only when 60 to 100 percent of the individuals in a given population have flowered (only adult populations will achieve such percentages) should seed collection for commercial plantations be undertaken.

To speed up the onset of the adult phase of the tree and thus speed up flowering and fruit setting, stands for seed collection are usually established in sites with fertile soils and optimum climates for the flowering of the specific species. Sometimes it is also possible to speed up the adult phase and increase flowering and fruit setting by applications of fertilizers or plant hormones.

None of the above-mentioned methods should be used unless accompanied by careful observations or prior experimentation to throw light on the specific characteristics and requirements of the species.

#### ACTUAL POPULATION SIZE

By population size is meant the proportion of genotypes actually participating in fertilization and seed production within any given year.

Ideally, to enhance the physiological and genetic properties of seeds, all gametes in populations with a large number of unrelated individuals should combine at random. This is because crosses with foreign pollen are a positive factor in selection, as they maintain allele heterozygosity and suppress the appearance of sub-lethal alleles.

The following factors affect actual population size:

- (i) absolute population size;
- (ii) mechanical barriers, which might consist of: natural windbreaks (reducing the movement of wind-borne pollen) or a very large mixture of non-hybridizing species;
- (iii) phenology and synchronization of flowering. Non-synchronized flowering can combine with scant flowering some years to drastically reduce actual population size and hinder continuous seed supply and progress in breeding programmes. Synchronization will affect the genetic make-up of the seeds collected, as genetic composition usually varies within the stand from one year to the next depending on which trees are flowering. It will often be necessary in breeding programmes to establish a series of seed orchards, each having a phenologically synchronized subpopulation;
- (iv) intra-genotype incompatibility. This phenomenon, which is usually a barrier to selfing, in particular, and fertilization among closely related trees can be based on the following factors:
  - the pollen does not germinate on the stigma;
  - the pollen tube does not penetrate the stigma;
  - the pollen tube interacts with the tissues of the style and does not reach the ovule;
  - the gametes do not function due to incompatibility;
  - gamete union takes place but the zygote dies as the endosperm is incompatible or else, in polyembryonic species, selection operates against the gamete.

## PLANNING SEED COLLECTING

### DETERMINING SEED REQUIREMENTS 1/

Planning for reforestation must include seed procurement and ensure a sufficient, constant supply of seeds,

The person in charge will calculate seed needs for forest nurseries or direct planting in terms of the size of the projected plantation, the geographical area and the species one plans to use for reforestation. If the plan is to reforest 1 000 ha with Pinus oocarpa, at spacings of 2.5 x 2.0 m, for example, the number of plants required will be 2 000 plants/ha. Therefore 2 000 000 plants will be needed to reforest 1 000 ha. Two good quality seeds are needed to produce one plant in a nursery bag in the forest nursery. The number of viable seeds needed for the planned reforestation will therefore be:

$$2 \times 2\,000\,000 = 4\,000\,000$$

The number of viable seeds in a specific volume of cones varies greatly with the species, and even within the same species. Assuming an average 48 000 Pinus oocarpa seeds per hectolitre of cones, the number of seeds in the example quoted above is

$$4\,000\,000 : 48\,000 = 83.3 \text{ hl.}$$

It therefore follows that approximately 83 hl of mature P. oocarpa cones must be collected to reforest 1 000 ha (plants in nursery bags).

Nonetheless, as it is unlikely the required number of seeds can be collected every year, the largest possible number must be collected in good years and kept in cold storage for the future. The provision for "x" number of years to be collected in a planned harvest will depend on such factors as flowering period and the storage life of the seed under existing storage conditions. It is a good idea to store enough seeds for at least two years plus the present year. In this instance, the amount of seed to be collected would be:

$$3 \times 83 = 249 \text{ hl}$$

Yearly records of production cone maturity dates for each species, and provenance are important, good planning and data on the periodicity of good harvest are dependent on such records.

### HARVEST FORECAST AND EVALUATION 1/

When the reproductive buds have formed, the collection planner or supervisor can use the appropriate sampling method to determine whether a potential harvest is developing. We stress the word potential because the many impediments to seed development can destroy the reproductive structures or maturing seeds at any stage of the process.

Early forecasts are based on sampling. Female buds are collected as samples from 10-20 trees. Buds for identification are collected three branches from the top of the crown. A statistical evaluation of the sample material will give an indication of harvest potential. Theoretically, the greater the production of female buds, the greater the probability of a good seed harvest. Unfortunately, the quantitative relationship between female bud counts and potential harvest size is not completely reliable. But comparisons between areas and periodicity are always of some practical value. The procedure described may be useful until such time as a more suitable technique is devised for forecasting harvests of a species important for reforestation.

The forecast of subsequent forecasts may be based on a female flower count or, later, a count of new cones.

1/ This part of the lecture is based on Mittak (1978).



The most common error in classifying cone harvests is to count old cones which have scattered their seeds in earlier seasons, and to use trees growing along roads as a basis for estimates. Such trees receive more sunshine and frequently have more cones and buds than those within closed stands.

Based on the qualifications of the various possible seed collection areas, the planner will assign collection priorities subject to the next seed yield evaluation (content) of the harvest.

The main objective of the harvest evaluation is to indicate the number of healthy seeds in cones. Cones are picked at random from different trees throughout the stand. Care must be taken to ensure that the samples are representative of all cones, i.e., they must be collected evenly all over the crown of each seed tree.

Some ten representative trees in the stand are selected for evaluation and ten cones collected from each. The ensuing one hundred cones are split lengthwise down the middle for examination. All the good seeds on one of the cut surfaces are counted and then minutely examined. They are then treated separately in a 65°C oven until the pine cone sections open releasing the seeds. The total number of good seeds from the cone is divided by the number of seeds counted on a single face of the split cone. An average figure can be worked out for the one hundred cones once these figures are available.

Seed pests and diseases not only affect cone or fruit ability to produce mature seeds, they also affect subsequent seedling development. The usual estimate is that if more than 50 percent of the seed is damaged, seeds should not be collected from that stand.

Together with the quality and number of seeds it is important to get some indication of how ripe they are so a date can be set for harvesting.

The seed incision test, used in conjunction with other indicators of maturity, is usually very helpful in determining maturity. The test consists of cutting each seed lengthwise exactly down the middle with a razor blade. The contents of 20-30 seeds are then examined under a 10 power lens. The normal process is that as the seeds mature, the embryos elongate and turn yellowish whilst the endosperm turns from milky and sticky to firm consistency (similar to coconut meat). The tegument and wing also darken. Usually, the embryo has to have elongated at least 75 percent of its potential length to ensure seed viability. The possible or potential length of the embryo is the length of the cavity within the endosperm.

The incision test should not be performed until 3-4 weeks before seed maturity as before then the unfertilized ovules of some species can simulate normal development. In other words, they contain endosperm and look like good seed. However, since they have not been fertilized, there is no embryo and they cannot form viable seeds. Some three weeks before maturing, most of the unfertilized ovules stop developing and their endosperm tissue will dry up and form empty pods.

#### SAMPLING IN SEED COLLECTION

See previous lecture.

#### SEED COLLECTION TECHNIQUES

##### ON-GROUND COLLECTION

Seed collection from natural seed fall, being a low-cost, easy method, is very widespread. It includes collecting seeds of fruits which have fallen from standing trees and collecting from felled or fallen trees.

This method is frequently used for fairly large seeds or fruits, including, in temperate regions Quercus spp., Fagus spp., Castanea spp.; in tropical areas Tectona spp., Shorea spp., Triplochiton spp. and Gmelina arborea (Turnbull 1975; USDA 1974). Where possible it is recommended that the ground under the trees be cleared prior to collection.

Although seed collection from natural seed fall is a relatively easy, economical method, it does have certain serious drawbacks. The seed viability of many species such as Shorea spp., is very quickly lost once the seeds have been shed. Seeds on the ground are also very prone to damage by insects, fungi and animals. It is therefore imperative that shed seed be picked as soon as possible, remembering that the first seeds or fruits to fall are usually of rather poor quality (Turnbull 1975). Another drawback with this method is that it is normally not possible to say from which tree the seed was shed and there is, therefore, no indication of phenotype quality.

A closely related method which does eliminate many of the above drawbacks is to use tree shakers. These consist of a hydraulic arm mounted on a tractor which is used during the collection season to shake the trunks to make the ripe fruit fall (Turnbull 1975; Ottone 1978).

Animals such as squirrels sometimes gather cones or seeds. Foresters sometimes raid these stores for quick seed collection. It is a very common method e.g. for Pseudotsuga menziesii in the United States (Turnbull 1975).

Collecting seeds from felled or fallen trees in thinnings or clear-cut areas or from trees grown specifically for seed collection is another common harvesting method. Though in theory it is possible to limit the collection to desirable stands using this method, one can never again collect seed from the same tree or stand. Cutting down trees just to collect seeds is shortsighted and wasteful.

#### COLLECTING FROM STANDING TREES

Seed collecting from standing trees is the most common large-scale method for collecting forest seeds. It is a sure method, but careful attention must be paid to follow the proper safety measures, use the right equipment, and keep the equipment in good condition.

They are two distinct harvest methods (i) collecting from standing trees without climbing, (ii) collecting from standing trees by climbing them.

##### (i) Collection from standing trees without climbing

There are various ways of harvesting seeds without climbing. Some use equipment to get the fruits and seeds down, such as long, light poles for striking and shaking branches, knives with telescopic or long handles for cutting fruit, collection sticks, pole pruners and the like.

In Australia a rifle is used to sever the fruit-bearing branches of trees. Another possibility is a flexible saw operated by two collectors from the base of the tree. This last method can be used to cut branches up to 20 cm in diameter (Turnbull 1975).

##### (ii) Climbing standing trees for seed collection

Tree climbing equipment varies with the species and environmental surroundings.

Burley and Wood (1978) lists of equipment needed for seed collection are found in Annex 1.

#### Climbing irons

The usual way to climb trees is to use climbing irons. The forged iron is fastened to the foot gear with two sturdy leather straps. The foot gear must be solid and firmly attached to the climber's foot and leg. The iron ends in a fixed spur of varying length depending on the tree climbing method used. One of the best has a short hook which does not extend past the sole of the boot. This enables the climber to walk on the ground without difficulty. Irons can damage trees with thin smooth bark and should therefore not be used for climbing young or thin barked trees (Mittak 1978; Turnbull 1975). To facilitate the climber's task, ropes can also be snaked around the trunk of the tree (Mittak 1978).

The IUFRO teams collecting North American conifer seeds used as standard equipment climbing irons, safety belt, a hook to bend back branches, safety hat and overalls (Turnbull 1975).

### Tree bicycle, "Baumvelo"

The use of a Baumvelo or tree bicycle is recommended for collecting seeds, cones or fruits from trees with very thin, smooth bark. Tree bicycles are very easy to use on trees with smooth boles. The tree bicycle is particularly used to collect buds and pollen from plus trees to avoid damaging them (Mittak 1978).

The bikes consist of two pedals supported by a vertical arm. The pedal is fastened by special straps to the operator's boots. The arm is connected to a steel band forming a circle of adjustable diameter around the stem of the tree to be climbed. The pedals must be about 5-8 cm greater in diameter than the tree for ease of movement. In climbing, the operator puts all his weight on one boot-pedal, then raises the other foot with the other boot-pedal as high as possible. He then moves the other foot up to meet it. Between the two operations, he must adjust his safety belt as high as possible. When he reaches the crown he can take off the pedals and fasten them to the trunk for freedom of movement. He must again strap on the pedals to climb down the tree. The tree bicycle is easy to transport. Climbing with the tree bicycle is easy and rapid after some practice (Mittak 1978; Turnbull 1975; Ottone 1978).

### Portable Ladders

Ladders for collecting forest seeds vary greatly in construction and the materials used. Ladders are a quick, safe method to climb trees up to 15 or 20 m or even higher. Mittak (1978) lists the following kinds of ladders for collecting forest seeds:

Rope Ladders, such as sailors use. A rope is shot over a sturdy branch to haul up the rope ladder which is then made fast to the branch.

One-legged ladders, with alternate short rungs on both sides of the supporting pole. These ladders are appropriate for uneven terrain and branchy trees. One-legged ladders are attached by chains to the trunk of the tree. There is usually a bolster between the tree and the pole ladder at chain height to facilitate access. They are easier to steady than regular ladders.

Scaling ladders in several sections, usually of aluminium, are needed for climbing tall trees. Sections vary in length (2-4 m), but for easy carrying no section should weigh more than 3-4 kg. The sections are designed to fit into one another and are attached by a chain to the trunk of the tree, which the operator grasps as he climbs.

In addition to the above-mentioned ladder types, ladders mounted on tractors are used, as well as hydraulic platforms of various types. Often these platforms are only used in seed orchards since per unit collecting costs are very high (Turnbull 1975).

### Nets and other various methods

A special device for climbing trees, especially small trees such as cypress, is the net built by the United Kingdom Forestry Commission. A triangular net is suspended by special ropes and snatch blocks from the crown of the tree. The operator can climb up the net to collect the small fruits which cannot otherwise be harvested without partially cutting branches, doing great damage to future harvests. This device produces good results in species like cypress, i.e. species with many small cones or fruits on the outer part of the crown (Mittak 1978).

Mention has also been made of the use of pulleys attached to a sturdy fork. Even balloons have been used in different parts of the world, but they are hard to use and the end result is generally disappointing (Ottone 1978; Turnbull 1975).

### TRAINING AND SAFETY 1/

It is very important to train climbers in the various phases of seed collection and the correct use of tools and equipment.

Foremen should know which trees will produce good seed and which will not, and mark them prior to harvest.

Personnel safety is, after genetic and biological know-how, the most important aspect of seed collection.

Personnel should receive practical and theoretical training in accident prevention and first aid.

Each team should be equipped with a first aid kit and stretcher. Tools, safety belts, safe hats, protective goggles, ropes, hooks, spurs, ladders, the first aid kit and all utensils for seed collection should be minutely examined before the climb or before beginning work. Any tool or other equipment which gets damaged on the job should immediately be reported and a request made for repair or replacement.

Equipment should be clean. A product should always be brought along to dissolve resin and other sticky substances like pitch once the job is finished. Equipment maintenance promotes safety and makes the equipment last longer.

### PACKAGING AND LABELLING COLLECTED SEEDS

After picking, dry cones should be packed in coarse sacks or in solid-bottomed fruit crates. It is not advisable to use plastic bags for this type of cones. Air circulation is inadequate and moisture condensation can affect the fruit and seed. The temperature also rises within plastic bags, which can cause various kinds of damage such as lowered germination rates, mildewed seeds and fewer seeds released.

The coarse sacks are not completely filled. They are tied with string but not sewed, so the work will go faster. The reason the sacks are not completely filled is to avoid tightly packing the cones while they are still in the field and during the pre-drying period to prevent mildew from moisture and lack of air circulation. The sacks should be protected from rain and rodents and covered with canvas tarps. The sacks should be moved and turned two or three times a day and should not touch. The ground or floor should be dry. If crates are used, they can be piled up to a height of 2-3 m. The corners at the top of the crate and slatted sides promote air circulation. This stage of the process constitutes a sort of pre-drying phase affecting subsequent work and final seed quality. The cones can also be more easily moved to the processing site.

Sacks and crates are also a way to keep the cones during the collection/drying period. The harvest period is short and so a large number of cones is being handled. Thus packed, they will keep perfectly (Ottone 1978).

Some species of fruits lose viability if not kept moist. They must be collected before dry and transported to the temporary storehouse as soon as possible. Plastic bags can be used for some species for very short times. Sturdy paper bags with or without an inner plastic lining are also used (USDA 1974).

To guard against lost identity of seed lots it is extremely important to identify and label them. Each sack or package should be labelled inside and out. The labels must be water- and moisture-resistant and will list data on the species, provenance, collection date, name and last name of the collector and so forth. A seed lot number identifies them on a more detailed data sheet (see Annexes 2 and 3 for sample sheets).

### DRYING, POST-HARVEST RIPENING AND CLEANING SEEDS 2/

The cones or fruits should be transported as quickly as possible from the temporary storage area to the final handling and storage centre.

1/ This part of the lecture is based on Mittak (1978)

2/ This part of the lecture is based on Ottone (1978)

The first step after transport is to dry the cones and extract the seed. There are two main drying methods: sun and air drying, and artificial drying.

The natural drying process involves less risk of lowering seed quality but takes longer. Nor can the process be used in very wet or rainy climates. For easier handling of cones and seeds and quicker cone drying, the cones and seeds can be piled onto canvases. The canvas is folded at night to protect the cones and seeds from dew or rain. Rough sheds in which the air circulates freely are another answer. Another possibility is trays which are shaken to make the cones release the seeds. Plastic roofs can accelerate the sun drying process. Tin roofs are not used as they cause moisture condensation.

Increased air humidity in the drying area can produce a condition known as case hardening (the same can occur in oven drying). What happens is that the cone reabsorbs water and the opening process is inhibited to the point that the cone closes or remains partially closed, preventing seed release.

Humidity and temperature are easier to control with artificial drying. Artificial drying is quicker (from 6-15 hours) but it does require equipment and installations which can be very costly. It should be considered that the equipment is only used a few days of the year. Artificial drying is only recommended for cold, wet areas. Drying should be done in the shortest possible time to avoid damage to the seeds. The air must be hot and dry for even, rapid drying. Case hardening can occur if the cone is reheated. Cones must be pre-dried. Good oven temperature control is essential. The cones should be dried at the minimum temperature for as short a time as possible. Ideal temperature range is 10°C at the beginning of the process and no higher than 52°C at the end.

High temperatures will cause physical and physiological damage to the seed as will humidity (which should be eliminated as quickly as possible). The pre-drying operation aids and shortens oven drying. Pre-drying is therefore always recommended - for how long depends on the tree species. If rotary ovens are not used, once the fruits have dried they can be put into a 60 x 150 cm wire drum (approximate measurements), which is rotated to detach the seeds not released during the drying process. The same should be done with sun-dried cones. Small quantities of seeds can be threshed by hand into a crate, or onto a tarpaulin or brick or wooden floor.

Eucalypt capsules release their seeds in a few hours or at most one day after picking. The best way to collect eucalypt seeds is therefore to spread them on canvas tarpaulins sheltered from rain. The seeds can easily be separated from the fruit, branches and leaves by straining them through a fine mesh screen. They are then packed in closely-woven cloth sacks.

Fleshy fruits usually have to be soaked to remove the external fleshy covering. The seed is then removed by hand or with special equipment. The treatment includes alternate phases of washing, drying and cleaning and must be begun immediately so the fruits will not have time to ferment (USDA 1974).

One limiting factor in collecting the fruits of various forest species is the time period in which harvesting is possible. The cones or fruits of some species can be picked before ripe to lengthen the collection period. They must be stored in such a way that they can complete their anatomical and biochemical development. The usual post-harvest ripening temperature, depending on the species, should be 5-18°C. Constant vigilance is necessary throughout the process to ensure that the above conditions are met and no problems arise which might adversely affect the fruit and seeds, such as mildew.

It is also important to know how early the fruits are to be picked. Certain pine species can be picked when they have reached 1.1-1.2 of their specific weight, or approximately 15-20 days before the normal collection date.

The fruits or cones are stored as above for one month during which time they complete the development process. They are then dried in the usual way. The wings of winged seeds must be removed after drying.

To remove the wings the seeds are placed in a wire drum containing two or three sets of rotary brushes, regulated in accordance with the size of the seed to be processed. These brushes are attached to a central axis driven by an electric motor. As the drum turns,

the seeds and wings are pressed against the wire and the wings are rubbed off.

The brushes must also be set to leave enough space between the brush and the mesh to avoid excessive rubbing which would raise the temperature, harming the seed.

If winged seeds are to be sown immediately after, they can be slightly moistened. The wings will swell with the absorbed moisture and can easily be removed. If seed treated in this way is to be stored, it must be dried before storage.

Ordinary wire sieves with wooden frames can also be used to remove the wings from the seeds. These are vegetable seed cleaners with mesh sizes calibrated to seed size. Seeds can also be winnowed directly out-of-doors or in variable draft winnowing fans.

Whatever method is used for winnowing, the operation also eliminates sterile seeds. Seeds should not be over-winnowed to avoid eliminating good seeds which happen to be lighter because they are smaller. It would be better to keep some sterile seeds than to lose good seed.

At all stages of handling cones, fruits and seeds, it must be remembered that they are living organisms. Rough handling will lower germination rates and adversely affect seedling development.

#### SUPERVISION 1/

Before leaving the field, the supervisor and foremen must check all the equipment. In addition to checking the equipment, the supervisor is also in charge of transport, fuel and daily subsistence allowance for his team. A successful harvest, staff safety and the cost of seed collection are largely dependent on how well the operation is organized.

Every day the supervisor marks the trees in the area from which seed is to be collected. The criteria is seed maturity.

It is recommended that harvesting be done by work quotas, first determining costs in accordance with the amount to be harvested and reception facilities. Inspectors should ensure strict compliance with quality standards.

The supervisor must also keep a written record of the output of individual collectors, listing the number of cones, seeds or fruits collected, the operation, the species, provenance and site number and any other necessary observations. He must also fill out the collection sheets (see Appendixes 2 and 3).

It is recommended that a random check of one sack in five from each collector be made to ensure that the fruit or seed collected has been properly identified, that the sack is not over-full and that good-quality seed has been picked.

Supervision is essential at all subsequent phases of handling to avoid damaging the seed and ensuring that each seedlot is properly identified. Any treatments must be listed on the corresponding sheets for each lot.

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Annex 1

EQUIPMENT NECESSARY FOR SEED COLLECTION, SITE

INFORMATION AND SAMPLES FOR HERBARIUM <sup>1/</sup>

A - Seed collection

Containers for seeds (in field). Sacks and bags (may be re-usable).  
Containers for seeds (for shipping). Cotton and canvas bags (sent with seeds).  
Tags for trees, e.g., plastic rings.  
Climbing equipment. Climbing irons, tree bicycles or ladders. Safety belt, safety harness, safety helmets, tool-carrying harnesses.  
Seed cutters, e.g. hooks and rakes for cones, pruning poles, hand shears.  
(Heavy) plastic tarps to protect fruits, extract seeds and so forth.  
Binoculars to examine tree crown, check fruit development, etc.  
Portable walkie-talkie (special permit may be necessary).  
Insecticide and fungicide dusts for seed protection (use with caution).  
Axes, saws, machetes, knives.  
Harnesses, ropes, labelling equipment and labels.

B - Site description

Notebook, site description sheets.  
Maps (including copies with major outlines to be filled out in detail).  
Compass.  
Altimeter.  
Meteorological equipment (hygrometer, maximum/minimum thermometer).  
Soil survey equipment (core drills, soil colour charts, pH test).  
Tree measuring equipment (altimeter, diameter belts, bark calibrators, etc.).  
Camera and equipment (wide angle lens).  
Tape recorder (batteries).  
Shovel.

C - Sample collection

Plant pressing equipment.  
Packing material (local newspapers can be used).  
Plastic bags.  
Bottles for liquid samples.  
Preserving fluids.  
Growth corer (for wood samples).  
Carpenter's brace and drill (for resin samples).  
Insulated container (e.g., ice box).  
Magnifying glass.  
Insecticide spray (for herbarium material).

ALSO: Any needed medicines, camping equipment, vehicles and equipment as needed.

1/ From Burley and Wood (1979)



Annex 2

SAMPLE SEED COLLECTION DATA SHEET

FAO/DANIDA SEED CENTRE, HUMLEBAEK

DAN/FAO NUM. -----

SEED COLLECTION DATA - DAN/FAO TREE SEED CENTRE

Scientific name:

Provisional number:

n name

Provenance

Latitude:

Country:

Longitude:

Province:

Altitude:

Region and/or administrative unit:

Map reference:

Detail location:

Soil type:

Slope:

Drainage:

Orientation:

Monthly rainfall distribution:

Annual rainfall:

Nearest weather station:

Plant association:

Density:      open      uneven      dense

Regeneration method:

Height:

Age:

Diameter:

Bole:

Stand condition:

Comments:

Method:

Date of collection:

Number of trees:

Spacing of trees:

Amount of seed/cones:

Condition of seed/cones:

Potential for commercial scale collection:

Comments:

Extraction method:

Treatment:

Yield per unit of volume:

Germination:

Comments:

Description written by:

Collector:

A  
R  
E  
A  
  
S  
I  
T  
E  
  
S  
T  
A  
N  
D  
  
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O  
N

Annex 3

SAMPLE SEED COLLECTION SHEET

COMMONWEALTH FORESTRY INSTITUTE, OXFORD

Species: Pinus oocarpa Shiede      Seed No.: K31 Storehouse No. 1/71  
 Country: Nicaragua                      Province: Nueva Segovia  
 District: Dipilto                              Area: El Junquillo  
 Latitude: 13°42'N      Longitude: 86°35'W      Altitude: 1 000 m

Situation: In western Nicaragua on the southern slopes of the Dipilto Cordillera. The Cordillera forms the northern boundary of Nicaragua in this area. The stands, which are some 5 km north of Macuelizo and 8 km west of Dipilto, are part of an area of some 150 000 ha of open pine forest which extends more than 70 km east and west along the cordillera and northwards to the pine forest of Honduras. Rainfall gradually increases eastwards and in this direction the lower slopes (below 800 m) gradually fill with populations of P. caribaea, whereas on slopes above 1 500 m P. pseudostrobus and deciduous forests tend to dominate. On the western side near Macuelizo, the low slopes and valleys support only dry thorn bush, and P. oocarpa is the only pine species. This is the major pine species throughout the cordillera.

Soil: Sandy, quick-draining soils or pebbly soils with abundant quartz, derived in situ by wearing of granite rocks, with frequent outcroppings on the steepest slopes and peaks. Active erosion. Soils are usually shallow except in depressions or valleys, and contain hardly any humus. pH = 5.7.

Climate: Mean annual rainfall in Macuelizo (5 km to the south) is 904 mm with the following distribution (in mm):

	M		M				N		D	
	21	16	113	180	110	85	149	163	49	13

No temperature data is available for Macuelizo but at the Ocotal weather station (20 km east and 400 m lower than El Junquillo), mean monthly maximums in the dry season range from 28-32°C.

Description of stand: Very open pine forest on very steep slopes (25-35°) with very scant herb cover, including Andropogon spp. and Pennisetum spp. Some Quercus spp. are found in very wet valley areas. The largest pines are over 30 m in height with a diameter at breast height of 80 cm. Pine regeneration is scattered but good in various places. Tree rings are not very well-defined and are difficult to interpret, but it seems that growth is slow, from 3-5 rings per cm.

Cone-bearing trees:      DBH                      40-60 cm                      Height: 25-30 m  
    Branch angle:      70°-80°                      Bole:      Straight, cylindrical, whole

Collection methods: Selected trees on cutting sites (36 trees)

Collection date:      January, 1971

STORAGE, TESTING AND CERTIFICATION OF FOREST SEEDS

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### INTRODUCTION

Effective planning and production of afforestation programmes depends on the availability at all times of sufficient quantities of seeds with the right physiological and genetic characteristics. In the first place, the seed must be stored until required, without losing its germinative capacity. Secondly, there must be continuous checking, by testing the physiological characteristics of the seed. Finally, it is important for the future production of plantations that the material have the right genetic quality.

### STORAGE

Storage may be defined as the conservation of live seed from harvesting to sowing (Holmes and Buszewicz, 1958).

The reasons for storing forest seeds may be summarized as follows (FAO, 1955):

- 1) To conserve seeds in the best conditions to protect their germinative capacity from harvesting to sowing;
- 2) To protect the seed against destruction by rodents, birds and insects;
- 3) To preserve quantities of seeds harvested in good years, in order to have reserves available for years when little or no seed has been produced.

Many forest species only produce seeds in sufficient quantities at intervals of several years; long-term storage is extremely important for a regular supply of forest seeds.

It is usually assumed that respiration and metabolic activities must be considerably reduced if the seed is to survive a long period of storage. In practice, this means that only seed which can tolerate a reduction in its moisture content, and storage in these conditions, can survive a long storage period. It is also important that the seed be fully ripe before drying and that it not suffer damage during harvesting and handling.

### PRINCIPAL FACTORS AFFECTING VIABILITY

Viability may be generally defined as the capacity to survive or continue developing. A live seed is one that is capable of germinating in favourable conditions. The germination of the seed is not necessarily either easy or rapid, and dormant live seeds may require lengthy special treatment to germinate (Owen, 1956). The most important factors influencing seed viability during storage are the moisture content of the seed and the temperature. In some cases it has been shown that various gases in the surrounding area influence the seed somewhat (Owen, 1956).

### MOISTURE CONTENT

According to the rules of the International Seed Testing Association (ISTA), the moisture content of the seed is expressed as a percentage of the weight of the seed in

its original moist state (ISTA, 1976):

$$\text{Percentage of moisture} = \frac{\text{Weight of moisture}}{\text{Weight of moisture} + \text{Weight of dry matter}} \times 100$$

A reduction in moisture content considerably slows the metabolic processes, which, in turn, slows the respiratory process and the consumption of stored nutritional matter. However, it must be pointed out that some forest species with large seeds - for example, many leafy species - do not normally survive drying. It is also important that they be dried with great care.

The moisture content of the seed increases before ripening. After ripening it is much lower. The natural moisture content in seeds after ripening varies between 15 and 50 percent, depending on the species and on conditions.

A change in moisture content during storage as a consequence of storage outdoors, or due to the opening and closing of the storage containers, destroys the capacity of the seed to germinate (Barton, 1961).

The moisture content obtained in storage depends to a large extent on the relative humidity of the air inside the storage area. After a few days or, in some cases, a few hours a characteristic balance is reached between the moisture content of the seed and the relative humidity of the air (Holmes and Buszewicz, 1958). Changes in the moisture content depend on the relative humidity of the air, the moisture content of the seed and type of testa and size of the seed lot.

It should be borne in mind that the results of studies of moisture content of a seed lot are mean values, and that there could be major variations in moisture content from seed to seed. Schonborn (1964) demonstrated, for example, that in one lot of Pinus sylvestris seeds with an average moisture content of 6.7 percent, individual percentages varied from 4.1 to 9.3.

#### TEMPERATURE

Seeds usually keep better at relatively low temperatures. Variations in temperature have an adverse effect on seed quality.

The interaction between temperature and seed moisture content is very important in storage, and it is often difficult to separate the two factors. As a general rule, it may be said that when the temperature is low, the critical moisture content is higher than when the temperature is high. In other words, low temperature can to a certain extent compensate for high moisture content, and vice versa (Holmes and Buszewicz, 1985).

Temperature influences absorption of moisture by the seed during storage. A general rule is that moisture content of the seed at a given relative humidity drops when the temperature goes down.

Schonborn (1964) made studies to demonstrate the lowest temperatures that could be tolerated by seeds of different forest species at different moisture contents.

Results show that seed tolerance of low temperatures is proportionate to low moisture content. Also, it appears from the studies that species such as Picea abies, Abies alba, Pinus Sylvestris, Fagus sylvatica, Pseudotsuga, Betula and Quercus tolerate temperatures as low as  $-20^{\circ}\text{C}$  at a moisture content between 8 and 10 percent.

For seeds requiring a high moisture content in order to conserve their germinative capacity, storage at temperatures below zero leads to frost damage, with the consequent loss of germinative capacity (Holmes and Buszewicz, 1958).

#### OXYGEN AND OTHER FACTORS

The respiratory process depends naturally on the moisture content in the seed. The purpose of lowering temperature and moisture content during storage is precisely that of

lowering respiratory intensity, since this is the only way of ensuring that the seed maintains its germinative capacity for a long time.

It is of course desirable to store seeds with low moisture content in airtight containers that maintain a constant humidity, slow the respiratory process and protect the seed against pests. For seeds requiring a high moisture content during storage, such as, for example, *Quercus* spp., storage in airtight containers can be harmful, apparently due to the fact that this group needs some change of air during storage (Wang, 1977). However, it is clear that air composition within the container undergoes modification with time, due to respiratory processes, something which could influence the life of the seed.

A series of studies has been made of the influence of different gases on the life of the seed, and the results have been published by Owen (1956) and Barton (1961).

### SPECIAL FACTORS AFFECTING VIABILITY

#### RIPENESS OF THE SEED

How ripe seed is at harvest is of course an important factor, and is responsible for some variations in seed viability. The timing of harvesting is therefore highly important, and it is also important to be able to determine the earliest stages at which a large quantity of live seeds can be collected.

The degree of ripeness can be assessed by a series of different methods, described in detail by Barner (1975).

However, it is often difficult to decide the most appropriate moment for harvesting seeds, especially in tropical countries where the period from maturation of the seed to shattering is often very short. In other cases there can be various degrees of ripeness on the same piece of land, or even the same tree, which can mean that unripe seeds have to be harvested, in the hope that post-harvest ripening can be induced before storage.

#### FUNGUS, BACTERIA AND INSECTS

Seeds stored under relatively humid conditions are easily attacked by the so-called storage fungi, of which the major groups are *Aspergillus*, *Botrytis*, *Rhizopus* and *Penicillium*. Holmes and Buszewicz (1958) provide more references.

The most widely used method of avoiding attacks by fungi and bacteria during storage is the use of relatively low temperatures or relatively low moisture contents, under which fungi and bacteria cannot survive. The use of both a low temperature (maximum +5°C) and a low moisture content (maximum 10%) provides the best natural protection.

According to Christensen (1972), the use of fungicides during dry storage often poses problems, since many fungicides have to be dissolved in water.

It is unusual for seeds which were not already infested before storage to be destroyed by insects, especially *Megastigmus* species.

In most cases, such losses can be avoided by controlling the temperature, bearing in mind that almost all insects in stored seed die at temperatures above 40-42°C (Holmes and Buszewicz, 1958). Chemical products can also be useful in controlling insects; however, it should be borne in mind that these products can considerably reduce germinative power, particularly in the case of seeds with a relatively high moisture content (Ezumah, 1976).

#### MECHANICAL DAMAGE

Mechanical damage can be defined as harmful changes due to damage during harvesting or handling of seed. Since the effects of the damage increase with time, mechanical damage also covers heavy damage resulting from mechanical damage (Moore, 1972).

The reaction of seeds to damage varies very much, and some species have a greater natural capacity for recovery. Major damage will immediately lower seed viability, while

the effects of less important damage will usually only become apparent after a certain time. Consequently, it is important that seeds which are going to be stored for a long time should be treated with care during both harvesting and subsequent handling.

The moisture content of the seed is important because of its effect on resistance to mechanical damage. Moist seed tends to swell, whereas dry seed tends to break.

The best method of detecting the presence and kind of damage is tetrazolium testing (Moore, 1969). Radiographic methods such as those described by Kamra (1967) also produce good results.

#### CYTOLOGICAL AND GENETIC CHANGES

Lowered viability means that yield is reduced in two ways. First, a drop in the germination rate lowers the number of plants per area unit, and second, the surviving plants may be of inferior quality (Roberts, 1972).

Many experts fear that a considerable reduction of germinative power involves changes in the genetic composition of a seed lot since the survival capacity varies from one genotype of another (Harrington, 1970, Frankel, 1970). They also fear that poor storage conditions may increase the number of chromosome changes (Harrington, 1970).

Wang (1977), however, reached the conclusion that these two kinds of genetic modification can largely be controlled and kept to a minimum by efficient harvesting, handling and storage of seed.

In practice, this means that seeds, stored under good conditions and which have maintained their germinative capacity can safely be used. But it is not very safe to use seeds with severely curtailed germinative capacity. When seeds have been stored for long periods, they should be used with circumspection, particularly in breeding and gene conservation.

#### STORAGE METHODS

As many be seen from the above, there are great differences between different species, or rather, between different genera, as regards capacity to survive storage. Seeds can be divided into five major groups in the light of this capacity. Guidelines as regards storage methods for the different groups, and examples of genera and typical species within each group, are given below.

- 1) Seeds of natural longevity. This group included Acacia, Robinia, Albizia, Sophora, Cercis, Cytisus and Gleditsia, all legumes, whose seeds have a hard testa and normally a very low moisture content.

The seed should be stored in a dry place; the temperature, however, is not very important, and it is not necessary to use airtight containers. In some cases it is necessary to use disinfectants and other control measures.

- 2) Seeds that can be stored 5-10 years with low moisture content and at low temperatures. Typical examples of this group are Picea and Pinus.

Preparation for storage: The seed should be handled properly from the beginning, and should not be harvested until it is fully ripe. The cones should be kept cool, and damage to the seed and abrupt changes in moisture content and temperature should be avoided. There should be adequate ventilation during extraction, and temperatures should not exceed 20°C at the start and 40°C at the end of extraction. After extraction the moisture content is very often 5-8 percent, and the seed should be dewed (trimmed) and cleaned as soon as possible before being stored. At the above-mentioned temperatures it is not normally necessary to disinfect the seed.

Drying process. The moisture content of the seed should be ascertained as soon as possible, by one the methods described in the paragraph on seed analysis.

If the seed does not have the right moisture content, it must be dried. Drying can be in the sun, in hot chambers or in an oven. It is important that air circulate freely during the drying process (Wakely, 1954), and that the temperature not exceed 30°C. Small lots can be dried chemically with CaO, sulphuric acid or CaCl<sub>2</sub> (Magini, 1962).

Moisture content and storage temperature. For most species of the genera Larix, Picea, Pinus, Pseudotsuga, Thuja, Tsuga, Chamacyparis, Cupressus, Cryptomeria, Alnus, Betula and Eucalyptus, the following can be recommended (Schonborn, 1964, Wang, 1974 and Barner, 1975):

Storage period	Moisture content %	Temperature °C
3 - 5 years	6 - 8 %	+2 to +4°C
More than 5 years	6 - 8 %	-10 to +4°C
More than 10 years	6 - 8 %	-10°C

In the case of Eucalyptus, Barner (1975) states that most species can be stored for a period of up to ten years in airtight containers at temperatures of 1-5°C, if the moisture content is kept at 4-8 percent. Turnball (1975), Filho and Lisbao (1973) provide more detailed information on some species of Eucalyptus.

As mentioned above, moisture content and temperature are closely linked. If factors fall short of the optimum, it can be offset to a certain extent by the other.

Storage containers. Cold storage rooms where the temperature can be kept at the desired level are normally very expensive to build, so it is important to store the seed in airtight containers. Glass or metal containers were originally used for this purpose. More recently, plastic containers and polythene bags have begun to be used; however, they are containers not recommended for long-term storage, since they are not entirely damp-proof (Owen, 1956).

3) Seeds that can be stored 3-5 years with medium moisture content and at low temperature.

- a. This group includes Abies (Barner, 1975) and Cedrus and Libocedrus (Holmes and Buszewicz, 1958).

Preparation for storage. Heat should not be used in extracting the seeds. The cones should be stored in a well-ventilated place until they begin to separate, after which a mechanical handler can be used, very carefully, to activate extraction. Care should also be taken in later handling, since seeds are extremely sensitive.

Drying for storage. Abies seeds should not be dried until a 1-2 month after ripening period. Drying should be done carefully at temperatures not exceeding 25°C.

Moisture content and storage temperature.

Storage period	Moisture content %	Temperature °C
1-3 years	12-13 %	-4 to -15°C
More than 3 years	7-9 %	-10 to -20°C

Storage containers. See group 2.

- b. To this group belong the leafy species, Acer, Fagus, Fraxinus, Ulmus, and possibly Tectona (Barner, 1975).

Preparation for storage. With the exception of Ulmus, whose seeds should be harvested before maturity, seeds should be fully ripe before harvesting.



The seed should always be spread out in well-ventilated rooms and turned over at regular interval.

Drying for storage. Normally it is not necessary or desirable to dry seed artificially.

It should be pointed out that Fagus sylvatica seed should after-ripen under cold, humid conditions for another two or three months, after which the moisture content can be carefully reduced (Barner, 1975).

Moisture content and storage temperature. For most species in the group the following may be recommended:

Storage period	Moisture content %	Temperature °C
1 - 2 years	20 - 25 %	-4°C
2 - 3 years	12 - 20 %	-4 to -10°C
More than 3 years	7 - 10 %	-10°C

For Tectona grandis there are no precise data, but it seems that the seed can remain viable for 2 to 3 years if it is in dry storage in plastic bags (Murthy, 1973).

Bonner (1978) estimates that the storage period for Triplochiton scleroxylon and Gmelina arborea is the same; seed is stored at temperatures of 0 - 5°C and moisture contents of 5 - 10 percent.

Storage containers. See paragraph 2. However, it should be observed that seeds with a moisture content of more than 15-20 percent should not be stored in airtight containers, but in bags which allow some air to circulate.

4) Seeds that can be stored 1-3 years with high moisture content and at low temperature.

This group includes various leafy species with large seeds and fruits, such as, Aesculus, Castanea, Juglans, Liriodendron and Quercus (Barner, 1975).

The most important principles of storage are good ventilation, uniformly high moisture content, and moderate to low temperature.

Holmes and Buszewicz (1958) provide a series of examples of methods of short-term storage (in the winter), both in the open air and in a building or under a protective covering. As a general rule, these methods are not used for long-term storage; also, it is very difficult to control moisture content and temperature during storage.

5) Very short-lived seeds

This group includes Salix and Populus (Barner, 1975).

Normally the seed loses its viability very rapidly, but with some species the seed can be preserved longer (Jones, 1962). Holmes and Buszewicz (1958) and Wang (1974) have provided more detailed information on individual species.

### TESTS

The purpose of seed analysis is to obtain actual data on a given seed lot (Justice, 1972).

One of the most important factors in successful testing is the use of standard methods providing comparable, replicable results. In this connection, mention may be made of the International Seed Testing Association (ISTA), which prepares and publishes standardized methods for seed testing. The last updated edition of ISTA standards was published in 1976 (ISTA, 1976).

### SAMPLING

For information from a seed lot to be reliable and accurate, the sample taken (and this is the purpose of the analysis), should be representative of the seed lot. It is therefore important to use standardized, objective sampling methods. Even very precise analyses are less valid if the sample taken is not representative.

Probes are often used, reaching all parts of the bag and designed in such a way that they extract samples of an equal volume.

Normally, the sample taken should be reduced to a standard portion, and also at this point it is important that the reduction should be done objectively and correctly. Turnbull (1975) describes various mechanical and non-mechanical methods of reducing the sample.

### PURITY ANALYSIS

Forest seeds can contain impurities in the form of weed seeds, seeds of other tree species, bits of seeds, leaves and other things. The purpose of seed analysis is to make a quantitative assessment of the composition of the lot under analysis. To this end, the lot is divided into its component parts (Turnbull, 1975).

Pure seed means seeds of one species. As well as ripe seeds, these can be undersized, shrivelled, immature, or germinated seeds, providing they can be identified with certainty as belonging to the species in question.

Parts of seeds more than half the original size (ISTA, 1976) are also included. Leguminosae and Coniferae seeds without testae belong to the inert matter group.

Inert matter includes seedlike structures, for example, broken wings and conifer seed coats.

Foreign elements include sand, stones, leaves, bark and any other element which is not seed.

The entire sample is weighed, including all impurities, after which the pure seed is separated out and weighed separately.

Calculation of the percentage of purity is expressed in the following way:

$$\text{Purity (\%)} = \frac{\text{Weight of pure seed}}{\text{Total weight of sample}} \times 100$$

Most of the work of dividing the lot to be analysed into the relevant component parts has to be done manually, using a magnifying glass, stereomicroscope, etc. However, there are today various apparatuses and methods of reducing the manual work to a certain extent. First, there is the seed blower, with which it is possible to divide the lot into heavy and light components. Among other methods may be mentioned: separation by density (Stermer, 1964), use of a vibrating table (Guldager, 1973), and X-rays (Kamra, 1965).

The pure seed component is often used for germination analysis, and is therefore important in any evaluation of the productive potential of a seed lot, provided that purity and germination analysis are both tested.

### VIABILITY TESTS

It is difficult to give a definition of seed viability broad enough to be applicable in all circumstances. For most purposes, a seed is considered viable if it germinates under favourable conditions, assuming potential dormancy has been eliminated (Roberts, 1972).

Methods of ascertaining germination potential and methods of indirectly measuring seed viability are described overleaf.

### GERMINATION ANALYSIS

The fundamental purpose of any laboratory analysis of germination is to estimate the maximum number of seeds that would germinate under optimum conditions.

Germination is expressed as the percentage of pure seed producing normal plants, or as the number of seeds germinating per weight unit of the seed lot. It is advisable to make germination analyses in accordance with ISTA standards.

### PREPARATION OF THE SAMPLE FOR GERMINATION ANALYSIS

All germination analyses should be made on pure seed.

The seed should be mixed and counted thoroughly, and the analysis should be repeated several times. For more information on details concerning preparation and use of laboratory equipment, see Turnbull (1975).

### GERMINATION EQUIPMENT

The choice of germination equipment will depend both on the quantity and the type of seed. The most important equipment recommended by ISTA is briefly described below:

- 1) Jacobsen and Rodewald apparatus. The seeds are placed directly over a water bath or damp sand. The substratum or filter paper bed is kept moist by means of a wick from the substratum down to the water. Alternatively, porous dishes containing seed can be placed directly over the damp sand or over water. The temperature of the container is controlled automatically.
- 2) Germination cabinet. In this apparatus trays can be fitted in layers, therefore requiring less space. Also, ambient humidity, temperature and light can be controlled to a certain extent.
- 3) Room Germinator. If a great many analyses are to be made, whole rooms can be used with the appropriate equipment to control temperature, humidity and light.

### GERMINATION CONDITIONS

Optimum conditions for the different stages of germination are not identical and can very often vary with different seeds within one seed lot. As a result, most of the research on seed has aimed at ascertaining the combination of conditions that provides the most uniform, rapid and complete germination of most samples in any one species.

Turnbull (1975) comments in detail on the following factors which must be borne in mind in germination analyses:

- 1) Germination substratum;
- 2) Humidity and ventilation;
- 3) Temperature control;
- 4) Light;
- 5) Distance between seeds;
- 6) Fungus control.

### DORMANCY

The seeds of most tree species germinate upon exposure to the right humidity and temperature. However, seeds of some species do not germinate even under favourable conditions, until they have undergone a physical or physiological change. This state is called dormancy. The state of dormancy may be transitory, and many species exhibit dormancy only during the first six months after harvesting.

Turnbull (1975) mentions the following types of dormancy:

- 1) Embryonic dormancy. "Embryonic dormancy" means the situation in which germination of the fully developed seed appears to be blocked by internal factors.
- 2) Dormancy of the testa. Many species of seed do not germinate because they have a thick testa.
- 3) Induced or secondary dormancy. A few species can enter into a state of dormancy due to incorrect storage or handling, and this type of dormancy is called secondary dormancy.
- 4) Unripe embryo. Seeds in which the embryo is not entirely developed when the fruit is ripe require a period of after-ripening before germination.
- 5) Mechanical resistance of the testa. In some cases considerable force is needed to break the testa. This applies to certain species of Prunus and Tectona grandis. As in the case of dormancy of the testa, scarification can be used to break the testa.
- 6) Double dormancy. Seeds of some species have two types of dormancy that have to be eliminated before they germinate. The most usual combination is embryonic dormancy and testa dormancy.

#### EVALUATION OF PLANTS

A seed is said to have germinated when it has developed into a normal plant. Various groups of abnormal plants (see more details in ISTA, 1976) are not included in germination trials because they seldom survive. Germination tests (even excluding abnormal plants) normally produce over estimates of viability under field conditions, due to the optimal testing conditions.

#### INDIRECT VIABILITY TESTS

The purpose of quick viability trials (Turnbull, 1975) is:

- 1) To ascertain quickly the viability of species that usually germinate slowly and show signs of dormancy in normal methods of germination;
- 2) To ascertain the viability of lots which, at the end of the germination test show a high percentage of hard or ungerminated fresh seeds.

Four different methods are described below:

- 1) Analysis by cutting open. By opening the seed it is possible to study the endosperm and the embryo directly and to see whether their colour is normal and if they are developing normally. The method is not very accurate and often leads to over estimates of germinative capacity.
- 2) Tetrazolium tests. By this method, living cells turn red when the colourless tetrazolium salt is reduced. The procedure has been described in detail by ISTA (1976).

Justice (1972) points out that the use of this method is in practice limited by a series of problems, such as the difficulties in staining some seeds; some seeds have to be opened for the colour to become visible. In several cases, results are not in line with those of germination tests; and interpretation of the different shades is difficult.

- 3) Trials of extracted embryos. Extracted embryos are placed on damp filter paper in Petri dishes. In a few days it is possible to see which embryos are alive and which are not.

- 4) X-ray technique. This method reveals empty seeds, mechanical damage, abnormal development of the internal structure of the seeds, and the thickness of the testa. It also assesses viability, using a technique of staining or contrasting matter.

#### RESULTS OF VIABILITY TESTS AND THEIR USE

The results of the viability tests may be described as follows (Turnbull, 1975):

- 1) Percentage of germination. This is the percentage of seeds in the lot which have germinated by the end of the trial.
- 2) Germinative potential. This is the sum of the germinated seeds and the remaining sound ungerminated seeds.
- 3) Germination energy. This indicates the percentage germinated within a given time, for example, 70 percent within seven days, 90 percent within 14 days, etc.
- 4) Number of live seeds per weight unit. The indication could be useful to the people who are going to use the seed.

#### ANALYSIS OF MOISTURE CONTENT

As mentioned above, determination of moisture content is very important for storage purposes.

ISTA recommends the following three methods of determining moisture content (ISTA, 1976):

- 1) Oven drying method (130° C). Owing to the high temperature, this method cannot, however, be used for forest seeds.
- 2) Oven drying method (105° C).
- 3) Toluene distillation method. This method should be used to determine the moisture content in seeds containing volatile oils, for example, Abies spp.

As well as the methods mentioned above, there is a series of automatic measurements of moisture content. They are not sufficiently accurate for official trials, but they can provide rapid and fairly reliable information on the moisture content of seeds.

#### DETERMINING SEED WEIGHT

Determining weight of 1 000 seeds has been described by ISTA (1976).

#### HEALTH TESTS

Health tests are run to determine the presence of micro-organisms or diseases in seeds. These trials are important for three reasons:

- 1) Disease-carrying seeds can lead to forest outbreaks of pests, lowering the commercial value of the trees.
- 2) Through seed lots, diseases can spread to new regions. Quarantine investigation and certification for the international trade may therefore be necessary.
- 3) Health tests provide more data on the causes of abnormal seedlings, and could supplement germination analysis.

The ISTA standards provide general rules for health tests.

### SEED TESTING EQUIPMENT

Both the seed testing equipment and its use are described by ISTA (1976).

### CERTIFICATION OF FOREST SEEDS

The purpose of certification of forest seeds and plants is to preserve and make available to working foresters sources of seeds, plants and other propagating material of superior provenances and cultivars that have been cultivated and distributed, thus ensuring the genetic identity and superior quality of seeds and plants (Matthews, 1964).

### CERTIFICATION PROGRAMMES

Barber (1969) summarized the problems relating to control of genetic identity in the following way:

Good results in tree improvement and afforestation programmes depend on accurate control of the genetic identity of reproductive material. We should try to use only reproductive material of known genetic identity. However, the precision with which we can identify the material will vary according to species, locality and final use.

The forest tree breeder must have full knowledge of the source of the seed plasm with which he is working. It is particularly important that the identity of each tree be maintained, so that the researcher may consider the risks of any negative trait from the mating of related individuals. As offspring are produced and grow, the breeder needs to be able to study the genealogical record of each individual to pinpoint which parent has contributed which character, whether desirable or not. He/she should be in a position to duplicate all crossings if necessary, and must catalogue and identify accurately all the material exchanged or approved for use.

The forester should know which source or line best meets his needs. To achieve optimal results, he/she should know the exact source of the material used for the establishment of plantations and for stand regeneration; knowledge of the genetic identity of the material used is necessary to plan proper spacing and cultivation techniques. As the use of a disease-resistant strain, for example, lowers mortality and produces fewer defects, the forester can space trees further apart or thin more frequently. Reports of major genotypic interaction in the environment indicate that tree breeders can develop cultivars that react favourably to qualitative difference in site or cultivation methods. If seeds or seedlings are not available from the appropriate source, it could be desirable, from the economic point of view, to postpone planting for a year or more.

For a certification programme to function satisfactorily, there should be a mechanism to facilitate the participation of all interested parties in the formulation of operational procedures. Certification should be backed by legislation.

Several countries use certification programmes (Matthews, 1964). Some programmes, such as the North American programme, are regional.

An international programme under OECD was established in 1967. In 1974 a few modified rules were prepared (OECD, 1974).

The OECD programme is based on the voluntary participation of member countries, but NATO member countries can also participate.

### IMPLEMENTATION OF CERTIFICATION PROGRAMMES

A broad programme should include the following elements:

#### Planning

- 1) Preparation of maps, with an indication of the distribution of important species.
- 2) Delimitation of regions of provenance of these species.

- 3) Delimitation of important regions for afforestation and reforestation.
- 4) Estimate of supply and demand of seeds and plants.

#### Execution

- 5) Organization and administration.
- 6) Classification and approval of sources.
- 7) Recommendations for the choice of provenances and transfer of reproductive material.
- 8) Production and control measures.
- 9) Record of data and documentation.
- 10) Sale of reproductive material.

Ref. items 1-4. These items are important for evaluation of the need to establish a certification programme. An estimate of the quantity of seeds and plants necessary should be made and compared with available sources, both on the site and elsewhere.

Ref. item 5. This item includes the designation of the various groups of authorities responsible, such as:

- 1) a director or directors;
- 2) an advisory group;
- 3) a working group for approval of sources;
- 4) inspectors.

Ref. item 6. This item is fundamental to the certification programme, and has been discussed in detail by Barner (1973). Major sources could be listed as follows:

- 1) Regions of provenance;
- 2) Stands;
- 3) Regions of seed production;
- 4) Individual trees;
- 5) Seed plots.

Approval of sources, in accordance with certain minimum requirements, would be the responsibility of the above-mentioned working group for approval of sources.

A national list of sources should be prepared. The list should include the most important data, such as Latin name, identification, location, origin, ecological conditions and results of trials. A definition of classes and instructions for collection of information has been provided by Barner (1975). It is not necessary that the national list include all the above-mentioned types of source, but it should be possible to extend the programme to include all types later.

Ref. item 7. One later development of the approval of sources could be the recommendation of these sources for general or specific uses. Sources have often been approved on the basis of the phenotypical appearance of the seed trees or on the basis of very limited progeny tests. Recommendations should be based on tests, but since these take a long time and seed must be produced, it is necessary to use sources of seed that have not yet been tested. In certification programmes, therefore, a distinction is made between tested material and untested material within each class of the approved sources. The certification

programme should be established and developed in close collaboration with forestry research and particularly with forest tree breeding.

Ref. item 8. As an example of rules relating to production and control measures, Barner (1975) indicates the minimum standards and requirements of the OECD programme as regards material from approved sources. The standards establish how inspection is to be carried out in the forest, the plantation and the nursery, and how to mark and package seeds.

Ref. item 9. Recording data and documentation is an integral part of the control procedures. Each seed lot, for example, should be accompanied by standard data with detailed indications of identification, harvesting, seed extraction storage and quality.

Ref. item 10. Once all the operations have been carried out in accordance with the programme, a certificate can be granted, to which reference can be made when material from the source in question is sold.

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EXPERIMENTAL DESIGNS

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### INTRODUCTION

The principles governing experimental designs may be expressed in the following way (Brown et. al., 1977):

- 1) Observation of a phenomenon.
- 2) Formulation of a hypothesis on the phenomenon.
- 3) Testing the hypothesis.
- 4) Application of Findings.

Tests are tools to test established hypotheses.

Successful test design and implementation are most important factors underlying the soundness of test conclusions (LeClerg, 1967).

Forest tree improvement tests have the following main objectives:

- 1) To evaluate the material for genetic improvement with respect to a series of desired properties, based on an established hypothesis. In most cases, these are field trials, where the material is tested under conditions similar to the growing conditions (habitat conditions) of the improved material. However, they could also be nursery, greenhouse or laboratory trials.
- 2) To study the fundamental genetic parameters which are important for research and for future development in the field of forest tree improvement.
- 3) To analyse different treatments, methods of genetic improvement, etc. Like the studies mentioned under point 2, these analyses should be made initially with a view to further research in this field.

Irrespective of the purpose of the test, all the different practical factors should be taken into account in planning it, so that maximum information is obtained.

### REQUIREMENTS OF A GOOD EXPERIMENT

Cox (1958) has established the following five considerations in planning a test.

#### No systematic errors

This means that experimental units containing a particular material, for example a particular provenance, should not deviate in any systematic way from the other provenances in the test.

#### Precision

If there are no systematic errors, the probable magnitude of random error in the estimate of the effect of the treatment (material), can generally be measured through standard error. Standard error (SE) is calculated as follows:

$$\sqrt{\frac{\sum (X-\bar{X})^2}{n-1}} \quad ; \quad SE = \frac{S}{\sqrt{n}} \quad ;$$

S = standard deviations

X = individual observation

$\bar{X}$  = the estimated mean of X values

n = number of observations

The precision of a test will depend on the following factors:

- a. The real variability of the experimental material and the accuracy with which the experimental work has been done.
- b. The number of experimental units (and the number of observations repeated per unit).
- c. Experimental design (and the method of analysis, if the latter is not completely effective).

A general requisite of precision is that the standard error be sufficiently small to allow us to draw convincing conclusions; on the other hand, it should not be too small. If the standard error is great, the test will be almost valueless, whereas an unnecessarily small standard error implies a loss of experimental material.

#### Field of application

Estimating the difference between two materials in a test, we reach conclusions that refer to the special set of units used and to the conditions governing the test. If we wish to apply the results of the test to other conditions or units, another uncertainty is added, as well as the uncertainty measurable as standard error. It is important that experimental material be tested under conditions not essentially different from those of the sites where it is planned to use the material.

#### Simplicity

This is a very important factor which should always be considered in planning a test. By simplicity is meant not only a simple design, but also that it is desirable to use simple methods of analysis. Fortunately, in most cases, efficiency in design is matched by simplicity in methods of analysis.

#### Estimate of uncertainty factor

It is desirable to estimate the uncertainty factor of the assumed differences between materials. This usually means estimating the standard error for these differences, and then, on this basis, calculating the limits of error (limits of reliability) for real differences at a given level of probability. From this, the statistical significance of the difference between two materials can be measured.

The standard error of the difference is calculated as follows:

$$SE = \sqrt{2} \cdot s \left( \frac{1}{\sqrt{n_1}} + \frac{1}{\sqrt{n_2}} \right)$$

$n_1$  and  $n_2$  = number of observations on which the two estimated means are based.

The limits of reliability for real differences may be calculated as follows:

$$(d_1 - d_2) \pm t \cdot s \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

$X_1$  and  $X_2$  = the two estimated averages

$t$  = value of student's  $t$  at a given level of probability

$n_1$  and  $n_2$  = number of observations on which  $X_1$  and  $X_2$  are based.

## PRINCIPLES OF EXPERIMENTAL DESIGNS

Series of fundamental and general factors in experimental designs is described below.

### Null hypothesis

As mentioned in the introduction, the purpose of the tests is to test a hypothesis based on existing differences between materials or treatments. Generally, a so-called null hypothesis is established, which assumes that any possible differences can only be attributed to contingencies. This null hypothesis is used in combination with a test of significance as an alternative to the established hypothesis being studied.

The concept of null hypothesis is very important in experimental designs. When we set up the test, we know some factors that produce differences between the units of the test, but there will always be differences not attributable to specific factors. To use the null hypothesis as an alternative hypothesis, there must be random distribution of causes of variation that cannot be attributed to specific factors.

### Purpose of the test

It is important to define the purpose of the test. For example, the purpose could be the study of a series of consignments of seed for subsequent selection of the best consignments of seed for further genetic improvement. In many situations the test are multi-factorial, and in such situations it is essential that the purpose be formulated before the design is chosen. For example, it would be desirable to know whether the purpose is the study of one or more of the principal factors of the test, or whether it is rather an estimate of a specific interaction.

It is also important to formulate the field of validity to which the results will be applied.

### Experimental errors

Experimental errors were described by Fischer (1951) as the lack of uniform gains in plots which had, on the whole, received the same treatment. The experimental errors that occur in nursery and field tests are, in the first place, caused by differences in soil conditions. Previously attempts were made to reduce this error by holding tests under homogeneous soil conditions using an improved experimental technique. However, experimental error cannot be completely eliminated, not even under apparently identical conditions. Instead, attempts are made to measure the error, so that the uncertainty affecting the conclusions drawn from the data material can be estimated. This then determines the selection of an experimental design in a given situation. A good experiment is described by LeClerc (1967) as an experiment that estimates the magnitude of uncontrolled experimental error.

Fischer (1931) formulated the following three decisive principles for obtaining exact data - principles which form the basis of the experimental design to be established and of the subsequent statistical analysis:

Repetitions. There are usually two possible ways of reducing error in the estimate of an effect. One consists in improving the experimental technique, for example, by using more precise measuring instruments and taking greater care in the collection of data, etc. The other possibility and, in many cases, the only one practicable, is to repeat the test a number of times and use the average of the results obtained. Unfortunately, the second method is not very efficient, since the error of the average is only reduced by the square of the number of repetitions. Thus the average of four repetitions will only reduce the error of one-half ( $\frac{1}{\sqrt{4}}$ ) of the error of the individual repetition. As well as reducing the error of the estimate, repetitions make it possible to estimate the uncertainty factor in the experimental results, e.g. calculating intervals of reliability. Repeated measurements in the same plot are not considered as repetitions but can only be considered as sub-samples, and the variation between them constitutes the sampling error.

Randomization. In any experimental design it is very important, according to Fischer (1926), that the different units of the experiment should be randomized. Fischer (1926) considers that "the estimate" of experimental error obtained through repetitions depends on existing differences between plots treated in the same way. An estimate of experimental error will only be valid for its purpose if, in the arrangement of the plots, we ensure that pairs of plots that have received the same treatment are neither closer together nor further apart nor in any other related way different from plots that have received different treatments".

In most cases, randomization is applied to the experimental area; however, it can also be applied to time.

In practice, randomization can be done in several different ways. In tests of limited scope, it can, for example, be done by consecutively numbered cards, which are shuffled and picked at random. Depending on the design in question, randomization can apply to the complete test or separately to individual lines, columns, etc. This is described in greater detail for individual designs. If the tests are broader in scope, randomization tables (or, where a computer is available, standard randomization programmes) can be used.

Local control. Local control means certain restrictions on the random distribution of treatments or materials in a repeated test, so that the part of total variation not applicable to comparisons of treatments or materials may be eliminated. Local control includes the arrangements of blocks and plots in the test. By arranging the blocks in such a way that the variation of, for example, soil conditions within the blocks, is minimized, while a considerable variation can be found between the blocks, an important improvement will be achieved in the precision of the test, since the variation between blocks can be calculated and eliminated when the data is analyzed.

Plot size and shape, plant spacing, etc., can often vary from one place to another, depending on the experimental area, the purpose of the test, the volume and quality of the material, and on other factors often of a practical nature. Concerning plot size and shape, there is a series of studies which illustrate optimal plot size and shape (Johnstone and Samuel, 1974). It does not seem possible to set any general standards for the arrangement of the plots, but the following points are important when choosing both plot size and shape:

- 1) An increase in plot size will produce a more reliable estimate of the plot mean. On the other hand, an increase in plot size will lead to a corresponding increase in the size of the blocks and therefore in the variation within the individual block. A greater variation within the blocks will reduce the possibilities of discovering intraplot differences, if any. Thus Wright and Freeland (1959, 1960) observed that a reduction in plot size to single tree plots led to more effective tests on pine height and diameter.
- 2) For tests of, for example, different fertilizers, fairly large plots must be used, perhaps surrounded by buffer strips to avoid any influence from adjacent parcels. The same applies to tests in which, with time, there could be competition between trees of adjacent plots.
- 3) As regards plot shape, in most cases it will be better to select square plots, thus obtaining the smallest perimeter and therefore minimal influence from adjacent parcels. However, where there are considerable systematic site variations, such as sloping land, it may be better to select oblong plots arranged in such a way that this variation is absorbed within the plots.

As mentioned above, the precision of a test can be improved primarily by increasing the number of repetitions. On the other hand, a useless increase of precision through a large number of repetitions will lead to a loss of resources in the form of plants and labour. It is therefore important to estimate, when preparing the test, the number of repetitions needed to give the required precision. For example, if it is desired that a 10 percent difference of materials show as significant at a level of significance of, for example, 5 percent, the necessary number of repetitions could be calculated via the

following formula:

$$LSD = \frac{\quad}{\sqrt{n}}$$

LSD = real difference from D

t = Student's t at the desired level of significance (5 percent) and with the same number of degrees of freedom as the experimental error (S)

S = experimental error

n = number of repetitions.

If the approximate magnitude of the experimental error is known, either from previous tests of the same kind, or on the basis of a general knowledge of the conditions, the equation could be solved with respect to n, as follows:

$$n = \frac{t^2 \cdot 2 \cdot S^2}{LSD^2}$$

#### Consideration of a practical nature

As well as considerations of a theoretical nature with regard to a test, there are often practical constraints setting up the test.

In the first place, the area available can lead to a series of limitations, which will oblige the planner to omit several blocks, repetitions or treatments, or to use a different and often less efficient design. The choice of one or another possibility will depend on factors related both to the experimental material and to the site. If, for example, there is a very small variation in soil conditions, the number of repetitions will naturally be reduced. Another possibility is to reduce the number of treatments or materials, if it is known beforehand that some are homogeneous and can perhaps be lumped together in the analyses.

In the second place, there may be problems in setting up the test at several different sites. If it is desired to apply the results more broadly, it will be necessary to set up tests at a number of sites representative of the field as a whole.

As well as these factors, it should be borne in mind that some parts of the test could be damaged or destroyed. If, for example, there is any risk of damage, a relatively sound design should be selected that could yield valuable information, even if some values are lacking.

Similarly, it is important that both the design and the methods of analysis be relatively simple, particularly when the people conducting the experimental work are not fully conversant with more complicated methods.

#### DESIGNS

With time, various different experimental models have been developed, some based on the principle of random distribution, others on that of automatic distribution of treatments or materials in the plots. A series of models is described below, which largely meet the requirements of a good experiment as described in the preceding section (Jeffers, 1960, Perarce, 1975).

##### Complete randomization

In this design there is no grouping of experimental units, and the different treatments are assigned to individual plots completely at random.

The method is very simple and flexible and can be used to advantage under the following conditions (Cox, 1958):

- 1) In very small tests where it is important to have the maximum number of degrees of freedom in the estimation of error. In a test which contains  $N$  plots and  $a$  treatments, there are  $N-a$  degrees of freedom, whereas in a test with an equal distribution of blocks, there will be  $N-a-b+1$ , where  $b$  is equal to the number of blocks in the test.
- 2) In tests where, as far as can be seen, there is no immediate reason for establishing a block design. This could be the case, for example, in laboratory tests where the environmental conditions are controlled and uniform.
- 3) In tests where an increase in precision can only be achieved through the use of a co-variable.

An example of a complete randomization design is illustrated in Figure 1.

A	B	C	C	A	B
C	B	A	B	C	A
B	A	C	B	A	C

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Figure 1. Complete randomization design with three treatments (A,B,C), each one repeated six times.

Random block design

In cases where it is hoped that there may be some form of variation in environmental conditions, complete randomization is not very practical, since the variation between plots treated in the same way, and therefore the experimental error, will be large, and precision considerably reduced.

Under such conditions, plots are usually grouped in blocks, so that each block includes all the different treatments once. With this design, variation between blocks can be eliminated by statistical analysis, reducing the experimental error and increasing the precision of the test. Random block designs are simple to establish, and Figure 2 shows an example of a test that includes four treatments and four blocks. The distribution of the treatments within each individual block must be random.

Block 1	A	B	D	C
- 2	C	B	A	D
- 3	B	A	C	D
- 4	D	C	A	B

Random block design with four treatments (A,B,C,D) and four blocks.

As mentioned above in connection with local control, blocks should be arranged in such a manner as to absorb the maximum variation between blocks, while variation should be maintained within blocks at as low a level as possible. Figure 3 shows examples of a good arrangement of blocks under the following circumstances:



1. Establishment in an area with a systematic environmental variation, such as uneven ground, near a window in a laboratory, etc.
2. Establishment in an area where there is marked variation in soil conditions; the plots should be adjoining, irrespective of their physical arrangement, in blocks within which conditions appear uniform.

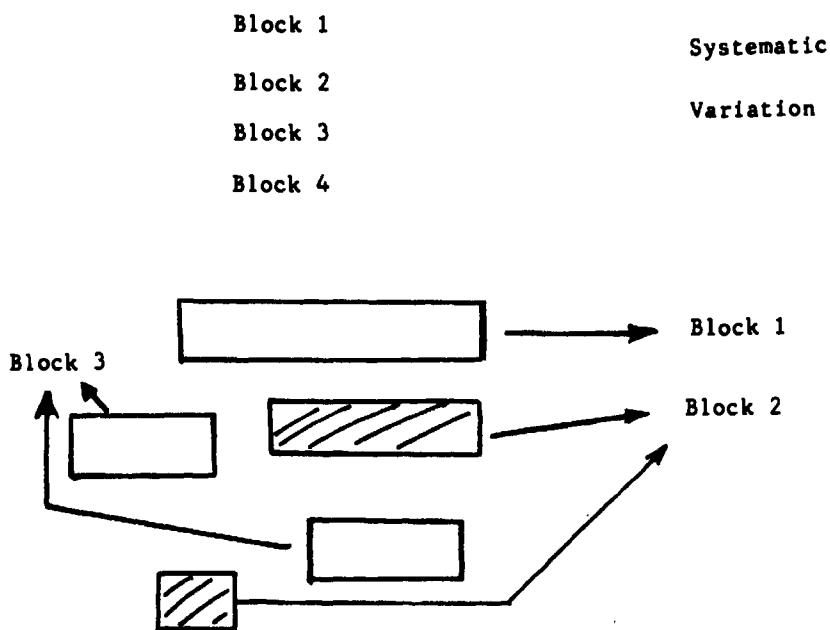


Figure 3. Arrangement of blocks in a random block design under conditions of 1) systematic site variation and, 2) considerable site variation.

The random block design is simple to establish, and analysis and interpretation of the test are also simple. At the same time, this type of test is very sound, since the analysis can be made, even if some values are missing, without any major problems (Brown et al., 1977).

In principle, this design can be used for testing a random number of treatments, but in practice problems arise to the extent to which the size of the blocks and the number of treatments are increased. With the increase in size of the blocks, the variation within the blocks is also increased, and the purpose of establishing blocks cannot be satisfactorily achieved. In such cases it may be decided to use an incomplete design (see below) or a reduction in the number of trees per plot.

#### Latin square design

In this design, plots have been double-grouped, dividing the test into lines and columns. A specific treatment is made once in each line and column, as illustrated in Figure 4. From this it may be concluded that the number of plots in the test will be equal to the square of the number of treatments.

This design is very effective where there are variations in two directions (for example, in greenhouses), but at the same time there are some restrictions with respect to the number of different treatments that can be studied. For example, ten will require the establishment of 100 parcels, and four or less will give too few degrees of freedom

to enable a valid test of the treatment to be made.

In this design there are certain restrictions on the possibilities of randomization, but partial randomization can be used, as described below.

- 1) One of the formal designs in Fisher and Yates (1957) is chosen at random.
- 2) The columns are arranged at random.
- 3) The treatments are designated at random by letters A, B etc., in the formal plan.

Column

	D	B	E	C	A
	A	D	C	B	E
Lines	B	E	D	A	C
	E	C	A	D	B
	C	A	B	E	D

Figure 4. Latin square design with five treatments (A,B,C,D,E).

Incomplete block design

These designs are called incomplete designs; that is to say, the number of treatments within a block is less than the total number of treatments which are being tested.

In lattice designs the incomplete blocks are grouped so that each group forms a complete repetition; see Figure 5.

	Rep. X				Rep. Y				Rep. Z			
	X1	X2	X3	X4	Y1	Y2	Y3	Y4	Z1	Z2	Z3	Z4
11	1	8	6	9	8	5	7	12	2	4	7	
12	3	9	5	6	11	2	4	6	10	3	1	
10	2	7	4	3	1	12	10	8	9	11	5	

Figure 5. Rectangular lattice, 3 x 4, with three repetitions (X,Y,Z).

The number of treatments in a lattice design should be the same as the square ( $4 \times 4 = 16$ ,  $5 \times 5 = 25$  etc.) or the product, according to the following formula:  $k(k+1)$  ( $3 \times 4 = 12$ ,  $4 \times 5 = 20$ , etc.). These two types are called square lattice design and rectangular lattice design, respectively. In each case  $k$  plots (3,4,5, etc.) are arranged within each block and  $k$  square or  $(k+1)$  (rectangular) blocks within each repetition. A completely balanced square design will require  $k+1$  repetitions.

It is not possible to establish completely balanced designs for  $k^2 = 36$ , 100 or 144, for rectangular designs.

In establishing a lattice design randomization will follow these rules:

- 1) Use as point of departure a formal design, as illustrated, for example, by Cochran and Cox (1957). Choose at random the number of repetitions desired

- 2) Randomize the order of succession of the repetitions.
- 3) Randomize the order of succession of the incomplete blocks within each repetition.
- 4) Randomize the plots within each block.
- 5) Assign at random different treatments to the numbers of treatment in the formal plan.

Experimental layouts in the field have the same requirements as those described for random block designs, i.e., that the blocks should be so placed that a variation in the experimental area is absorbed as an inter-block variation, while the individual blocks are as homogeneous as possible.

The lattice design is useful, and at least as exact as a random block design, with the same number of repetitions. However, the statistical calculations involved are relatively complicated; it could be difficult, especially in the case of missing values, to make a satisfactory analysis.

Nevertheless, the lattice design has the great advantage that it can always be analyzed and interpreted as an ordinary random block design.

#### Split plot design

A split plot design is a special factorial design, inasmuch as it includes two degrees of repetitions. A set of factors is linked to the larger plots, while the other set or sets of factors are linked to plots within each one of the larger plots. In other words, the larger plots are sub-divided into a number of sub-plots; see Figure 6.

As there are fewer plots than sub-plots, the factors linked to the larger plots and the sub-plots respectively will be tested with different degrees of precision. It is therefore an advantage to use this design in situations in which one of the sets of factors is of special interest, or in situations in which a specific treatment will require a relatively large area (for example, in fertilizer trials).

The larger plots can be arranged, for example, in random block designs, Latin square designs or corresponding designs. The allocation of sub-parcels must be random.

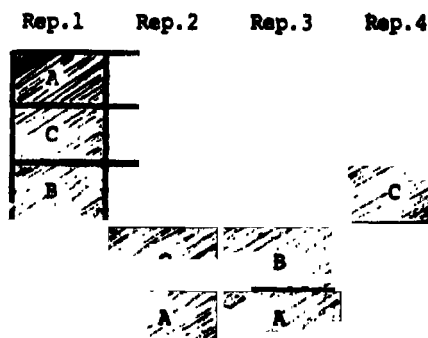


Figure 6 Design of split plots with two larger plots within each repetition (indicated by shading or no shading) and three sub-plots within each larger plot.

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STATISTICAL INTERPRETATION OF TEST RESULTS

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## INTRODUCTION

It is important when preparing a test to define the answers one hopes the test will provide, and the methods of analysis one plans to apply in appraising the results of the test. Thus, the possibilities of drawing sound conclusions from a test will depend to a considerable extent on whether or not the test is properly planned. In other words, one requisite for a good test will be clear formulation of the purpose of the test, the use of a design that can give the required answers, and careful control of the preparation of the test.

Using statistical analysis methods, tree breeder can make a statistical interpretation of the test. A knowledge of the experimental design of the material and the treatments sampled, as well as of the statistical results, are usually sufficient basis for a later statistical interpretation of the results.

Some general aspects of statistical interpretation are described below, giving examples of the most widely used statistical methods. Genetic interpretation will be mentioned only briefly, since this question is discussed in greater detail in another paper.

## FIXED AND RANDOM EFFECT MODELS

In making an analysis of tests, it is essential to define the statistical model to be used. A distinction is made between so-called "random effect" and "fixed effect" part (sample) chosen at random from the total of possible treatments. The test results are applicable to all treatments represented by the treatments sampled.

In a fixed effects model, the purpose is to study a specific set of treatments in such a way that the test results are not applicable to a group of treatments greater than those in the test.

As well as the models mentioned above, there are also mixed models, in which one or more treatments are considered random, while others are considered fixed.

It is important to define the type of model to be used in each individual case, since both the test of the treatments and the computing of the variability components will depend on this. Also, the final conclusions and the scope of the test will naturally depend on these basic considerations.

However, very often it can be difficult to decide if the effects of a test should be considered random or fixed, and it is difficult to establish univocal standards in this respect. The problems have been thoroughly discussed by Kempthorne (1975), who also gives examples of how the two different approaches influence the variance analysis test.

## STATISTICAL SIGNIFICANCE

The point of departure for the concept of significance is the establishment of a null hypothesis, and possibly of an alternative hypothesis, on the test material. Roughly speaking, the null hypothesis is that hypothesis which, as problems appear, it is neither natural nor advisable to reject, unless observations indicate very clearly that there are other possibilities.

Significance tests are used to decide whether results obtained from a test are in conformity with the established hypothesis. These are tests to check whether the results deviate significantly from the results anticipated under the null hypothesis.

A test size is calculated on the basis of the trial and its theoretical distribution under the null hypothesis is known. If the calculated size of the test is very unlikely under the theoretical distribution, there is reason to reject the established null hypothesis. However, the test of significance is not univocal, since the random variability of the results of the test can mean that some results, through the random effect, deviate significantly from the results anticipated under the established null hypothesis.

The principles related to significance tests are illustrated in Figure 1.

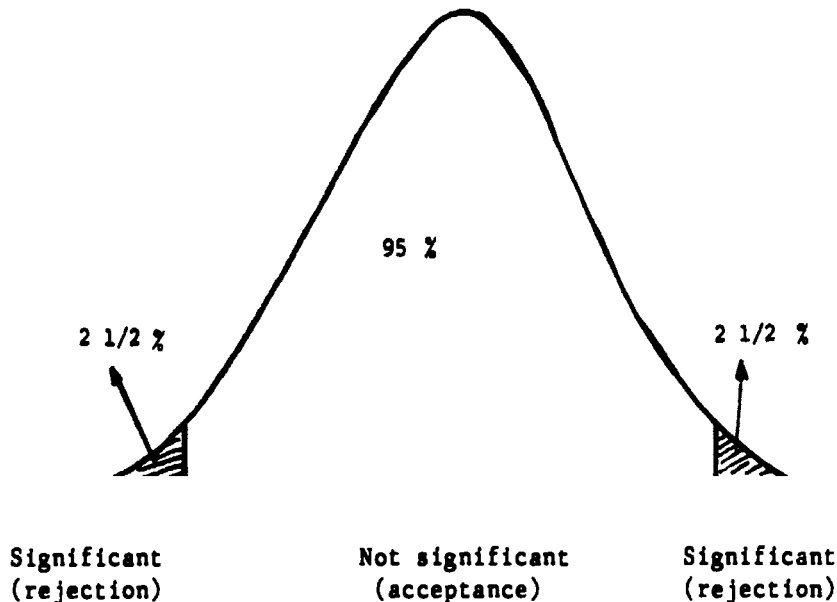


Figure 1 Distribution of the size of the test, if the null hypothesis is genuine. The figure also illustrates a bilateral test at the 5 percent level.

However, on the basis of statistical theory, it is possible to calculate the probability that a specific deviation will occur at random. Significance tests are therefore made at different levels of significance, indicating the probability that the deviation could have occurred at random. Instead of merely indicating that the results deviate significantly from the null hypothesis, it is indicated that the deviations are significant at the 5 percent level.

Finding significance, for example, at the 5 percent level, implies that there will continue to be a 5 percent probability that the deviation encountered is the result of contingencies. For this reason, if a test of significance at the 5 percent level is used to reject the established null hypothesis, there is a 5 percent probability that this hypothesis has been erroneously rejected, whereas there is only a 1 percent probability that the rejection of the null hypothesis is erroneous if the deviation is significant at the 1 percent level.

A significance test is often considered as an automatic norm related to the "acceptance" or rejection of the null hypothesis. As mentioned above, a significance test can never reject with 100 percent certainty a hypothesis, and therefore, the tree breeder should take these limitations into account, attempting in each situation to supplement the information from the significance test with information on the volume of data material, the experience gained from relevant tests, etc. (Brown et al., 1977).

### TESTS

In the previous paragraph mention was made of the principles governing significance tests. We give below a brief description of three tests frequently used, which include a fairly large number of the most important methods of analysis mentioned in the present article.

Chi squared test

Chi squared is shown by the following formula:

$$\text{Chi}_f^2 = \frac{(o_1 - e_1)^2}{e_1} + \frac{(o_2 - e_2)^2}{e_2} + \dots + \frac{(o_n - e_n)^2}{e_n}$$

$o_1 - o_n$  = frequencies observed

$e_1 - e_n$  = frequencies expected

$f$  = number of degrees of freedom

The chi squared test is used to test whether the frequencies observed are in conformity with the established expected frequencies (the null hypothesis). The values, calculated in accordance with the above formula, are adjusted to chi-squared distribution, so they can be tested via theoretical chi squared distribution.

The so-called "t" test is used to evaluate whether the differences between two means can be considered statistically significant at the given level of probability.

The size of t is calculated according to the following formula:

$$t_f = \frac{\bar{x}_1 - \bar{x}_2}{S \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad \text{where}$$

$\bar{x}_1$  and  $\bar{x}_2$  = estimates of means

$S$  = standard deviations

$n_1$  and  $n_2$  = number of observations forming the basis of  $\bar{x}_1$  and  $\bar{x}_2$

$f$  = number of degrees of freedom ( $(n_1 - 1)(n_2 - 1)$ )

The calculated value is adjusted to the t distribution, which can then be tested via the theoretical distribution of Student's t.

F test

The F test is used to test the homogeneity of two variances. The value of F is calculated according to the following formula:

$$F_{f_1, f_2} = \frac{S_1^2}{S_2^2} \quad \text{where}$$

$S_1^2$  and  $S_2^2$  = variances (mean squares)

$f_1$  and  $f_2$  = number of degrees of freedom for  $S_1^2$  and  $S_2^2$

The test is based on the so-called F distribution (variance ratio distribution).



## PRELIMINARY INVESTIGATIONS

Before starting the statistical analysis itself, and interpretation of the results of tests, certain preliminary investigations should be made, partly to detect faults or direct errors in the data material, and partly to verify that the requisites necessary for implementation of statistical analysis have been fulfilled.

### Outliers and missing values

In a first study of the data material it should be checked if there are values that deviate considerably from other data (outliers) and that should be assumed liable to error. Such investigations can easily be made, for example by tracing each datum in a diagram, thus localizing and studying in more detail values which deviate markedly, if any. If there are large quantities of data and a central data processor is available, it might be desirable to use an automatic tracing programme, which is becoming standard equipment in all data processing centres.

Another possibility is to calculate estimates of the means (for example, means of plots) and revise all values which deviate by, say, more than three times the standard deviation from the mean total of the test. Since this involves a fairly large quantity of data, the calculations take a long time, and therefore it is easier to data process them.

As well as making the above-mentioned tests of individual values, a check should be made to see whether there are any missing values, and generally, whether the number of observations per test unit is in conformity with the test plan.

In a simple design like complete randomization, it does not matter, for variance analysis, if there are one or several missing values, apart from the fact that this will reduce the number of degrees of freedom for test error. In other designs, it may be necessary to replace missing values by estimated values, in order to complete the analysis. These estimates, related to different designs, have been demonstrated by Freese (1970). Apart from reducing the number of degrees of freedom, missing values can be a problem in interpretation of results, especially in fairly complicated designs.

### Tests of requisites

Most of the usual methods of analysis require that certain requisites be fulfilled with regard to data material. Tests of three essential requisites (normality, homogeneity of variance and additivity) are described below.

#### Normality test

In view of the fact that many statistical methods are based on the assumption that data material is adjusted to normal distribution, it is often useful to have a method for the study of this normalcy.

A chi squared test can be used to test for normalcy, showing whether the distribution of the data material can be expected to match normal distribution. Snedecor and Cochran (1967) give a detailed explanation of the procedure for the test.

The test mentioned can only show whether there is conformity with normal distribution. If not, special tests can be used to determine Skewness and Kurtosis, where these exist (Snedecor and Cochran, 1967).

### Homogeneity of variance tests

As mentioned above, the F test can be used to test the homogeneity of two variances. However, if several variances are involved, Bartlett's test (for the homogeneity of a set of variances) can be used. The test has been explained in detail by Snedecor and Cochran (1967).

Variance homogeneity is one requisite for the t test. It is also a requisite for a correct F test in variance analyses.

### Additivity test

In the statistical models established later in the present article, it is assumed that the individual factors of the model are additive, that is to say, that the result obtained on one plot or test can be expressed as the sum of the effects of the model, for example, effects of treatments or blocks and residual effects. Turkey's test, described by Snedecor and Cochran (1967), can be used to ascertain additivity.

However, preliminary study of data material will often reveal any lack of additivity, since in many cases non-additivity will only be revealed by tracing the data material.

### Transformation

If the tests mentioned above show that one or more requisites have not been fulfilled, it may be necessary to make a transformation of the data material before completing the statistical analysis. The following are the three most frequently used forms of transformation:

1. Arc sine transformation. This transformation can be used for the values of binomial distribution expressed in percentages in the field from 1 to 100. This type of data occurs frequently at the nursery stage, when survival, frost damage, and other such forecasts are made.
2. Square root transformation. This transformation can be used in cases where variance depends on the mean, for example, in estimating the number of branches by branch crowns (Burley and Wood, 1976).
3. Logarithmic transformation. This transformation can be used in situations where the variance is proportionate to the mean square. According to Burley and Wood (1976), as in forecasting flowering rates, using a logarithmic scale (1 = 1-5 flowers, 2 = 6-15 flowers, 3 = 16-35 flowers, etc.).

A detailed description of the different transformations and their applications is given by Snedecor and Cochran (1967).

Apart from the arc sine transformation of values expressed in percentages, in most cases it is not necessary, if the analyses are made on the basis of plot means, to make transformations of data. However, the individual researcher should study and evaluate in each situation the consequences that the missing requisites, if any, could have for the test conclusions.

### Contingency tables

In many situations, tree breeders face the problem of having to compare proportions from two or more independent samples.

Contingency tables are frequently used, especially in relation to qualitative (Mendelian) genetics, to determine whether a specific variation with respect to a qualitative property is in conformity with what was expected.

However, contingency tables can also be of interest in forest tree improvement, where quantitative properties are studied in the first place; the tables can be used in preliminary investigation of the material, or studies of the different treatments of the material.

As an example, a 3 x 2 table is shown below containing results of an investigation of two types of planting machines (I and II). The plants are grouped as A = undamaged; B = damaged, C = felled.

		A	B	C	Σ
Machine I	observed	117	31	7	155
	expected	(116.1)	(28.6)	(10.3)	
Machine II	observed	131	30	15	176
	expected	(131.9)	(32.4)	(11.7)	
Σ		248	61	22	331

On the basis of the selected grouping (A,B,C,) it can be ascertained, through a chi squared test, whether a difference is expected between the two types of machine. The number expected in each square of the table is calculated beforehand as follows:

$$\text{Expected number of undamaged plants (A) for machine I} = \frac{155 \times 248}{331} = 116.1$$

$$\text{Expected number of damaged plants (B) for machine I} = \frac{155 \times 61}{331} = 28.6, \text{ etc.}$$

Chi squared is calculated as follows:

$$\frac{(117 - 116.1)^2}{116.1} + \frac{(31 - 28.6)^2}{28.6} + \dots + \frac{(15 - 11.7)^2}{11.7} = 2.38$$

It may be seen from a chi squared table with two degrees of freedom ( (3-1)(2-1) =2) that the value of 2.38 given there provides no grounds for assuming that the two machines in the tests are different.

#### VARIANCE ANALYSIS

Variance analysis is the most widely used method of interpreting the results of tests. Variance analysis gives the following information:

- 1) estimates of the relative size or significance of each identifiable source of variation;
- 2) estimated differences among the materials, the treatments and the sites used in the test;
- 3) indications of the precision of the estimated differences among the estimated means, through their standard error and their limits of reliability;
- 4) tests of statistical significance of variances and differences.

The exact form of the variance analysis will depend both on the test design and on the mathematical model used as a basis. Also, both the significance test and the later interpretation of the results will depend on whether the individual variables are considered as fixed or random.

The essential part of all analyses is, however, to estimate variances linked to each source of variation (e.g. material, site, residual).

Examples of analyses of five different designs are shown below. (Sheffé, 1959, Searle, 1971).

Complete randomization

In this design there is only one source of systematic variation which can be identified, i.e., among the treatments. A systematic variation that may exist on the site cannot be segregated, unless it is contained in the variation from plot to plot.

The mathematical model takes the following form:

$$x_{ij} = \mu + \alpha_i + \epsilon_{ij} \quad \text{Where}$$

- $x_{ij}$  = individual observation
- $\mu$  = mean total
- $\alpha_i$  = effect of the  $i$ th treatment
- $\epsilon_{ij}$  = residual effect

A summary of variance analysis table is shown below.

Source of variation	df	cs	F
Between treatments	$a - 1$	$\sum_i J_i (x_{i.} - x_{..})^2$	↑
Residual	$N - a$	$\sum_i \sum_j (x_{ij} - x_{i.})^2$	
Total	$N - 1$	$\sum_i \sum_j (x_{ij} - x_{..})^2$	

- $N$  total number of plots in the test
- $a$  number of treatments
- $J_i$  number of plots per  $i$ th treatment
- $x_{ij}$  individual observation
- $x_{i.}$  estimated mean of  $i$ th treatment
- $x_{..}$  mean total

The F test appears in the last column of the analysis table. If the F test reveals significant differences between the treatments or the materials, the real difference of D can be calculated, and the limits of reliability can also be calculated for the individual differences among the estimated means.

The real difference of D (LSD) is calculated in accordance with the following formula.

$$LSD = t \cdot \frac{\sqrt{S}}{\sqrt{n}} \quad \text{where}$$

- $t$  = the value Student's  $t$  at a given level of probability.
- $S$  = test errors (residual MS (mean square) of the table)
- $n$  = number of plots which are the basis of the values compared.

The limits of reliability for the difference among means may be calculated in accordance with the following formula:

$$D = (a_1 - a_2) \pm t.S \sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \quad \text{where}$$

$a_1$  and  $a_2$  = estimate of means of  $a_1$  and  $a_2$  treatments

$t$  = the value of Student's  $t$  at a given level of probability

$S$  = test errors (residual MS of the table)

$n_1$  and  $n_2$  = number of observations forming the basis of each of the estimates of the means  $a_1$  and  $a_2$ .

### Random block design

Variance analysis of a random block design is not much more difficult than the complete randomization test. There are two systematic sources of variation which can be identified; these are blocks and treatments.

The mathematical model takes the following form:

$$X_{ij} = \mu + \alpha_i + \beta_j + \epsilon_{ij} \quad \text{where}$$

$X_{ij}$  individual observation

$\mu$  = mean total

$\alpha_i$  = effect of the treatment  $i^{\text{th}}$  ( $i = 1, \dots, I$ )

$\beta_j$  = effect of the block  $j^{\text{th}}$  ( $j = 1, \dots, J$ )

$\epsilon_{ij}$  = residual effect

A summary variance analysis table is shown below.

Source of variation	df	cs	F
Treatments	$I-1$	$J \sum_1^I (x_{i.} - x_{..})^2$	↑ ↓
Blocks	$J-1$	$I \sum_1^J (x_{.j} - x_{..})^2$	
Residual	$(I-1)(J-1)$	$\sum_1^I \sum_1^J (x_{ij} - x_{i.} - x_{.j} + x_{..})^2$	
Total	$IJ-1$	$\sum_1^I \sum_1^J (x_{ij} - x_{..})^2$	

In cases where, at a given level of probability, there are significant differences among treatments, the real difference of  $D$  can be calculated and limits of reliability established for the differences.

The test appears in the last column of the variance analysis table.

Latin square design

There are three identifiable sources of variation, which are lines, columns and treatments, and it should be noted that the number of lines, columns and treatments is equal. Through this design it is possible to isolate in the calculations variations occurring both between lines and between columns, that is to say, in comparison with the random block design, a further division has been made of the systematic site variations. As may be seen from the variance analysis table below, the fairly strict design means that the number of degrees of freedom for the variance of errors is reduced in comparison with the random block design.

The mathematical model takes the following form:

$$x_{ijk} = \mu + \alpha_i + \beta_j + \lambda_k + \epsilon_{ijk} \quad \text{where}$$

$x_{ijk}$  = individual observation

$\mu$  = mean total

$\alpha_i$  = effect of the line  $i^{\text{th}}$  ( $i = 1, \dots, I$ )

$\beta_j$  = effect of the column  $j^{\text{th}}$  ( $j = 1, \dots, I$ )

$\lambda_k$  = effect of the treatment  $k^{\text{th}}$  ( $k = 1, \dots, I$ )

$\epsilon_{ijk}$  = residual effect

A summary of variance analysis table is shown below.

Source of variation	df	cs	F
Lines	(I-1)	$I \sum_i (x_{i..} - x_{...})^2$	↑ ↓ ↓ ↓
Columns	(I-1)	$I \sum_j (x_{.j.} - x_{...})^2$	
Treatments	(I-1)	$I \sum_k (x_{..k} - x_{...})^2$	
Residual	(I-1)(I-2)	$\sum_{ijk} (x_{ijk} - x_{i..} - x_{.j.} - x_{..k} + 2x_{...})^2$	
Total	$I^2 - 1$	$\sum_{ijk} (x_{ijk} - x_{...})^2$	

\* Since the values represented by i, j and k are aggregated, all possible combinations will not be found.

The F test appears in the table; the real difference of D and the limits of reliability are calculated as usual through standard error.

Incomplete block design

Incomplete block designs, particularly lattice designs, are relatively difficult to analyze. Since they are used for fairly large and complicated tests, it is best to use electronic data processing.

A brief description is given below of a general "intrablock" analysis, which can also be used for different lattice designs.

The mathematical model takes the following form:

- $X_{ij} = \mu + \alpha_i + \beta_j + \epsilon_{ij}$  where
- $x_{ij}$  = individual observation
- $\mu$  = mean total
- $\alpha_i$  = effect of the block  $i^{\text{th}}$
- $\beta_j$  = effect of the treatment  $j^{\text{th}}$
- $\epsilon_{ij}$  = residual effect
- $N = I \cdot K$ , where  $K$  = number of plots per block

A summary of variance analysis table is shown below.

Source of variation	df	CS	F
Blocks	I-1	$K \sum (x_{i.} - x_{..})^2$	1
Treatments (corrected)	J-1	$K \sum Q_j^2 / \lambda I$	
Residual	N-I-J+1	(difference)	
Total	N-1	$\sum \sum (x_{ij} - x_{..})^2$	

The following comments may be made on the summary:

The corrected sum (CS) of treatment is calculated in accordance with the following formula:

$$k \cdot \sum_j Q_j^2 / \lambda \cdot I \quad \text{where}$$

$\lambda$  = the number of times that two treatments occur in the same block

$$Q_j = T_j - \frac{1}{k} \cdot \sum_i n_{ij} B_i \quad \text{where}$$

$T_j$  = the sum of all the observations included in treatment  $j$

$B_i$  = the sum of all the observations in block  $i$

$n_{ij} = 1$ , if the treatment occurs in block  $i$ ,  $\sigma = 0$ .

The F test and the calculations of the real difference of D and the limits of reliability are made as usual.

In lattice designs, instead of the "intra-block" analysis described above, an "interblocks" analysis can be made, also using a variation that can occur between the blocks. The "interblocks" analysis is described in detail by Cochran and Cox (1957); Burley and Wood (1976) explain the method of analysis in connection with provenance tests.

The lattice design analysis will be considerably more complicated if there are missing values, and in such situations it may be necessary to make the analysis as in random block designs, in this case omitting the division into incomplete blocks.

Split plot design

Split plot designs are composed both of main plots and of sub-plots. The main plots can be arranged in different designs, but in the example given below it is assumed that the main plots are grouped in blocks and arranged in a random block design.

The mathematical model takes the following form:

$$X_{ijk} = \mu + \alpha_i + \beta_j + \lambda_{ij} + \psi_k + \xi_{ik} + \epsilon_{ijk} \quad \text{where}$$

$X_{ijk}$  = individual observation

$\mu$  = mean total

$\alpha_i$  = effect of treatment  $i^{\text{th}}$  ( $i = 1, \dots, I$ )

$\beta_j$  = effect of block  $j^{\text{th}}$  ( $j = 1, \dots, J$ )

$\lambda_{ij}$  = error (A) ( $k = 1, \dots, K$ )

$\psi_k$  = effect of treatment  $k^{\text{th}}$

$\xi_{ik}$  = interaction between A and B

$\epsilon_{ijk}$  = residual effect (B error)

The variance analysis takes the following form:

Source of variation	df	CS	F
Treatments (A)	I-1	$JK \sum_i (x_{i..} - x_{...})^2$	↑
Blocks	J-1	$IK \sum_j (x_{.j.} - x_{...})^2$	
Error (A)	(I-1)(J-1)	$K \sum_{ij} (x_{ij.} - x_{i..} - x_{.j.} + x_{...})^2$	↓
Treatments (B)	K-1	$IJ \sum_k (x_{..k} - x_{...})^2$	↑
(A) x (B)	(I-1)(K-1)	$J \sum_{ik} (x_{.ik} - x_{.i.} - x_{..k} + x_{...})^2$	
Residual (Error (B))	J(I-1)(K-1)	difference	↓
Total	IJ(K-1)	$\sum_{ijk} (x_{ijk} - x_{...})^2$	



As may be seen from the summary, two variances of errors are used to test the effects linked to the main plots and those linked to the sub-plots, respectively.

The real difference of D and the limits of reliability are calculated in the same way, using different standard errors for main plots and sub-plots respectively.

The split plot design is useful in those cases where it is desired to achieve, for the effects linked to the sub-plots, greater precision than that desired for those linked to the main plots.

### CORRELATION ANALYSIS

The simple correlation coefficient is a measure of the degree of linear association between two variables. This can often be useful in forest tree improvement, or for investigation of the correlation among properties within the same individual, or for the investigation of the correlation of a property among different and often related individuals.

The simple correlation coefficient ( $r$ ) is estimated as follows:

$$\frac{SP_{xy}}{\sqrt{SC_x} \sqrt{SC_y}}$$

where SP indicates the sum of the products of the corresponding values of x and y, and  $SC_x$  and  $SC_y$  indicate the sums of the squares of the deviations for the values of x and y respectively.

The value of  $r$  can vary between -1 and +1. The values of -1 and +1 respectively indicate complete negative or positive correlations, that is to say, all the points included in the bidimensional diagram are found in a straight line with a downwards (negative correlation) or upwards (positive correlation) skew.

The statistical significance of a coefficient of correlation at a given level of probability can be determined as follows:

The null hypothesis: the coefficient of correlation has the hypothetical value of  $\rho = 0$ .

$$t = \frac{r}{\sqrt{(1-r^2)}}$$

The equation is used to indicate the size of the test.

If a t table is consulted and the size of the t test with (n-2) degrees of freedom turns out to be significant at a given level of probability, the established null hypothesis may be rejected.

### REGRESSION ANALYSIS

The relation between the specific values of a variable and the mean of all the Correlative values of another variable that depends on the first, is indicated as a regression of the second variable over the first.

Regressions have the following general form:

$$y_1 = a + \beta x_1 + \varepsilon_1 \quad \text{where}$$

y = dependent variable

a = coefficient

$\beta$  = coefficient (coefficient of skew)

x = independent variable

$\varepsilon$  = residual effect

Coefficients  $a$  and  $\beta$  are estimated as

$$\frac{SP_{xy}}{SC_x} = a + b x$$

The significance of linear regression can be tested through variance analysis, as shown in the following table.

Source of variation	df	CS	F
Regression	1	b. $SP_{xy}$	↑ ↓
Residual	1-2	(difference)	
Total	1-1	$\sum_1 (y_1 - y.)^2$	

In many situations it will be necessary to use a more complicated model, including several independent variables (multiple regression), and in which may also be found terms of squares or products or different variables.

#### COVARIANCE ANALYSIS

As in variance analysis, there are a series of different models for covariance analysis. We will give only one example: a model of complete randomization tests, in which, as well as the single identifiable systematic effect, an additional datum has been registered in relation to each measurement.

In covariance analyses an adjustment is made of the values of plots through a covariable. In most cases these are adjustments compensating for existing site differences, but they can also be adjustments to compensate for the initial value of the material, etc.

The mathematical model takes the following form:

$$y_{1j} = \mu + a_1 + \beta(x_{1j} - x.) + \varepsilon_{1j} \quad \text{where}$$

- $y_{ij}$  individual observation
- $\bar{y}$  mean total
- $\tau_i$  effect of the treatment  $i^{\text{th}}$  ( $i = 1, \dots, I$ )
- $\beta$  coefficient
- $x_{ij}$  covariable
- $\epsilon_{ij}$  residual effect
- $N$  total number of plots in test

A summary covariance analysis table is shown below:

Source of variation	df	SC	F
Treatments	I-1	$SC_{\text{treat.}} = SC_{\text{tot.}} - SC_{\text{res.}}$	$\updownarrow$
x (covariance)	1	$SC_{\text{Cov}} = \frac{(\sum_{ij} (x_{ij} - \bar{x}_{i.})(y_{ij} - \bar{y}_{i.}))^2}{\sum_{ij} (x_{ij} - \bar{x}_{i.})^2}$	
Residual	N-I-1	$SC_{\text{res.}} = \sum_{ij} (y_{ij} - \bar{y}_{i.})^2 - SC_{\text{Cov}}$	
Total	N-1	$SC_{\text{tot}} = \sum_{ij} (y_{ij} - \bar{y}_{..})^2$	

By including the covariable in the analysis, it is possible, as is shown in the table, to calculate a corrected MS error and MS treatment, after which an F test can be made in the usual way.

#### VARIABILITY COMPONENTS

If in an analysis there are random variables, the estimated MS can be disaggregated in one or more variability components, each one relating to an identifiable source of variation. The following table shows the distribution of expected MS in a random block design.

Source of variation	df	Expected MS (E(MS))
Treatments	I-1	$\sigma_e + J \cdot \sigma_{\text{treatment}}$
Blocks	J-1	$\sigma_e + I \cdot \sigma_{\text{block}}$
Residual	(I-1)(J-1)	$\sigma_e$
Total	IJ-1	

$\sigma_{\text{treatment}}$  = the treatments component  
 $\sigma_{\text{block}}$  = the block component  
 $\sigma_e$  = the residual component

The individual variability components can be calculated from the MS values estimated in the analysis.

The most important application of variability components in relation to forest tree improvement is the estimation of genetic parameters within populations, also for forecasting the genetic gains that could be achieved by selection.

The present article will not discuss in detail the different genetic parameters, since this subject is covered in the article on quantitative genetics.

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Putting him on the spot with some difficult questions....  
(Experimental plantation of Bombacopsis quinata)

SPECIES AND PROVENANCE TRIALS 1/

R.L. Willan

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1/ -Most of the following lecture has been extracted from "Manual sobre investigaciones de especies y procedencias con referencia especial a los trópicos" (Burley and Wood 1979).

## OBJECTIVES

As described in the lecture on tree improvement in relation to national forest policy, the objectives of afforestation and hence of species and provenance trials, should be stated precisely in advance, in terms of closely defined materials or amenities to be produced. The produce required may have a variety of possible uses, e.g. a sawlog crop from which thinnings can provide poles and firewood, or it may have a very precise use, e.g. a high quality veneer for export. Alternatively, what is desired may be an amenity e.g. decoration, shade, shelter or soil improvement.

## THE NEED FOR SPECIES AND PROVENANCE TRIALS

Trials are needed whenever adequate information is lacking, either on the requirements of the species, or on the characteristics of the site, or both. In such cases embarking on afforestation schemes without a carefully planned and executed experimental programme has often led to costly failures.

The choice of species and provenances to use for afforestation involves the extrapolation of information from elsewhere. Climatic and ecological matching of a new site and the original habitat of a species is rarely enough since it cannot reveal the adaptability of the species to new conditions or its ability to grow satisfactorily on a range of sites. When information is lacking, the best way to acquire it is through trials of a number of species in small plots on representative locations within the area of the proposed afforestation project. Provided the locations are carefully selected to sample the range of planting sites and are properly looked after, extrapolation of performance from small plots to the whole afforestation area should involve far less risk than imprecise comparisons, based on inadequate data, between widely separated regions of the world.

The advisability of species and provenance trials is now generally accepted, but the need for their careful planning and for high standards of maintenance and assessment has often been less appreciated. The trials themselves can be wasteful and misleading if badly planned or executed; and a proliferation of plots, if they are ill-sited, ill-tended and ill-protected, is no substitute for a small, wisely planned programme which is tailored to the staff and financial resources available. The objective is to derive the greatest possible information from a given cost or, put the other way, to obtain the desired information at the lowest possible cost.

For species with naturally wide geographical or ecological ranges, provenance testing is essential. It is easy to be misled in the comparison of species for afforestation if the total range of intra-specific variation is not known.

## THE TYPES, SEQUENCE AND TIME SCALE

The ultimate phase is, of course, the complete afforestation project where the source populations are reduced to one or two provenances of one or a few species and where the annual planting area is reckoned in hundreds or thousands of hectares. It must be recognized that there is no standard procedure or time schedule for passage through successive stages of testing; nor is there always a need to use every stage. However, the following distinct phases are commonly encountered.

The species elimination phase, the mass screening of a large number of possible species in small plots for a short period (1/10-1/5 rotation) to determine survival and promise of reasonable growth. The species testing phase is assigned for the critical testing or comparison of a reduced number of promising species in larger plots for longer periods ( $\frac{1}{4}$ - $\frac{1}{2}$  rotation). The species proving phase is designed to confirm, under normal plantation conditions, the superiority of a few probable species. Three similar stages apply to provenance testing for species with a wide natural distribution, a range-wide provenance sampling phase, a restricted provenance sampling phase and a provenance proving phase. Since these phases usually apply to species considered likely or promising, plot size and time-scale may exceed those utilized for the comparable phases of species trials.

### CONTROL OF TRIALS AND THEIR FOLLOW-UP

The detailed planning and conduct of species and provenance trials is the responsibility of the silviculturist or research officer. However, the head of the forest service, or the policy-maker to whom the silviculturist is responsible must be capable of evaluating the research, and of deciding whether it will answer the right questions, with efficiency, and within the resources available.

To facilitate control the research staff must be required to produce and follow a project control plan for each species and provenance trial. This plan must be checked and approved before the project is initiated. After any amendments are made the forest director should signify approval in writing; this imposes on him the moral obligation to do his best to ensure continued finance and staff for the project. If there is no promise of continuity in this respect, there is little point in starting the programme. Once a project is initiated, however, regular reports should be required (usually annually).

A pilot planting project may frequently form an essential intermediate step between species/provenance trials and large scale afforestation. It will enable the forester to determine optimum cultural and managerial techniques and to make the vital decision on whether or not to proceed with the complete afforestation programme.

It must be remembered that in some cases the results of species and provenance trials are applied to the second, rather than the first, rotation. For example, many countries are already planting large areas of Pinus caribaea var. hondurensis Barr. & Golf., mainly derived from the Mountain Pine Ridge, Belize. Indeed some countries have initiated selective breeding programmes based on this material. Nevertheless other provenances may be better or contain some valuable genes, and these countries should carry out comparative trials to identify such provenances for later planting. There is a danger that foresters who have a readily accessible seed source of a "satisfactory" species or provenance may feel it unnecessary to test others that could be potentially better.

### SITE ASSESSMENT

It is important to realize that each trial does not measure just the performance of a given species or provenance, but its performance on a particular site and with a particular cultural treatment. Each of these factors interacts with the other two. The recognition and mapping of the major site types in a potential afforestation area is therefore an essential preliminary to an efficient programme of species and provenance trials. It permits the eventual extrapolation of results from the trials to unplanted areas of the same site type.

It is not satisfactory to locate trials by scattering them at random throughout potential afforestation areas. Such areas are unlikely to have uniform environmental characteristics. In these circumstances the random location of trials may fail to sample a widely occurring site type.

The procedure of assessment should, therefore, be a process of progressive division and sub-division to arrive at environmental units useful for the planning and interpretation of trials.

Each unit should be a 'site' as defined by Coile (1952): -

"an area of land with characteristic combination of soil, topographic, climatic, and biotic factors".

The ultimate definitions of these sites will depend on the degree of variability encountered. However, a generalized procedure can be followed, as follows:

Classify each proposed planting area by:

- (i) Latitude - to the nearest degree. (Latitude is related to day length).
- (ii) Rainfall - according to its distribution throughout the year e.g. uniform, one dry season, two dry seasons. If the annual rainfall shows wide variation with-



in any category a secondary division according to mean annual rainfall will be necessary.

Draw the boundaries of proposed plantations on maps or aerial photomosaics, preferably using a scale of 1 : 50,000. On these maps, or a series of transparent overlays, mark the following, if known, in this sequence.

- iii) Geological boundaries, or the boundaries of generalized soil groups.
- iv) The boundaries of conspicuous geomorphic features e.g. flood plains, river basins, undulating hills, escarpments, dissected plateaus.
- v) The boundaries of major topographic categories e.g. valley bottom, slope, hill crest, plateau.

The ultimate units in the classification are, therefore topographic.

#### HOMOCLINAL COMPARISONS AND THE CHOICE OF SPECIES TO TEST

The close matching of natural habitat and site for species introduction does not eliminate the need for trials, since, however accurate the formulae used, the adaptability and plasticity of a species cannot be assessed without testing. Moreover, the natural distribution of a species may be due as much to the incidence of fire, ecological competition or man's activity, as to the measurable features of climate and soil. Many species perform strikingly better in a new environment than they do in their natural habitat - Pinus radiata and Eucalyptus saligna are excellent examples of this.

On the other hand homoclinal information gained from the performance of a species as an exotic can be of much greater value, and a review of information from other countries can often reduce the number of possible species considerably and lead to the inclusion of valuable exotic land races in provenance trials.

Most obvious non-starters - e.g. Douglas fir at low altitudes at the equator, can be eliminated from the start, but in less certain cases it may be better to allow a species to eliminate itself in trial, than to eliminate it on theoretical grounds, only to have it reconsidered later when these grounds are forgotten. On the other hand, the re-testing of species that theoretically should have done well, but did not, is often worthwhile, because improved techniques or the build-up of mycorrhizal populations may reverse earlier failures.

It is usually desirable to include a 'standard' well known species of provenance in trials, in order to have a reference point against which to judge the performance of the unknown populations.

#### PRACTICAL LIMITATIONS

The size of a programme of species and provenance trials depends upon many factors, including staffing, finance and the availability of land, not only for the trials, but also for subsequent planting on an operational scale. Security of tenure for the trial areas, and public cooperation in the protection of the trials themselves, are essential. The availability of suitably qualified staff will govern the kind of work that can be undertaken, and training programmes may be a necessary part of the project. The availability of transport may be critical in some countries.

The programme of operations must be worked out carefully in advance and costed as far as possible. The total cost must cover not only the initial expenses but also the essential maintenance of the plots throughout the duration of the experiments.

When staff or funds are limiting (and they are almost everywhere) the work needed must be limited in advance, and in some circumstances an inadequately replicated series of trials may be better than nothing. A precise estimate of species-site interaction, on the other hand, costs money and this must be budgeted for.

The need to limit the research programme to a practical size makes it essential to locate trial plots to ensure:

- (a) Representative coverage of the main site types
- (b) Easy accessibility for maintenance and assessment.

A larger number of small plots necessitates a long total perimeter, and hence more costly protection. A high degree of replication and numerous species involves meticulous labelling and supervision which may be difficult with relatively untrained field staff. The propaganda value of a set of vigorous plots within sight of a road may be considerable and, from the practical point of view, the simpler the statistical design and layout, the better.

#### PHASING AND TIME SCALES OF SPECIES TRIALS

##### Species elimination phase

**Object:** To compare the performance of a large number of different species on one or a number of sites, and to select a smaller number for more intensive trials.

**Features:** The individual species unit, or plot, is kept as small as possible.

The duration of such trials is commonly 0.1 to 0.2 x rotation age, and perhaps 20 to 40 species could be tested in the initial stages, though continued introductions of small number of species are often made over a number of years.

##### Species testing phase

**Object:** The comparison of a restricted number of promising species, based on previous experience, on sites within a broad climatic region.

**Features:** Properly designed statistical layouts are particularly important, and plots must be of a size to enable reliable assessments to be made up to, at least, the first thinning.

The duration of these trials may be about 0.5 x estimated rotation length. Between 5 and 10 species is suggested at this stage.

##### Species proving phase

**Object:** To confirm, under normal plantation conditions, the results shown by a small number of species that have shown themselves superior in earlier phases.

**Features:** Plots must be large enough to provide data on growth and yield for the full rotation, surrounds must be large enough to eliminate or minimize edge effect. In addition to 'normal' plantation methods, a range of other management techniques may need to be tested, always in statistically valid designs. It is also appropriate to investigate wood quality at this stage.

#### PHASIC AND TIME SCALES OF PROVENANCE TRIALS

The 'ideal' sequence of provenance trials follows very closely that outlined for species above. They may be described as the Range-wide provenance phase, the Restricted provenance phase and the Provenance proving phase.

##### Range-wide provenance phase

**Object:** To determine the extent and pattern of variation between provenances (populations) of promising species with wide natural variation.

**Features:** Depending on the geographical distribution and variation of the species, 10-30 provenances are suggested at this stage. It often indicates groups of promising provenances, and also areas from which large scale seed imports should be avoided.

This phase is often run concurrently with species elimination or testing. Plot size should be small but adequate for a duration of 0.25 to 0.5 x rotation age.

#### Restricted provenance phase

**Object:** To find sub-regions and ultimately provenances most suited to the sites under test.

**Features:** The differences to be detected between provenances may be relatively slight, and experimental design must take account of this. Generally, 3-5 provenances may be expected, with a duration in excess of 0.5 x estimated rotation, using plots of the appropriate size. This phase is often run concurrently with species testing and species proving phases. Local land races and other derived provenances should be included where possible.

#### Provenance proving phase

At this stage one or two provenances only will have been selected for each species, site and enduse. The procedure is the same as that described for species.

#### PLOT SIZE, SHAPE AND COMPETITION

The size of plots, as indicated above, depends on the duration of the trial and the expected growth rate of the trees.

As expense is also an important factor, it should be remembered that trials are grown to provide information, and that this may be obtained as well from small plots as from large. The single tree plot is of limited use except where a large number of species or provenances is being screened for early survival, though it is cheap in space and cost, and lends itself to a high degree of replication. Assuming an initial spacing distance of 2 to 3 metres the following numbers of trees per plot are recommended.

#### Species elimination phase

Minimum plot size: 5 tree line plot; Maximum: 25 trees (5 x 5). No surrounds.

#### Species testing phase

Plot size 16-25 trees (4 x 4 or 5 x 5) with a 1 or 2 row surround.

#### Species proving phase

Because yield estimates are important, a central plot of 100 trees (10 x 10) plus a 2 row surround may be considered a minimum.

#### Range wide provenance phase

25 tree plots, no surrounds.

#### Restricted provenance phase

25-49 tree plots, 1 or 2 row surround.

#### Provenance proving phase

100 tree plots (or more), 1 or 2 row surround.

Plots are usually square or rectangular, but may need to be elongated to fit certain site configurations.

EXPERIMENTAL DESIGN

This is covered in a separate lecture. The most commonly used design is the Randomized Complete Block. It is simple, flexible and robust, but is less suitable if there are very many species or provenances to be compared.

CULTURAL TREATMENT AND PROTECTION

'De luxe' treatment, that is measures to combat local hazards, such as intensive weeding or the use of insecticides against leaf cutting ants or termites, should be used in order to reduce as far as possible the chance of cultural methods masking the effects of other site characteristics. Generally, therefore, competing vegetation should be reduced to a minimum and the type of planting stock and method of planting should be the optimum for the area concerned.

Clear prescriptions must be included in the experimental plan on such items as the need for fencing or fertilization, time and method of planting, replacement of casualties, weeding, protection against fire and pests, pruning and thinning. At planting it is essential to ensure that plants are clearly labelled at all times and that planting is organized to prevent the confounding of species/provenance plots with individual workers whose planting skill may vary.

PRIORITIES IN FIELD ASSESSMENT

Assessment is time-consuming and expensive; therefore the characters to be assessed, and the timing of assessments should be laid down in the control plan.

The initial calibrators of the field stage are assessment of height a few weeks after planting (to allow the soil to settle) and a survival count.

The following are notes on the most important assessments.

Character	Frequency stage	Method
Health	continous	Note incidence of pests and diseases Identify pests and pathogens.
Survival	1 yr. old. Subsequently after climatic extremes, etc.	100% count. Sample count.
Mean height ( $\bar{h}$ )	Annual up to about 7 m height. Then every 2-5 years	Use measuring poles up to 7 m then by optical instruments. Accuracy: aim at 5%. 100% in initial stages, or sample.
Dominant height ( $\bar{h}_{dom}$ ) (mean height of 100 trees of largest diameter per ha)	Annual up to 7 m height. Then every 3-5 years	As above, but less time consuming. Accuracy: as above.
Mean diameter ( $\bar{d}$ ) at breast height	1.3 m from ground. Annually after crop is 2-3 m high.	Diameter tapes most convenient, or calipers. 100% sample essential Accuracy: aim at 1-2 mm.
Basal area		Obtained from measurements of d.
Stem form Branch size and angle	Start when trees are 7 m tall. Then at 3-5 year intervals.	Simple realistic systems best, using scoring, 1-7 basis.
Bark thickness	Whenever d is measured and on thinnings	Bark gauge, or bark removal on thinnings; sample 5-10% of trees.

## RECORDING SYSTEMS

A clear and accurate data recording system is essential for all experimental work. Each item of data must be clearly identified and errors in recording and transcription occur all too easily. Most commonly, data are recorded by hand on specially designed forms, and these should be simple to use and provide a permanent record. The data should be analysed as soon as possible, as the results may affect the future management of the trial.

## INTERNATIONAL COOPERATION

The transfer of forest reproduction material, throughout the world, has reached unprecedented heights during the past few decades; many countries have been trying to intensify their forest production by introducing new species of provenances (Lacaze, 1978).

At the same time, there has been an increase in organized research aimed at supplying silviculturists with objective information on the vegetative material to be selected.

An effort on this scale is inconceivable without active international cooperation. Some progress has been achieved, but much remains to be done in this field.

During the past ten years numerous projects have been put into operation, very often on the basis of international collaboration. In this connection special mention should be made of the work done by various bodies such as the IUFRO working groups on provenance seed collection of North American species, FAO, the Commonwealth Forestry Institute, the Danish FAO Forest Tree Seed Centre and the Centre Technique Forestier Tropical (France).

The number of species on which provenance trials are conducted is very high: just as examples, we can list:

- For species concerning temperature zones: Abies grandis, Picea abies, Picea sitchensis, Pinus contorta, Pseudotsuga menziesii, Larix europaea and Populus trichocarpa.
- For species concerning Mediterranean zones: Pinus halepensis, Pinus brutia, Eucalyptus camaldulensis, and Eucalyptus dalrympleana.
- For species concerning subtropical and tropical zones: Cedrela odorata, E. camaldulensis, E. deglupta, E. microtheca, E. tereticornis, E. urophylla, Pinus caribaea, P. kesiya, P. oocarpa, P. pseudostrobus, Tectona grandis, Terminalia ivorensis and T. superba.

In most cases the species studied are exotic to the country in which the experiments are being conducted.

The many experimental plots (past and future) set up using material collected within the framework of international efforts are or should be analysed in a cooperative manner. This entails an effort of coordination at all stages:

- Establishment of experimental designs which are, if not identical, at least comparable with each other in the various zones and countries.
- Development and utilization of identical procedures for measurement and observation. A particular effort should be devoted to the methodology of observations on phenological stages, pest and disease damage, and measurements of wood quality.
- Establishment of coordinated timetables for measurements and observations.
- Utilization of modern means of data processing, at least at regional level.

In addition to the possibility of checking the results of each experiment against those obtained in all the others, this method also has the advantage of making it possible to estimate the effects of the interaction between genotype and environment and to identify "plastic" population, i.e., those adaptable to a large variety of ecological situations.

In addition, such coordinated action also has the great merit of enabling countries or regions with limited research, infrastructures or equipment to benefit from the resources available and the experience acquired in other countries (Lacaze 1978).

Recent examples have demonstrated the effectiveness of the assistance that can be provided through the implementation of programmes of this kind.

In countries where there are a considerable number of programmes for species and provenance trials and conservation plantations, it is suggested that simple catalogues be prepared on the work done and the results achieved, for exchange between specialists.

Finally, at world level, a publication such as "Forest Genetic Resources Information", edited by FAO, constitutes an interesting initiative for diffusing the most impressive results of the main programmes.

#### SUMMARY

The objectives and methodology of trials have been well summarized by Eldridge (1979). It is necessary to have:

- (1) Objectives clearly stated;
- (2) Seed collected by a reliable worker, preferably the investigator himself, and well documented;
- (3) Seedlings grown in the nursery under uniform conditions and with suitable replication;
- (4) A sound statistical design;
- (5) Plot size determined by the expected variation in the material and by the anticipated age of final assessment;
- (6) Planting sites representative of future planting areas and as uniform as possible;
- (7) Great care in labelling and recording at all stages.

In addition the cooperation of countries in international trials allows a more rapid and more efficient accumulation of knowledge at a reduced cost to each country.

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SEED STANDS

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GENERAL REMARKS

Seed stands are areas selected in natural formations or plantations to ensure a supply of seed of known geographic origin and parentage.

Seed stands constitute a reliable source of seed of certain genetic quality, variable according to the quality of the formation, until such time as seed orchards prove necessary and come into production. Since they constitute a local source, usually in or near plantation areas in which a certain natural selection has already occurred, they offer the advantage of providing seed that is genetically more reliable for the site than seed brought from outside or from different environmental conditions.

Seed stands are a stage prior to the formation of seed orchards. The areas selected for seed stands, unlike those chosen for seed orchards, were not originally intended for this purpose: they acquire this function owing to certain characteristics of the formation and the needs of the plantation programmes. The selection differential is usually lower than in seed orchards and the rules concerning the trees present are less strict.

Genetic improvement through seed stands depends on the quality of the formation and on the characteristics under consideration. The trees in the stand are not usually subjected to progeny trials, so that their real genetic value is not known.

SELECTION OF SITE

The best natural or artificial stands of a given species are located where conditions are similar to those of the area in which the seed is to be used. In selecting these stands account is taken of the development of the formation (quality of the individuals) and of the capacity of the wooded area available to produce enough seed to meet the minimum requirements of the plantation programme or programmes.

In the case of plantations, particularly of exotic species, age is an important factor in selection of the site, since the trees must be mature enough to guarantee the production of viable seed in acceptable quantities within an acceptable period of time,

but also have deep, wide, green crowns for maximum production of seed in the future. Often the areas of physiologically mature or nearly mature trees available are very small; and where the areas are sufficiently large, they have been planted only recently. Areas of high mortality are usually discarded for seed stand purposes. For some exotic species in zones with a difficult environment (such as high altitude or low temperatures, poor soils or low rainfall), there is the problem that even when the species grows, reproduction is seriously affected, which is one constraint to the establishment of seed stands.

#### ASSESSMENT OF AREA

Once the area has been selected, the phenotypic quality of the individuals and the initial average production are assessed morphologically and quantitatively. This will enable us, in addition to laying down criteria for establishing the seed stand, to have a basis for calculating the genetic advance to be expected in plantations grown from the seed produced in that stand.

Morphological assessment is based on a few characteristics -3 to 5- considered to be of importance for use of the plantation product. For timber and wood-based products straightness of the trunk, forking and anomalies (particularly in conifers) are frequently used, with different scales or categories. Some characteristics may be decisive with only two criteria: rejection or acceptance. For example, trees with visible signs of attack by certain insects or diseases are completely rejected, because of the ease with which susceptibility can be inherited and the decisive importance of this character for the success of future plantations. For the other characteristics, it will depend on the quality of the formation how rigorous the selection is.

Quantitative assessment is made by measuring height and diameter and evaluating the form and quality of the trunk.

#### SIZE AND DENSITY OF STAND

For a given quantity of seed required in a given programme, the size of the area will depend on the productivity of the species and the density of the stand used.

The productivity of a species is given by the number of viable seeds per tree. This is dependent upon the number of fruits per tree, the number of seeds per fruit and the viability of the seeds. Prior sampling is essential to provide an estimate of productivity.

The density of a stand depends on its age and/or development. In plantations, between 100 and 300 trees per hectare are generally used, depending on the species and on the environmental conditions. Competition between the crowns is always avoided in order to ensure the maximum number of reproductive buds.

In tropical natural areas the possibilities of establishing seed stands are limited owing to the heterogeneity of the stands and the limited number of each species per hectare, except in some specific types of forests.

Seed stands are characteristically monospecific, since the movement of pollen between trees of a species is facilitated if the other species are eliminated. However, in natural stands the possibility could be considered of combining two or three taxonomically very different species so as to avoid problems connected with hybridization. In this way more effective use can be made of an area devoted to producing seed.

For reasons of cost and productivity it is considered that an area of less than 5 hectares is not suitable for the commercial production of seed. Above this minimum, the size will depend on the requirements of the programme, the original area covered by the species, and the resources available for effective management of the area.



### GENETIC GAINS

The main value of a seed stand is that it constitutes a local source of seed of sufficient quality and quantity to minimize or eliminate dependence on external sources that are quantitatively and qualitatively less reliable.

Any gain that may be achieved will depend on the quality and original conformation of the stand. The more regular the distribution of qualities among individuals in the stand, the more opportunities there are for a selection that will lead to an important genetic improvement, since there is more likelihood of all the desirable combinations being achieved in one or few individuals. The more uniformly one or another type of quality is distributed, the less advances are to be expected.

In first-generation plantations, particularly of exotic species and under somewhat limiting environmental conditions, distribution is often observed to be slanted towards poor quality, with very few good individuals. In this case the greatest gain to be hoped for is in survival, with a slight or regular improvement in development quality. The improvement in survival is explained by the fact that the seed comes from individuals that have survived well for a first-generation plantation, showing a certain degree of cultural adaptability to the site, demonstrated by the fact that they have achieved an acceptable stage of development under certain limitations.

Improvement in development is expected because, although the structure of the stand and the need for a minimum number of trees per hectare may lead to the selection of trees that fall outside the category of "good", the latter will be relatively more frequent in the new (select) population and hence have a greater genetic impact.

### LAYOUT OF AREA

A seed stand consists of a production area, or effective area, and a buffer area.

The production area is the area where the seed will be collected and which may receive the cultural operations needed to promote production.

The buffer area serves to limit contamination by pollen from uncontrolled external sources, since seed stands are usually established in plantation zones. The buffer is composed of the same species as the stand and therefore contributes pollen to the production area. The same criterion regarding the effects of selection of individuals is used as in the production area, but no cultural operations are undertaken.

The buffer area will be between 100 and 500 m wide, depending mainly on environmental factors that favour dispersal of the pollen.

### CONFORMATION OF STAND

Once the area has been selected and assessed, the guidelines for intervention and conformation of the stand are established. Individuals should as far as possible be distributed regularly over the whole area, with a minimum space between them to encourage flowering and pollen dispersal. The minimum space is that necessary to avoid precocious competition and may be as much as 1.5 times the initial spacing in young stands. In any case, spacing will depend on conformation of the neighbouring trees and the density adopted.

In plantations work can be done systematically by rows, thus encouraging regularity of the resulting stand. Since the aim of selective thinning is to leave only one quarter to one sixth of the original crop per hectare, it is often done in stages (2 to 4 years), so that any necessary corrections can be made to the initial operation.

of the area the first year and the remaining three quarters in the other two years.

The time taken to establish a stand usually depends on the area to be covered and the constitution of the initial formation (density and size of trees).

It is essential that the project leader mark the trees to be operated on so that at the same time as he/she trains the auxiliary staff who usually complete the work, the necessary correction can be made. Technical supervision is necessary in any case in order to guarantee good results. Marking should always be done well in advance of tree clearing, and this should be taken into account in planning activities.

Felled trees must be removed from the stand in order to eliminate obstacles and possible sources of attacks by pathogens.

The stumps should usually be fumigated to prevent them becoming foci for insects and diseases.

#### MANAGEMENT AND UPKEEP OF STAND

The main management activity in a seed stand is thinning. Protection against fire, insects and diseases is also of great importance. The maintenance of firebreaks and adequate access roads permits effective mobilization in the event of fire. The elimination of low vegetation and control of stumps also helps to avoid possible centres of infection.

Biological and genetic research work, such as studies on the use of fertilizers or other means of encouraging flowering and fruiting, can also be conducted in seed stands.

SELECTION AND MANAGEMENT OF SEED STANDS  
WITH SPECIAL REFERENCE TO CONIFERS

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INTRODUCTION

The use of seed stands is an interim measure in most forest improvement programmes, which enables improved seed to be obtained in a short period of time. It is considered an interim measure because the intensity of selection from stands can never be the same as that from seed orchards. There will therefore be less improvement, or rather, fewer genetic gains.

In regions where large-scale afforestation programmes are undertaken, as is usual in tropical or sub-tropical areas, there is a great demand for seeds. The lack of sufficient quantities of seeds is often a bottleneck in plantation planning.

The source from which the seed is extracted, (its provenance) is important to the future of the plantation. This source will influence not only the volume to be obtained, but also adaptation to the plantation site, plant health, type and rate of growth, wood quality, etc.

Seed stands can be selected both in native forests within the range of natural dispersion of the species, and in plantations within and outside the area of origin.

This paper is based on the lecture given by H. Keiding at the FAO/DANIDA Training Course on Forest Seed Collection and Handling, Thailand, 1975, with additional information from H. Barner, from the FAO/DANIDA Training Course on Forest Tree Improvement, Kenya 1973.

Various names have been given to seed stands, particularly in English-speaking countries, such as "seed source", "selected stands", "seed stands", "seed production areas" which are discussed in detail by Barner (1973). A distinction must be made between stands selected for the general quality of the trees and stands in which intensive thinning has been carried out, eliminating inferior individuals.

The following definitions are adopted in accordance with the OECD (Organisation for Economic Cooperation and Development) scheme:

Stand: "A population of trees possessing sufficient uniformity in composition, constitution and arrangement to be distinguished from adjacent population".

Seed stand/Seed Production: "A plus stand that is generally upgraded and opened by removal of undesirable trees and then cultured for early and abundant seed production".

The objectives of creating seed production areas of seed stands are, according to Matthews (1964):

- 1) To produce seed of improved quality through selection and elimination of inferior trees, favouring those that are vigorous, straight-stemmed, healthy and producing wood of good quality.
- 2) To concentrate seed collection in a few specially treated parts of the forest, thus making seed collection easier to organize and control.
- 3) To improve the germinative energy and germinative capacity of the seed collected.

#### BACKGROUND AND PRESENT SITUATION IN LATIN AMERICA

The selection and establishment of seed stands is the quickest method of obtaining any improvement in the quantity and quality of seed harvested. It would appear that integral and long-term improvement procedures include the selection of seed stands to obtain improved seeds, until seeds can be obtained from more carefully selected trees in seed orchards.

At present, seed stands are sometimes still the only way for some countries to obtain seed for their plantation programmes. This was the practice most frequently used in the past.

Stands are usually selected from mature forests, and subsequently treated to transform them into seed producing areas.

Forest gains or improvements, and the efforts needed to achieve them, will depend on the nature of the basic material one has to work with.

Following Barner (1973) and Jones and Burley (1973), the basic material has been classified in accordance with its origin and location, as follows:

- 1) Mainly located within the range of the species, whether in natural stands or plantations.

This group, particularly the conifers, includes such countries or regions as the United States, Canada, Mexico and countries of Central and Southern Europe.

- 2) Mainly exotic species, introduced into the region, where they have been cultivated fairly extensively.

This group can be found in almost all the countries whose forest production is based on extensive cultivation of exotic species.

Conifers, particularly, can be found in countries such as New Zealand, Australia, Chile and Spain, where Pinus radiata has been extensively cultivated; in South Africa, Zimbabwe, Malawi and Kenya (Pinus patula); in Argentina, Brazil and Australia (pines from the southeastern United States); Great Britain and central western Europe (Pseudotsuga menziesii and other species of pines), to give only a few examples.

3) Mainly in experimental plots of uncommon or recently introduced species.

This group includes most tropical and sub-tropical countries, and also many species now being tested in developing regions. It applies particularly to species trials and provenances within species which have performed outstandingly in trials as compared with the material widely used throughout the region.

As regards the use of seed stands of native species in tropical regions, the limited use of this system can be explained by the fact that native species are usually replaced by fast-growing species which are almost always exotic. Even when some native species can be used, the mixed nature of the forest makes it very difficult or practically impossible to transform a forest into a seed stand.

Tropical areas in Latin America are no exception to this rule for native species. Species are scattered throughout mixed forests, where a large number of species, mainly hardwoods, grow side by side. Native conifers occur in climates ranging from sub-tropical to cold temperate. Apart from some exceptions, such as certain pine species in Mexico and Araucarias in Argentina, Brazil and Chile, most conifer species are not cultivated and are Araucaria angustifolia. In the Argentine province of misiones alone, some 30 000 hectares have been planted. So far, seed has been collected from native stands - although seed stands are now being developed.

Group 2, as mentioned above, includes Chile, Brazil and Argentina. The questionnaire to be completed by course participants will probably provide further information of species cultivated in other American countries.

The remaining species used on a large scale in many American countries are still included in group 3, since there are no forest plantations old enough for selection of seed stands. The oldest and most successful experimental plantations are used for this purpose.

#### LOCATION AND SELECTION OF SEED STANDS

Here again, a distinction must be made between native species in their native area and exotic species widely cultivated and recently introduced.

In the first case, selection will have to be based fundamentally on existing information from the various provenance trials which determine suitability for climates and soils. Once the region of area has been determined, a stand will be selected for optimum wood quality and quantity, and quality and regularity in seed production.

As regards exotic species, a distinction must be made between those widely cultivated, such as Pinus radiata, P. caribaea, P. elliottii and P. patula in the southern hemisphere, and those not widely cultivated or only recently introduced. The methodology indicated below refers to the first group, where selection of stands will have to be stretched as far as possible using all available information on the value of the seed source, reproductive quality of the stand under consideration, results obtained in previous plantations, etc. As regards the second case (species not widely cultivated), progress will have to take its own course, little can be done about it.

The total area needed for seed stands for any given region depends on the annual demand for seed, productivity of stands, by tree or by area, and quality of production.

#### Selection criteria

In selecting the seed stand, its uniformity and volume production must be borne in mind, and the trees must have well-shaped trunks, good growth habit, quality of wood and good health.

In European countries (for example, Sweden) stands are graded into "plus", "normal" and "minus", there being a tendency to subdivide the plus stands into different categories depending on their degree of superiority. In other countries (for example, Great Britain), the stands is classified on the basis of individual trees. Samples are taken systematically, within which all the trees are measured and classified. The total of points in the sample determines the total points of the stand, according to which it is declared plus, almost plus, normal or minus.

Although they appear different, selection criteria in both cases are similar with respect to the characteristics chosen to classify the trees. Selection criteria are also similar to those of individual phenotypic selection, but they differ fundamentally in the intensity of selection.

### Characteristics of the stand

#### Age

Age varies with species and region. A stand should be old enough to have proved the value of its seed in areas where it was used before. It should be mature enough for good flowering and fruiting. It should also be old enough to permit correct evaluation of stand characteristics. Barner (1973), however, maintains that, due to possible difficulties in evaluating some characteristics in older stands, it is desirable to start evaluation at an early age, if the stand promises to be valuable, and keep this information on file and up to date until needed. The seed stand, although it should be mature, should not be very old, so that seed extraction can continue for a reasonable number of years.

#### Area

It is not possible to establish the area of a seed stand in advance. In general the criteria in the minimum area in which it is economically worthwhile to collect seed. In western Europe, 2 to 5 hectares are considered the minimum area for seed stands. The stand should also contain enough individual trees of the desired species to allow for reasonable cross pollination. This is particularly important in mixed forests.

#### Isolation

The isolation factor should be borne in mind, to avoid contamination by inferior stands. Wind-pollinated conifer species are more difficult to isolate than broadleaved species, which are usually insect-pollinated. Isolation can be achieved by choosing stands which are between 300 and 1 000 metres away from any possible source of contamination. In some cases, plus stands can be found sufficiently far away from contaminating minus stands for the forest itself to be used as the buffer. In this case, only the area of the plus stand farthest from the contaminating source is harvested, using part of the same stand as a buffer zone.

#### Accessibility

Normally, easily accessible stands should be selected, to reduce the cost of management, inspection, upkeep and seed collection. When genetically adequate species are found off the beaten track, it is preferable to collect their seed and sow it in places where it is easier to reach.

### STAND MANAGEMENT

The treatments normally given to a stand within an area to be used as a seed source, and to convert it into a seed stand, are as follows:

- 1) Removal of minus trees to improve the genetic quality of the seed.
- 2) Thinning, to allow adequate space for flowering, fruiting and seed collection.
- 3) Clearance of the undergrowth to facilitate seed inspection and collection.
- 4) Demarcation of the stand, particularly when there are contamination problems.
- 5) Treatments to increase production, such as pruning or application of fertilizers.
- 6) Other treatments to protect fruiting, such as application of fungicides and insecticides.

To improve management of seed stands, it is desirable to keep a record covering all activities and treatments applied, phenological information, and information on seed harvesting.

### SEED PRODUCTION

Relatively little is known about seed production from a seed stand, as compared with a stand that has not been treated. It is known that when a stand is thinned and the canopy opened, an increase in seed production is immediately obtained. However, the duration of this effect is not known. It is probable that there is an increase in production per tree, but it is not known if there is greater production per area. An improvement in seed quality is certainly achieved by eliminating minus trees and thinning to get more light to the crowns of selected trees.

Nor is there any concrete information on increased production as a result of fertilization, since almost all research has been done on seed orchards. In Japan, studies made on Pinus densiflora and Larix leptolepis showed that the application of fertilizers improved seed quality, and thinning produced an increase in seed quantity. The best result was obtained with light thinning; this was not only better than the control treatment (without thinning), but also better than heavy thinning (Asakawa et al, 1969).

### GENETIC GAINS

To date, there has been an increase in the quantity and physiological quality of the seed produced in seed stands.

In species with wide variations in breed or ecotype, usually species with a large range, maximum genetic gains of the seed stand depend on the correct choice of the basic population. The original source of seed should be known through previous studies of provenance trials or as a result of intensive and extensive silviculture. For this, both the area of origin and plantations established in the region with material from the same source can be used. For example, in Argentina in provenance trials it was found that populations of Pinus taeda from central Florida with 7-year rotation grew 200% in volume as compared with populations from the foothills of Georgia. Something similar happened with the same species in Queensland. As the basic population used for seed stands is from different sites in Georgia, the production in volume can easily be improved by using seeds from Florida stands.

As regards characters within the population such as shape, width of crown, density of the wood, etc., this will depend directly on the heritability of the character and the intensity of selection. This being a mass selection, with relatively low selection intensity, genetic gains will depend on heritability.

One example from Shelbourne (1969) for diameter low (heritability) and bole straightness (high heritability) in Pinus Radiata at a selection intensity of 1 in 10, expressed in percentage of the average population before thinning, is 25% for bole straightness and 5.6% for diameter. At a selection intensity of 1 in 20, the gains anticipated are 29.2% and 6.7% respectively.

In Latin American countries, where many factors relating to species, provenance, site and their interactions, have not yet been explained, much greater gains may be hoped for in the search for species and provenance better suited to each region. For this reason a technique recommended is that of establishing simultaneously with species and provenance trials, large-scale plantations of each of the biological units tested. This material could be used in the future as a source of seeds in the short term, and selections could be made from it for long-term improvement programme.

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SELECTION AND MANAGEMENT OF SEED STANDS: HARDWOODS

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INTRODUCTION

The purpose of a seed stand is to meet immediate needs of relatively large genetically somewhat improved quantities of seed by setting aside stands of not lower than average quality and managing them with the primary objective of seed production.

General principles of selection and management of seed stands, as outlined by Barrett in the previous lecture, are valid for hardwoods as well as for conifers. Points on which methodology between hardwoods and conifers differ or which may require particular attention when dealing with hardwoods, are outlined below. References to publications dealing with the establishment and management of hardwood seed stands are listed at the end of this note.

STAND SELECTION

- Hardwoods are often dioecious. In selection of stands, the availability of both male and female trees must be ascertained and when thinning, care must be taken to leave a balanced sample of male and female trees;
- In species with pronounced root-succering ability large areas of trees which are genetically identical sometimes occur. For these species the seed stand approach may not be suitable;
- When dealing with plantation species it is very important that origin of the stand is known. Exotic plantations may be based on seed from relatively few trees and although the stand itself may be of superior growth and form, the genetic quality of the seed collected from it is likely to be poor due to inbreeding effects. Sometimes, e.g. in the case of eucalypts, the stand may be of hybrid origin, and seed collected from F<sub>1</sub> hybrids and from subsequent generations will produce unacceptably variable stands because of segregation of the genes;
- Selection criteria such as health of trees, yield and form are universal. However, additional, species-specific selection criteria will often be included for hardwood species; examples of such criteria are selection against genetically controlled defects characteristic of some species, such as the tendency to produce epicormic shoots having bud traces extending to the pith as in liquidambar styraciflua and against the formation of a large number of kino veins in Eucalyptus regnans; selection for extremely low wood density in Ochroma lagopus selection for specific wood characteristics such as attractive colouring or patterns of wood in some high-quality cabinet timbers; selection for high coppicing ability especially in some species grown on short rotations.

### AGE

The stands must be young enough to be able to respond to the first thinning by the development of crowns capable of producing large seed crops, but old enough to give some indications of the characteristics to be selected for.

### AREA

The distances between individual trees of the same species are often large in forests with a heterogeneous species composition. Provided these species are outbreeding and the seed stand appearance therefore per se is valid, the areas needed are much larger than if dealing with forests consisting of one or only a few species. If the density of the species is very low, the seed stand approach cannot be used.

### ISOLATION

Knowledge of the breeding system of a species is fundamental. If a species is inbreeding, no isolation is naturally needed. However, forest tree species are largely outbreeding, possessing various mechanisms to prevent selfing.

Effective pollen flight distances and the distance pollen will be transported by insects are not well documented for many hardwood species. The isolation of hardwood seed stands should be kept similar to that for conifers ( $\pm$  300 m) until further studies have been undertaken.

### STAND MANAGEMENT

Seed stands should undergo a series of thinnings to increase quantity and improve quality of the seed produced. The first thinning should be made before serious crown competition sets in; the main purpose of this thinning is to allow the development of wide, deep and dense crowns, i.e. to increase potential quantity of seed at the same time removing inferior phenotypes. During the development of the stand, further variation will manifest itself; as phenotypic selection will generally be more reliable in mature trees, the improvement achieved through thinnings will gradually shift its main emphasis from quantity to quality.

Knowledge of the biology of flowering and seed production is essential for the management of seed stands, and this knowledge is often scarce or lacking in hardwoods. It is important to be able to forecast the exact time of the year that flowering will take place so that thinnings can be timed to precede flowering any one year; incorrect timing may cause a delay in the benefits of the thinning equal to the period between successive seed crops. It is also essential to know the time required between pollination and the maturation of seed so that the relative degree of improvement, which is directly related to selective thinnings, can be forecast.

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## SELECTION OF FOREST TREES

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### GENOTYPE AND ENVIRONMENT

In practice, the commonest improvement methods are based on the selection of individuals meeting certain minimum requirements for specific characteristics which are important for some specific purpose.

The external appearance, or phenotype, of an individual is the first guide for the breeder. Although the phenotype is based on 2 components: genotype and environment, which may or may not be of equal importance in the resulting appearance, the breeder bases him/herself initially on the probability that a good phenotype has a sufficient genetic basis to produce a reasonably favourable reaction in different environments.

Many characteristics are known to be genetically controlled, either partly or almost entirely, so that external appearance reflects inherent potential to a large extent. Other characters vary more in this reaction to environmental conditions, so that a specific phenotype reflects only one of the many possible reactions.

The existence of different forms or alleles of a gene, and the occurrence of polygenesis, pleiotropy epistasis, etc. result in great complexity in the expression of a character or various combinations of characters. The breeder selects from the whole range of expressions, or variations, the most favourable types or combinations. The selection practised by the breeder is controlled or truncated, in that he/she selects towards an extreme of the original population and tries to shift the mean of the future populations in that direction.

The importance of the genetic component of a character can only be determined by field trials, either through vegetative propagation of the individuals selected in different environments, or through their progeny (progeny trials). Meanwhile, external appearance will continue to be the basis for work.

The stricter the selection criteria, the more guarantee there will be of good genetic gain. However, this depends on the species, the product and the quality of the population available for selection.

An initial survey of the areas of distribution (plantations or natural forests) helps to establish a criterion for the requirements of the various characteristics. This is particularly important for selection programmes with first-generation exotic or native species affected by dysgenic selection over much of their range.

#### FACTORS TO BE CONSIDERED IN THE SELECTION OF INDIVIDUAL TREES

The success of selection based on phenotype expressed as genetic advance or gain, depends on various factors, in particular the type and number of characters in the selection, the intensity of selection and the method of propagation.

##### Type and number of characters

The type of character (high or low heritability) has a decisive influence on the advance that can be achieved. Highly inheritable characters are easier to manipulate and more predictable in their responses. Such characters are straightness of the trunk, forking, and resistance to diseases. Characters with low heritability are less predictable, since they require greater environmental control. They include important economic characteristics such as physical and chemical properties of the wood.

The number of characters also affects the response obtained. It has been shown that the greater the number of characters involved the more difficult it is to obtain advances of specific individual characters. This is due to two factors: first, different characters have different inheritance patterns that require different selection intensities. If the number of individuals possessing a given character is increased, they will be increased danger of introducing undesirable phenotypes of this character. Secondly, different characters may be inversely correlated, so that greater strictness in one would have a negative effect on the expression of the other.

It is therefore necessary to concentrate on a few characters at a time. First, one chooses the most manipulable and the most important selection factors, such as straight bole, forking, vigour, etc., and second, one considers the properties of the wood (5).

##### Intensity of selection

Trees are selected with two considerations in mind, among others: that the trees selected have as little family affinity as possible, in order to avoid problems connected with consanguinity; and that it be possible to obtain a minimum number of individuals, in accordance with the purpose of the selection. As regards the first, in natural stands distance is a reliable indicator. The closer the trees, the greater the probability of consanguinity, simply because of how pollen moves. Widely spaced trees, either in the same area or, better still, in different areas, show fewer family affinities. In plantations we expect at least the trees planted in the same year to be more related to each other. From one year to another, and one site to another, the specific source of seed may vary, particularly when very large lots of seed are required. In this instance an effort will be made to reduce the total number of selections on any one area of the plantation.

On the other hand, the number of selections influences the range or genetic base. A limited number of selections will create a very narrow base, which could rapidly lead to problems, including problems of consanguinity. In seed orchards 20 trees are considered an absolute minimum for maintaining a sufficiently broad genetic basis to achieve important advances, and to ensure that the seed produced can adapt to the natural variability of plantation sites. This is based on the assumption of regularity in time and quantity of

flowering and fruiting of all trees. Since this does not always happen it is preferable to use a greater number. In seed areas the number of trees left will depend on seed requirements, the development of the plants and the area available, but it is usually between 150 and 250 per hectare.

Strictness with regard to intensity of selection diminishes as parameters of variability, such as heritability, become available. Intensities of 1 tree per 700 hectares and 1 tree per 1.2 hectares have been used for Pinus radiata in New Zealand and Australia respectively; 1 tree per 8 000 for Cupressus lusitanica in Colombia and 1 per 750 (1 per 0.65 hectare) for Pinus caribaea in Cachipo, Venezuela (4, 5, 8).

In any case the final decision will depend on the variability of the species and on the immediate needs for seed in terms of quantity and quality.

The intensity of selection is determined in various ways. One is by means of a selection differential expressing the difference between the mean of the original population and the mean of the selected trees.

The mean of the original population can be estimated by sampling the population. Since this may be expensive and time-consuming, the means of the 4 or 5 best trees near the plus tree have been used as a population reference model.

With this value, and with the estimated heritability value ( $h^2$ ) for a particular character, we can calculate the genetic gain (R) expected. (See the paper on quantitative genetics for more detailed information).

#### Propagation of plus trees

In the case of trees selected for inclusion in seed orchards, there are two alternative methods of propagation: sexual and asexual: which determine the type of orchard to be formed (seedling and clonal respectively).

### SELECTION PROCESS

#### Method of improvement through selection

The two most common methods of selection are stand selection and selection by family (1, 10).

In stand selection, individuals are selected on the basis of phenotype and then allowed to cross-fertilize freely. This is the usual practice in seed stands and seed orchards, where the seed is mixed without concern for family relations. To test the effectiveness of stand selection, a progeny trial may be conducted with groups of both plus and normal trees from the original populations. This procedure has proven effective for highly inheritable characters.

Selection by family makes it possible to control parental relationships in the resulting progeny, thus facilitating continuous evaluation of the plus trees. The most common family relationship is sibs or half sibs. Different procedures and cycles of assessment, grouped under the generic term of recurrent selection, permit the elimination of trees originally selected and the incorporation of new selections. The practice is most common in seed orchards for production and control of development (with progeny trials).

#### Sources of trees for selection

The source of the trees to be selected is determined by the use to be made of the selections. In the case of seed stands, selection is made within a specific area, normally a plantation of known origin, but sometimes a natural stand which has good overall characteristics of vegetative and reproductive development and is large enough to guarantee sufficient seed output. It must also be located in the zone where the seed will later be used. For seed orchards, the total area of natural and artificial stands within a climatic region is taken as the reference. In order to have a good initial basis for work, initial selection can be in the best stands of the best provenances.

### Selection criteria

There are two practical methods for assessing trees: individual evaluation and comparative evaluation. The first method consists of evaluating each tree on its own merits, according to scales of values for the classes in the characteristics. The different classes in each individual characteristic will be given by technical criteria, in accordance with the phenotypic variants discernible in each one. This alone establishes a certain level of subjectivity. This method of evaluation is appropriate in samples made in formations that are to be used for seed stands, and in which it is desired to assess the formation in order to intake decisions on the intensity of and criteria for interventions. It is also used to evaluate the development of plants in progeny trials. In this system a level is established beneath which any tree is automatically eliminated, regardless of the values in other characteristics.

The second method uses scales of values resulting from the superiority of the candidate tree over comparable trees in the vicinity. Usually a number of additional points are assigned for so much percent or absolute value of superiority, the magnitudes depending on the weight it is desired to give to each characteristic.

This works fairly well for characters quantifiable by specific units (height, diameter, volume), but it is also used for more qualitative characteristics where somewhat subjective classes are taken as a basis.

Some characteristics are determinant, regardless of the selection criterion. An example is resistance to pests or diseases: usually any trace of attack automatically eliminates the tree that is being assessed.

### Terminology

A tree which appears phenotypically desirable and which is to be the subject of evaluation is called a candidate or preselected tree. Once its characteristics have been assessed and it has been accepted for further use, it becomes a select or plus tree.

Once its superior genetic characteristics have been ascertained, it is known as an élite tree. Several cycles of progeny trials are often required before a tree attains this status.

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#### Annex 1

#### EXAMPLES OF SELECTION CRITERIA:

#### SELECTION CRITERIA FOR SEED STANDS

##### I. Straightness of trunk

1. Straight
2. Slightly crooked
3. Very crooked

##### II. Forking

1. No forking
2. Forked in upper third
3. Forked in middle or lower third

##### III. Defects (particularly for Pinus)

1. No defects
2. Recuperated visible defect
3. Average to well-developed defect

##### IV. Flowering and fruiting

1. Fruit
2. Flowers only
3. Neither flowers nor fruit

The first three characteristics are determinant: the order of preference is: 111, 211, 112, 121, 122, 221, 222.

Class 3 will only be included in extreme situations, and would in any case indicate a fairly bad stand.

Flowering and fruiting will serve as a basis for selection between trees in the same category, when the trees to be left or eliminated are marked.

Data on d.b.h., height and any other obvious features will also be taken.

Annex 2

EXAMPLES OF SELECTION CRITERIA:

SELECTION CRITERIA FOR SEED ORCHARDS

A candidate tree and 4 neighbouring trees to be used for comparison are located.

1. Vigour (basal area or volume)

3 points will be awarded for each 10 percent of superiority of the candidate over the mean of the neighbouring trees, up to a maximum of 30 points (100% superiority). The same amount will be deducted if the candidate is inferior to the mean.

2. Trunk

- Categories:
1. Straight
  2. Slightly crooked
  3. Very crooked (only for neighbours)

1 point will be awarded if the candidate is in the best category and 1 additional point for each 0.25 of superiority over the mean of the neighbours. The same amount will be deducted for inferiority to the mean.  
Maximum number of points: 9.

3. Quantity of verticils

Points will be awarded as follows:

1 point if the candidate is better than the worst of the neighbours but is below the mean.

2 points if it is equal to the mean.

3 points if it is better than the mean but is inferior to the best neighbour.

4 points if it is equal to the best neighbour.

6 points if it is better than the best neighbour.

Maximum number of points: 6.

4. Average number of branches in the first 3 verticils

The same as for total number of verticils.

Maximum number of points: 6.

5. Crown characteristics

- Categories:
1. Live branches only in upper third.
  2. Live branches as far as middle third.
  3. Live branches as far as lower third.

Scoring as for trunk

Maximum number of points: 9.



6. Diameter of branches

The thickest branch (live or dead) up to the middle of the trunk will be taken.

- Categories: 1. No branches  
2. Thin branches (up to 1/10 of d.b.h.)  
3. Medium branches (up to 1/4 of d.b.h.)  
4. Thick branches (more than 1/4 of d.b.h.)
- Scoring as for trunk  
Maximum numbers of points: 13.

7. Angle of branches

- Categories: 1. 90° or more with respect to the trunk above the branch  
2. Between 90° and 45°  
3. Less than 45°
- Scoring as for trunk  
Maximum number of points: 9.

8. Attacks

- 5 points:: healthy tree in a stand that shows slight evidence of attacks  
- 10 points: healthy tree in a stand considerably infested (more than 30%)

Basic conditions

1. A candidate tree must not be worse than the worst of its neighbours in any characteristic.
2. A candidate tree must not be below the mean of its neighbours in more than 2 characteristics (negative values).
3. No tree showing signs of attack by insects or diseases will be considered for selection.

Contribution of characteristics

Maximum value of plus tree - 92 POINTS

Vigour	32.6%	Crown	9.8%
Trunk	9.8%	Diameter of branches	14.1%
Verticils	6.5%	Angle of branches	9.8%
Branches	6.5%	Attacks	10.9%

QUANTITATIVE GENETICS :

GENERAL PRINCIPLES AND PRACTICAL APPLICATION

IN FOREST TREE IMPROVEMENT

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INTRODUCTION

Quantitative genetics deals with the hereditary transmission of those differences among individuals that may be called quantitative, or differences of degree, unlike Mendelian genetics, which deals with differences of a qualitative nature (Strickberger, 1968).

The basic genetic functions are the same in quantitative and Mendelian genetics, but in quantitative genetics the differences are the result of differences of genes at many loci, while differences in Mendelian genetics are due to differences in genes at one or more loci, the different types appearing in specific proportion (Falconer, 1964).

QUANTITATIVE GENETICS

Most of the characters which are of interest in connection with forest tree improvement are controlled by a number of additive effects, genes, i.e. such typical quantitative characters as height, diameter, shape of the trunk and volumetric weight. Studies of the heredity of these characters must be made on populations, not individuals (Wright, 1976).

Analyses and studies of quantitative characters can employ a number of different statistical methods.

Analyses of quantitative characters study the concordances between related individuals, and one purpose of the analysis is to forecast the effect of a particular selection and to consider how it should be done.

As mentioned above, statistical methods are essential, in studies of quantitative characters as are such magnitudes as average and variances.

One important task will be to break down the phenotypic variation into its causal components such as external effects and genetic effects. It is also important to break down the genetic component into additive, dominant and epistatic components (Falconer, 1964; Shepherd, 1977).

GENOTYPIC AND PHENOTYPIC VALUES OF THE POPULATION

The genetic composition of a population is often expressed in the form of gene and genotype frequencies. To find a relation between gene frequencies and the quantitative differences evident in measurable characters, we may introduce a new term, the term "value", expressed in the units in which the character is measured (Falconer, 1964).

The following terms are used:

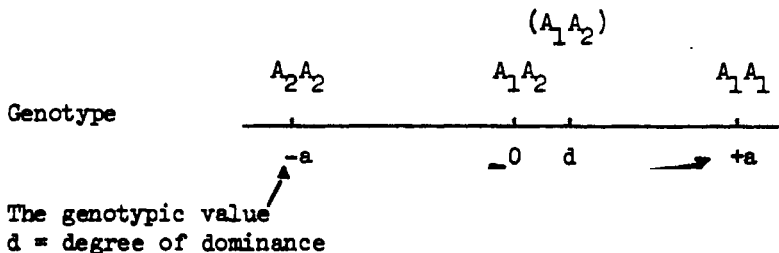
- P = The phenotypic value of a given character.
- G = The genotypic value. "Genotype" means the complete genetic make up of an individual.
- E = The deviation due to environment, or to all the nongenetic circumstances influencing the phenotypic value.

The relation among the values may be expressed as:  $P = G + E$ .

For the population as a whole, we have:

The mean value  $m(E) = 0$  or  
 $m(P) = m(G)$

The above may be illustrated by a simple example in which the characters are determined by a single locus with two alleles A1 and A2. The individual genotype is given a value of -a, d and +a respectively, as shown in the following equation:



In the above example, the heterozygote A1A2 does not appear as the mean value of A1A1 and A2A2, but as the value d, which is called degree of dominance.

If we imagine that the genes A1 and A2 appear in a balanced population with the frequencies of p and q respectively, the genotypic value of the population may be calculated as in the following table:

Genotype	Frequency	Value	Mean value
A <sub>1</sub> A <sub>1</sub>	p <sup>2</sup>	+a	p <sup>2</sup> . a
A <sub>1</sub> A <sub>2</sub>	2.p.q	d	2pq . d
A <sub>2</sub> A <sub>2</sub>	q <sup>2</sup>	-a	q . (-a)
TOTAL	1		a(p-q) + 2pqd

The value  $a(p-q) + 2dpq$  is the genotypic value of the population insofar as it refers to this locus only, and at the same time the phenotypic value, since the sum of population deviations due to environment is zero.

The mean of the population insofar as it refers to all those loci influencing the character in question (a quantitative polygenic character) is:

$$M = \sum_{\text{loci}} a(p-q) + 2 \sum_{\text{loci}} pqd$$

#### Mean effect of a gene and reproductive value

In the study of the transfer of a "value" of the parents to their descendants, we cannot use the genotypic value alone, since the parents transmit not their genotype but their genes to the next generation; instead, the term "mean effect" is used. It is defined as follows: the mean deviation from the average of the population obtained by individuals receiving the gene in question (assuming that the allele gene is taken at random from the population).

The mean effect will therefore depend both on the gene in question and on the population in question.

Based on the term "mean effect", the reproductive value (A) of an individual may be defined as follows:

1. The sum of the mean effects of the genes (the genes controlling the character in question).

The reproductive value is, by virtue of the definition quoted, a theoretical magnitude. Another, more practical, definition is the following:

2. Twice the mean value of the progeny (measured in deviations from the average of the population), when the individual has paired at random with a series of members of the population.

Reproductive value is also called additive genotype.

In a balanced population, we find that the mean of the reproductive values of the individuals is zero.

The reproductive value of an individual in a population may be calculated on the basis of the mean value of its offspring after free pollination. According to definition number 2, the reproductive value may be calculated as follows:

$$A = 2 \times (\text{average of population} - \text{average of progeny}).$$

The term "reproductive value", as an expression of that part of the hereditary mass that can be transmitted in an additive way to future generations, is very important in forest tree improvement.

#### Deviations due to dominance and epistasis

In the preceding paragraph on the individual, we mentioned the portion of genotypic value that can be transmitted in an additive way to progeny. The remaining portion of the value of the individual consists of a non-additive gene effect between the two alleles of a locus, and is called dominance (D). We therefore have:

$$G = A + D$$

For a balanced population we find that the mean of deviation due to dominance is zero, or

$$\bar{m}(D) = 0$$

If we study a polygenic character, there may also be effects of non-additive genes among loci. This phenomenon is called epistasis (I) and means that the genotypic value of polygenic characters may be broken down as follows:

$$G = A + D + I.$$

#### VARIATION OF QUANTITATIVE CHARACTERS

In the previous paragraph, we discussed characters and values in individuals; we now discuss the appearance of characters and values in the population. To this end, let us study first of all the variation of the characters and values and the relation between them.

The values of the individuals and the variances of the population (in the form of variance components) may be set out as follows:

$$P = \frac{G}{A + D + I} + E \qquad V_P = \frac{V_G}{V_A + V_D + V_I} + V_E$$

- VP = Phenotypic variance
- VG = Genotypic variance
- VA = Additive variance
- VD = Dominant variance
- VI = Epistatic variance
- VE = Variance due to the environment

The simple breakdown of phenotypic variance into the above-mentioned components of variance is based on the assumption that G and E are independent of each other and that A, D and I are independent of one another.

Variances can be used to express the relative importance of a cause of variance such as the relation between the variance components in question and the phenotypic variance. The importance of the genotype can, for example, be expressed as the ratio  $\frac{V_G}{V_P}$ .

The components of genotypic variance and variance due to the environment cannot be determined directly from observation of a natural population. On the other hand, the above-mentioned components can be determined by trials or in experimental populations when the parents are known.

#### Concordance between related individuals

The components of variance in the previous paragraph can be traced to variations and therefore we call these components causal variance components.

On the contrary, if we wish to measure the degree of relationship between related individuals, another distinct division must be made in the phenotypic variance, the grouping of individuals into families. These components can be directly estimated on the basis of phenotypic values, and therefore we call them observed variance components. To avoid confusion, we will use V for the causal components,  $\sigma^2$  for the observed components.

We discuss below the four most usual kinds of relationship, which are:

1. The progeny and one of the parents (the other taken at random from the population);
2. The progeny and both known parents;

- 3. Half-sibs
- 4. Full sibs.

The concordance between parents and their offspring can be indicated by the inclination (b) of the regression of parent-children:

Offspring (O)

coefficient of inclination

Parents (P)

b (coefficient of inclination) is estimated as:

P = parents                      SP = sum of products

O = offspring                    SS = sum of squares

Concordance among siblings can be indicated by size:

$\sigma_B^2$                        $\sigma_B^2$  = Variance among groups of siblings

$\sigma_o^2 + \sigma_w^2$                $\sigma_w^2$  = Variance among individuals within groups of siblings

Now we want to link the observed components with the causal components, i.e. to find the ratio between the observed values of b and t and the causal components VA and VP.

It is possible to deduce these ratios for the above mentioned relationships. We give one example below; the relationship of progeny and one of the known parents.

The concordance is indicated by the coefficient  $b = \frac{\text{Cov}_{PO}}{\sigma_P^2}$

According to definition 2 of the reproductive value of an individual the mean (m) progeny is equal to 1/2A, or the co-variance must be calculated between one of the parents (with the value = G) and the mean of the progeny (with the value = 1/2 A).

$$\text{Cov}_{PO} = \text{Cov}(G, 1/2 A) \quad \text{Cov}(A + D, 1/2 A)$$

$$\text{SP}_{PO} = \{(A + D) (1/2 A)\} = 1/2\{AD + 1/2A^2\}$$

Assuming that A and D are independent, the sum of their product is A . D = 0.

$$\text{Cov}_{PO} \quad \frac{\text{SP}_{PO}}{(n-1)} = \frac{1/2\{A^2\}}{(n-1)} \quad 1/2 V_A; \quad b = 1/2 \frac{V_A}{\sigma_P^2}$$

The genetic interpretation of the other relationship may also be deduced. The results are summarized in the following table:

Relationships	Concordance observed	Genetic interpretation
Offspring and one parent	b	$1/2 \frac{VA}{VP}$
Offspring and the two known parents	b	$\frac{VA}{VP}$
Half-sibs	t	$1/4 \frac{VA}{VP}$
Full sibs	t	$\frac{1/2 VA + 1/4 VD}{VP}$

#### HERITABILITY

The concept of heritability of a character means the proportion of total variance which is due to the action of genes.

Two concepts of heritability are used, which are defined as follows:

1. Heritability in its widest sense  $h_{b.s}^2 = \frac{VG}{VP}$
2. Heritability in its narrower sense  $h_{n.s}^2 = \frac{VA}{VP}$

It is important to note that heritability is not any fixed magnitude, but depends both on the population and on the environment. Indication of heritability should always, therefore, be accompanied by an indication of the environment of the components.

As a general rule, we may say that the heritabilities of current stands are relatively low, due to the fact that the environment has a relatively great impact on the phenotypic value of the individual. However, heritability can be fairly high in well-planned trials.

As mentioned above, a genetic interpretation may be made of the coefficients of regression observed (parent-offspring) or coefficients between classes (between siblings). Likewise, the coefficients observed can be used as estimates of heritability. We give below a summary of the relations between the coefficients and  $h^2_{n.s.}$  in the four following relationships:

1. Offspring and one parent  $b = 1/2 h^2$
2. Offspring and both parents  $b = h^2$
3. Half-sibs  $t = 1/4 h^2$
4. Full sibs  $t = 1/2 h^2$

Normally, heritability is linked to individuals, but both family heritability and heritability within the family can be estimated from the guidelines described at the beginning of this section. Family heritabilities are higher than the corresponding individual heritabilities since, using average values (average of family), an important reduction may be achieved in the environmental effect component.

We indicate below how heritability may be calculated on the basis of the results of a progeny test. The test includes groups of half-sibs and is arranged as a random block design. The components of variance described in the following diagram of variance analysis are used to make the calculation:

Source of variation	df	variance components
Progeny (d)	n-1	$\sigma^2 + r \cdot \sigma_d^2$
Blocks (b)	r-1	$\sigma^2 + n \cdot \sigma_b^2$
Residual	(n-1)(r-1)	$\sigma^2$
Total	rn-1	

With groups of half-sibs, the variance between the groups can be interpreted as 1/4 VA, or:

$$\sigma_d^2 = 1/4 VA; \quad VA = 4\sigma_d^2; \quad VE = \sigma^2/r$$

If we assume that there is no dominance, the phenotypic variance could be written as follows:  $VF = VA + VE$ .

$$h^2_{n.s.} = \frac{VA}{VP} = \frac{VA}{VA+VE} = \frac{4\sigma_d^2}{4\sigma_d^2 + \sigma^2/r}$$

#### GENERAL AND SPECIFIC COMBINING ABILITY

The variance between families was formerly divided into genetic components called causal components. However, the variance between families can also be divided into the two following components, which can be observed:

1. General combining ability g. c. a.
2. Specific combining ability s. c. a.

The g.c.a. of an individual is defined as the average offspring resulting from the crossing with various other individuals. The s.c.a. of two specific individuals is defined as the deviation of their offspring from the average g.c.a. of the two individuals.

The average offspring between two individuals x and y can therefore be described as follows:

$$M_{XY} = GCA_X + GCA_Y + SCA_{XY}$$

Consequently, the variance between crossings may be analysed in two components: variance in the general combination capacity and variance in the specific combination capacity. The latter appears in the statistical analysis as the interaction component.

From definition 2 of reproductive value it may be seen that the g.c.a. is equal to half the reproductive value of the individual.

The specific combination capacity depends exclusively on non-additive genetic variance.

A knowledge of g.c.a. and s.c.a. is important for the selection and combination of material for future seed production.

G.c.a. and s.c.a. can be calculated on the basis of crossing designs that will be described in more detail in a later article, and we give below only one example of the calculation of g.c.a. and s.c.a.



1. Mean values of four progenies:

Parents	1	2	Average
3	20	60	40
4	30	90	60
Average	25	75	50

2. Deviation from the average total of the progeny and calculation of the g.c.a.

Parents	1	2	g.c.a.
3	-30	10	-10
4	-20	40	10
g.c.a.	-25	25	0

3. Calculation of the s.c.a. through the equation

$$\text{s.c.a.}_{13} = -30 - (-25) - (-10) = 5$$

$$\text{s.c.a.}_{23} = 10 - 25 - (-10) = -5$$

$$\text{s.c.a.}_{14} = -20 - (-25) - 10 = -5$$

$$\text{s.c.a.}_{24} = 40 - 25 - 10 = 5$$

#### SELECTION AND GENETIC GAINS

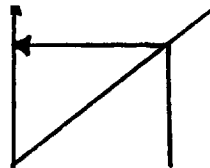
Some of the above mentioned genetic parameters, particularly heritability, are very important for selection and the estimation of genetic gains through selection.

The strength of selection in a population may be expressed as the selection differential S which indicates the difference between the mean of the population and the mean of the selected fraction, or as intensity of selection i which is expressed through the formula  $i = \frac{S}{\sigma_p}$ ,  $\sigma_p$  being equal to the phenotypic dispersion of the population.

If we select the best individuals in a population, we can express the genetic gains (R) as the displacement of the mean among the progeny of the selected individuals and the entire population.

The relation is illustrated in the following figure:

Offspring (O)



b = coefficient of slope

Average of the two  
parents (P)

The slope of regression which expresses the relation between S and R is equal to heritability.

The coefficient of regression  $b = h^2_{n.s} = \frac{S}{R}$ , hence  $R = h^2_{n.s} S$ .

The selection differential S. depends on the dispersion of the population, and it is therefore a good idea to standardize it by dividing it by phenotypic dispersion, as in the case of i.

Using i instead of S the following function is obtained:

$$R = i \cdot h^2_{n.s} \sigma_p$$

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VEGETATIVE PROPAGATION METHODS

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DEFINITION

Plants can be propagated sexually or asexually. The basic difference is the process of fertilization that occurs in the first but not in the second method.

Asexual propagation, in turn, takes two forms: apomixis and vegetative propagation. Apomixis is propagation through the development of one of the gametes (the ovule) without fertilization, or of a cell without reduction, to form seeds or seed-like organs. Vegetative propagation is propagation from well-differentiated vegetative parts.

PRACTICAL USE

Practical use of vegetative propagation methods is based on two biological considerations:

- a) Maintenance of the physiological condition of the parent tree in the propagated part.
- b) Maintenance of genetic constancy. That is to say, the part propagated is genetically identical to the original individual.

Vegetative propagation has been widely used in breeding for, among other things:

- a) the establishment of clonal seed orchards;

- b) the establishment of clone banks, in which controlled pollination is effected, owing to the possibility it affords for obtaining flowers at low height;
- c) the propagation of special breeding material: exceptional hybrids (e.g. heterotics) that are lost through sexual reproduction, sterile hybrids, etc.;
- d) the propagation of selected plants on a large scale.

Its usefulness depends on, among other factors:

- a) The ease with which the species can be manipulated. Many species are difficult to propagate vegetatively, others are extremely easy. This often affects production costs, both for the establishment of orchards and for large-scale production of plantation material.
- b) The extent to which development of the parts propagated can be controlled. In some cases the phenomenon of topophysis occurs: the development of the propagated part is influenced by the part of the tree from which it comes, e.g. lateral branches sometimes tend to grow in a horizontal direction.

Another phenomenon which affects development is graft incompatibility: in grafting the scion may be rejected, sometimes after a year or more.

#### GENERAL TERMINOLOGY

The original tree from which the parts to be propagated are taken is known as the ortet. Each part already propagated is a ramet. A set of ramets from the same ortet is a clone. Differences observed between trees propagated by the same method is called clonal variation.

#### METHODS

There are three main methods of vegetative propagation: cuttings, layering and grafting.

Cuttings are sections taken from the tree and put to root in an appropriate medium.

Grafts are plants obtained by fusing a part from the tree to be propagated with another part which has its own root.

Layers are sections of the tree which are induced to root and then separated from the tree.

For breeding purposes the methods most used are cuttings and grafts. Layering can be of help in special cases as a transitory measure.

#### Cuttings

Cuttings may be of wood or leaves. The first come from branches or the trunk and are more important in forestry. Leaf cuttings are more common for ornamental plants particularly those with fleshy leaves.

It is the most economical method of vegetative propagation in species with good reserves of aqueous tissue, such as Bombacaceae.

Rooting depends on, among other things, the age of the plant, the condition of the cutting, the time of collection, the rooting medium and special treatments.

Tree age is difficult to determine in natural tropical forests, but the dimensions of the tree, in particular the diameter, can be used as a guide. Very stout trees, more than 50 cm. in diameter, are usually old and therefore do not root easily; when rooting is achieved, the root system often develops poorly. The best propagation is achieved with young trees, but this often runs counter to specific purposes, such as the production of flowers, fruit and seeds.

As regards the condition of the cutting, very woody cuttings do not sprout or root easily. Very herbaceous cuttings tend to be very susceptible to drying out. An intermediate condition is therefore best, particularly when the cutting is planted out in the field immediately. A guide for the collection period is the stage of activity of the plant; the most favourable period is when the buds on the tree are starting their most active growth. In the low-lying tropical zones of Venezuela this coincides with the onset of the rainy season (March/April).

The rooting medium must guarantee sufficient but not excessive moisture; this is normally achieved with a medium, semi-sandy textured soil and adequate atmospheric humidity. This is easy to control under artificial conditions, but in the field it can only be guaranteed during the rainy season.

As regards treatments, rooting hormones such as indoleacetic, indolebutyric and naphthalenacetic acid are useful for small-scale work (and even for orchards). For commercial purposes, powdered dusts such as Rootone, Hormodin, Hormonagro, etc. or pure solutions of 100 to 1 000 p.p.m. are recommended.

After the cutting has been planted, the upper surface, if it is the site of the cut, should be protected with a substance to reduce evapotranspiration.

### Grafting

This involves the removal of a vegetative part from the parent tree (the scion) and its attachment to a part with its own root (the stock) so that the tissues fuse.

Depending on the taxonomic relations between stock and scion, we have heteroplastic grafts if they belong to different species (e.g. Cedrela odorata on C. angustifolia) and homoplastic grafts if they belong to the same species. Homoplastic grafts are called autoplastic if stock and scion have the same genotype.

According to the position of the scion, we have top and side grafts, depending on whether the scion is inserted into the top or the side of the stock.

Top-grafting entails beheading the stock, which in many cases results in a drastic reduction in the plant's foliage. This technique is used for many hardwood species.

Side grafting makes it possible to maintain adequate foliage on the stock, and has been much used for conifers, where the moisture factor is very important.

Diagrams of some grafts commonly used for forest trees are given in Annex 1. A good, step-by-step description of grafting and layering with special reference to pines, is given in Dorman (1976).

The cuts should be made with grafting knives, which should be kept clean and sharp, in order to ensure a clean cut which will not be a focus for infection. These knives also have a metal or hard rubber spur to separate the bark in budding.

Cutting must be rapid and uniform for a clean, even cut.

The scion should be bound to the stock with a strong but slightly flexible material. A semi-elastic plastic strip called grafting tape is usually used. It may also contain a fungicidal compound to prevent attacks by fungi.

Outdoor grafts must be effectively protected to prevent the scion drying out. A double covering is often used, the inside layer consists of a plastic bag which helps to retain moisture, and the outer of cloth or non-transparent paper which protects the graft from the direct rays of the sun. As a precaution, it is advisable to effect the graft on a cloudy, slightly humid day.

In selecting the scion the main consideration is its stage of growth. Buds that are in full activity should be sought; this can be checked by their size and by the time of collection (little differentiation and collection at the onset of vegetative growth).

The scion can be the bud itself with part of the bark to attach it to the stock, or it can be a piece of the branch with one or more buds. In the latter case the piece of branch must be neither too soft nor too hard, a second-year growth is ideal.

Care must also be taken to see that the scion is kept in a cool, damp place for no more than two days, if not used immediately.

The stock must be young and healthy. The main guide is compatible thickness of scion and stock. Diameters of between 0.5 and 2 cm. are preferable to ensure good adhesion.

### Layering

It may often be difficult to propagate a species by cuttings, and grafting may present problems. One possible solution is layering. The procedure consists of making a wound in a section of the tree and covering this with a medium which retains moisture (moss, earth, etc.). Healing causes the formation of a callus from which adventitious roots may grow.

This process is helped along by hormone compounds similar to those used for cuttings.

The most common type of layering is aerial layering in which the covering is a medium other than soil and the operation takes place rather high off the ground. When long, low, flexible branches are available, these can be inserted into the soil; we then have ground layering. Usually the part propagated is a branch, but in some species (e.g. Platymiscium sp.) interference with the roots can cause them to sprout, constituting a form of layering in that they do not separate from the stem.

The recommended size is as for cuttings; branches with a diameter of 1 to 2 cm.

One of the biggest problems of this method is transplanting, which often results in considerable losses. It is recommended that the first transplant be made in a fairly loose (sandy) medium to encourage root adaptation. The plant can then be transplanted into a more compact medium.

### Tissue culture

Another form of vegetative propagation consists of tissue cultures, (cultures of cells with the potential mitotic activity, in an appropriate medium under aseptic conditions). The method has been tried with varying degrees of success in gymnosperms and angiosperms, and everything seems to indicate it is feasible for many forest species. The great advantage is that only a very small portion of material is needed. The main disadvantage is the very controlled work conditions required and the same limitations as for cuttings, grafts, etc. (e.g. genotypic variation in ease of propagation).

### VEGETATIVE INCOMPATIBILITY

One of the main problems in grafting is incompatibility which produces rejection of the scion by the stock.

Rejection simply indicates (often) that the cut areas have not been fitted together well (e.g. uneven cuts minimize points of contact). Sometimes, however, rejection is

an indication of conditions inherent in genetic somatic differences between the tissues. This phenomenon may occur at an early stage, making it necessary to effect more grafts to fulfill a given quota (e.g. clone(s), problems with clone(s)). A greater problem is that of delayed incompatibility which may emerge one or more years after the grafts have been established in the field, thus leading to greater losses, e.g. losses of productivity in the case of seed orchards.

In many species external signs have been detected which indicate incompatibility. These include: a) consistent early defects in specific trees. b) unequal rate of growth of scion and stock, c) excessive growth in, above or below the juncture zone, and d) abnormalities in colouring and leaf development of the scion.

The last three are obvious signs of delayed incompatibility which appear between six months to ten years after grafting.

This phenomenon may occur not only in heteroplastic grafts, where it might be expected because of taxonomic differences, but also in homoplastic grafts, i.e. within the same species. In the latter instance, it has more to do with differences in provenance or geographic source. One way of controlling this phenomenon is to seek the greatest possible affinity between the plant serving as stock and the tree from which the scions are taken, to ensure optimum histological affinity.

It is to be noted that there is no best method of grafting: success often depends on the skill of the grafter using a specific method. Various tests have shown different degrees of difficulty in manipulating scion and stock, but the final results have been practically the same as regards percentage of take, as shown below.

Vegetative propagation characteristics of some forest species in Venezuela:

<u>Species</u>	<u>Ease of vegetative propagation</u>
Bombacopsis quinata	VE
Cedrela odorata	M - E
Tabebuia rosea	M - E
Swietenia macrophylla	D
Anacardium excelsum	M - D
Pithecelobium saman	VD
Podocarpus rospigliosii	D - VD
Cordia alliodora	M - D
Cordia spurensis	M - D
Podocarpus oleifolius	M
Hura crepitans	M - E
Tectona grandis	E
Gmelina arborea	E
Pinus caribaea v. hondurensis	M - E
Pinus oocarpa	M - E
Pinus radiata	M - E
Pinus patula	M - E

- N.B. VE = Very easy, percentage above 80%  
E = Easy, average percentages 60%  
M = Moderately difficult, percentages around 40%  
D = Difficult, percentages around 20%  
VD = Very difficult, percentages usually 0%  
Species between 2 classes show great clonal variability.

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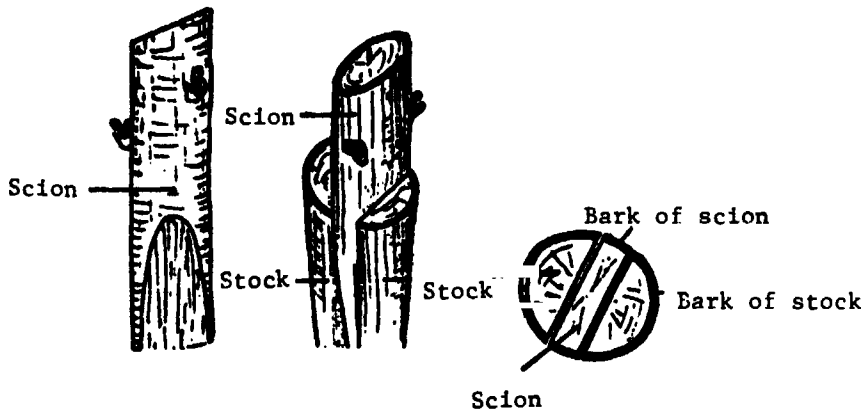


ANNEX 1

FOREST TREE GRAFTING METHODS <sup>1/</sup>

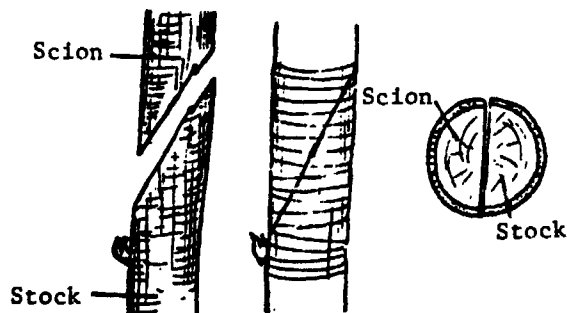
In a graft the cambium of the stock and the scion should coincide at least on one side in order to form the new tissues uniting the two parts rapidly. The cuts must be flat and smooth so that as few cells as possible are damaged. To obtain these conditions various grafting methods have been developed, depending on the diameter of scion and stock. The main grafting methods used for forest trees are the following:

a) Cleft graft



In cleft-grafting the scion cut in the form of a wedge is inserted into a cut made in the top of the stump. Scion and stock must be of approximately the same diameter. In simple or radial cleft-grafting, the scion occupies only one side and may have a diameter inferior to that of the stock.

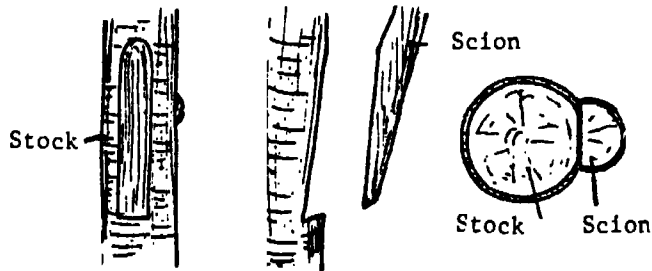
b) Splice or whip and tongue graft



Scion and Stock (similar diameters) are joined by means of a long diagonal cut so that the cut on the stock coincides with the cut on the scion.

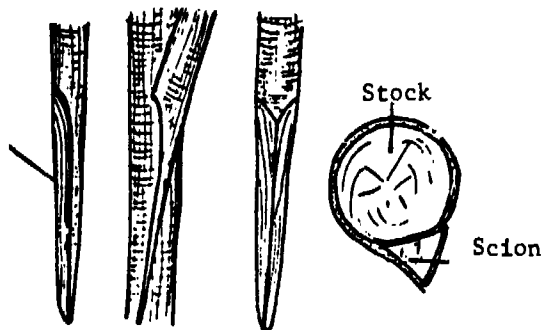
<sup>1/</sup> From Koenig and Melchior (1978).

c) Veneer-graft



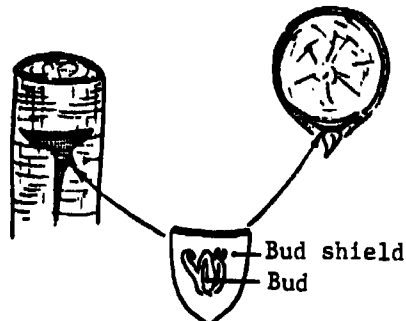
This method is used when the diameters of stock and scion differ considerably. The stock is prepared by a slanting cut which penetrates as far as part of the xylem, and the cut piece removed. The scion is prepared so that the cut coincides with that in the stock.

d) Underbark graft



This method is also used for different diameters, only the bark of the stock being cut. The scion, cut in a triangular shape, is placed in the opening.

b) Budding



The insertion of buds used in the propagation of fruit trees and roses, called budding, can also be used for tropical forest trees, if only a small number of scions are available, or if the methods described above do not prove successful enough.

CONTROLLED CROSSING SYSTEMS AND DESIGNS

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INTRODUCTION

One of the most important decisions to be made in those genetic improvement programmes that include controlled crossings, is the choice of a crossing system. Apart from tree selection, the choice of a crossing system is the only way in which the tree breeder can improve a genetically variable population.

We describe below a series of important aspects to consider when choosing a crossing system. In practice, however, it is often difficult to choose the best system, since there are usually different competing requirements that cannot always be satisfactorily met by one system alone. The final choice, therefore, will probably be a compromise solution. Lastly, there may be some practical and economic constraints.

PURPOSE OF CONTROLLED CROSSINGS

As indicated above, the purposes of controlled crossings are many and various, and we set out below the most important ones for forest tree improvement (Brown, 1977, Roberts, 1969).

1. Determination of general combining ability (g.c.a.). It is usually difficult to estimate the reproductive value, or general combining ability of an individual tree, from the phenotypic value of the individual; only studies of its progeny will provide us with the necessary information on the capacity of the individual to transmit its good characters to its offspring.

Information on the g.c.a. of individuals can in practice be used for:

- a. Choosing the best individuals for seed orchards;
  - b. Genetic thinning in existing seed orchards;
  - c. Choosing the parents of the progeny which it is desired to use in future genetic improvement.
2. Determination of specific combining ability (s.c.a.). Data on specific combining ability can be used in establishing seed orchards of two clones; this makes it possible to select for special effect in the offspring of two individuals.
  3. Determination of variance in general and specific combining ability.
  4. Estimation of heritability. Knowledge of both the variance in g.c.a. and s.c.a. and heritability is very important in deciding for the establishment of the best procedure for genetic improvement and for optimization of, for example, the number of individuals for progeny and the number of progeny per clone.
  5. Production of material for selection of individuals for the next generation of seed orchards. We may assume that the best individuals in a group of siblings are better than the average of the parents and, consequently, it is better to select the best individuals within the best groups of siblings for use in the future seed orchard.
  6. Production of material for continued improvement. To raise the genetic quality still further from the level achieved by a seed orchard of clones whose progeny has been evaluated, it is necessary to recombine the hereditary characters through crossings and new selections. This procedure can be repeated several times before selecting the individuals that will form part of the future generations of seed orchards. In this way it is possible to eventually achieve several combinations of genes that are very seldom found growing wild but that offer great advantages from the breeding standpoint.
  7. Estimation of genetic gains in the first generation of seed orchards and in successive generations. Decision-makers should be able to get information on the degree of improvement (genetic gains) achieved in seed orchards as compared with seeds from stands, and on the genetic gains that can be expected from the establishment of seed orchards of the next generation.

Lastly controlled crossings could be useful in practical forestry work to obtain plus material. For example, two clones might have a very high capacity for specific combination, but without simultaneous flowering periods; they could not therefore, be used in a seed orchard of two naturally pollinated clones.

The establishment of controlled crossings of forest trees is an expensive time-consuming operation. In consequence, it is often best to use crossing designs that meet several of the desired objectives at the same time.

#### SELF-POLLINATION

Controlled self-pollination is studied mainly in research on selfing. In seed orchards, selfing clones can produce much selfed seed, which in turn produces minus plants.

Controlled self-pollination can also form part of an intra-crossing/crossings programme in which attempts are made to produce strongly intra-crossed individuals which are later crossed with other, also intra-crossed, individuals to achieve a heterosis effect. The method is better known in agriculture, but it has also been tested in forest tree improvement (for example, with Larix, see Keiding (1968)). The possibilities of using intra-crossings and crossings in forest tree breeding are discussed by Lindgren (1975).

### CROSSING SYSTEMS WITH UNKNOWN FATHER

In this paragraph we shall discuss two designs: free loss of flowers and poly-crossing.

#### Free loss of flowers

After free loss of flowers the seed is usually collected by one of the two following methods.

1. Collection of seed from plus trees selected from a stand. The plus tree has been fertilized by the other trees in the stand, and it may also have many selfed seeds.
2. Collection of seed from established seed orchards. If the seed orchard or the plantation is producing large quantities of pollen, it may be assumed that individual clones in the plantation have been fertilized by the other clones in the plantation or, in some cases, by self-pollination.

In both cases, the uncertainty of the relationship between the individual seeds is considerable. In analyses of results of tests and in later interpretation it is normal to assume that individuals of the progeny after free loss of flowers are half-sibs, or that they have the same mother but different fathers.

We have already mentioned that in certain cases certain quantities of selfed seed may be expected, and also, it may be assumed that some of the progeny are full sibs (that they have a common mother and father).

The uncertainty as regards relationship may lead to erroneous interpretations, and the most important disadvantage of free loss of flowers is the difficulty in determining the general combining ability due to the fact that the fathers are unknown and that they vary.

#### Poly-crossing

The disadvantages of free loss of flowers, namely the risk of self-pollination and fertilization by different pollen for different mothers, can be avoided through the so-called poly-crossing system. In poly-crossing, artificial pollination is effected, using a mixture of pollen from a large number of fathers (not, however, from the mother's clone). In this way self-pollination may be avoided, and all the mothers are pollinated with a constant mixture of pollen.

So many different fathers are involved that specific effects of combination, if any, are neutralized, and poly-crossing is therefore a good, cheap system for determining g.c.a. However, it should be mentioned that non-randomized pollination (because the pollen of some clones is more viable than that of others) can result in erroneous estimates of g.c.a. (Roberds, 1969).

One characteristic common to free loss of flowers and poly-crossing is that, since the fathers of the offspring are not known, the possibilities of making a selection of progeny for use in the next generation of seed seedlings are considerably limited. On the one hand, it is impossible to select progeny with a good quality father, and on the other hand, there is the risk of choosing individuals already related to each other.

Systems in which the fathers are unknown do not allow for evaluation of the possible specific effects of combination.

Nevertheless, the above-mentioned disadvantages of the unknown fathers system are offset by the fact that these systems are cheap and simple to implement, and both the trials and the statistical analysis are easy to carry out.

The following is a diagram of the analysis and interpretation of a poly-crossing design laid out in a field trial as a random block design. The genetic interpretation

has been based on the assumption that the progeny are half-sibs.

Variance Analysis

Source of variation	df	MS	expected MS
Blocks	b-1		
Families	a-1	M <sub>1</sub>	$\sigma_w^2 + w\sigma_e^2 + bw\sigma_a^2$
Error	(a-1)(b-1)	M <sub>2</sub>	$\sigma_w^2 + w\sigma_e^2$
Within plots	a · b · (w-1)	M <sub>3</sub>	$\sigma_w^2$

Genetic interpretation

$$\sigma_a^2 = \frac{M_1 - M_2}{b \cdot w} \quad 1/4 V_A ; \quad V_A = 4\sigma_a^2 ;$$

$$\sigma_e^2 = \frac{M_2 - M_3}{w}$$

$$\sigma_w^2 = M_3 = V_G - \sigma_a^2 + V_{Ew} \quad V_P = \sigma_a^2 + \sigma_e^2 + \sigma_w^2$$

n.s.  $\frac{V_A}{V_P} ;$

- 2 Variance due to families
- Environmental variance among plots
- Environmental variance among trees in the plots
- Additive variance
- V<sub>D</sub> = Dominant variance
- Environmental variance within plots
- V<sub>P</sub> = Phenotypic variance
- Genotypic variance

CROSSING SYSTEM WITH KNOWN FATHER

In this group of crossing systems the offspring are full sibs, i.e., the individual offspring have a common mother and father. Therefore, as a general rule, we may expect to have better information from progeny trials than from systems where the father is unknown. However, systems where both the mother and the father are controlled are more difficult, so various fairly complete designs have been developed; they are described in detail below.

Complete diallel crossing plan

Figure 1 shows a complete diallel crossing plan.

Fathers	1	2	3	4	5	6	7	8	9	10
1	x	x	x	x	x	x	x	x	x	x
2	x	x	x	x	x	x	x	x	x	x
3	x	x	x	x	x	x	x	x	x	x
4	x	x	x	x	x	x	x	x	x	x
5	x	x	x	x	x	x	x	x	x	x
6	x	x	x	x	x	x	x	x	x	x
7	x	x	x	x	x	x	x	x	x	x
8	x	x	x	x	x	x	x	x	x	x
9	x	x	x	x	x	x	x	x	x	x
10	x	x	x	x	x	x	x	x	x	x

Fig. 1. Complete diallel crossing plan. Self-pollination is indicated in the figure.

This crossing plan is the best one, since it includes all crossing possibilities and provides the most complete information on the genetic characters of the clones studied.

This design can provide information on the general and specific effect of combination and on its variances. The material also constitutes the best starting point for the selection of superior individuals or pairs of clones suitable for two-clone plantations.

For practical purposes this design is, unfortunately, very difficult to use. In the first place, it usually yields clones that produce too small a quantity of male or female flowers; however the most important disadvantage is an economic one. A complete diallel crossing plan with, for example, 20 clones, will require 400 controlled crossings, or 380 if self-pollination is avoided. However, it is not very realistic to spend so much on each clone, and a cheaper design, such as the one described below, is more generally used.

Modified diallel crossing plan

One way of shrinking the crossing plan, and thus making it cheaper, is to omit reciprocal crossings and self-pollinations, as shown in Figure 2.

Parents

10

1									
2	x								
3	x	x							
4	x	x	x						
5	x	x	x	x					
6	x	x	x	x	x				
7	x	x	x	x	x	x			
8	x	x	x	x	x	x	x		
9	x	x	x	x	x	x	x	x	
10	x	x	x	x	x	x	x	x	x

Fig. 2. Modified diallel crossing plan.

This design provides roughly the same information as the full diallel crossing plan, but the limited material in the plan does not, of course, guarantee the same accuracy in trials and determination of parameters.

Below is a diagram of the statistical analysis and the genetic interpretation of a modified half diallel crossing plan in a random block design.

Variance analysis

Source of variation	df	MS	Expected MS
Blocks	b-1		
Families	a-1		
GCA	n-1	M <sub>1</sub>	$\sigma_w^2 + w\sigma_e^2 + wb\sigma_s^2 + wb(n-2)\sigma_g^2$
SCA	n(n-3)/2	M <sub>2</sub>	$\sigma_w^2 + w\sigma_e^2 + wb\sigma_s^2$
Error	n(n-1)(b-1)/2	M <sub>3</sub>	$\sigma_w^2 + w\sigma_e^2$
Within plots	nb(n-1)(w-1)/2	M <sub>4</sub>	$\sigma_w^2$

GCA = General combining ability  
 SCA = Specific combining ability

Genetic Interpretation

$$\sigma_g^2 = \frac{M_1 - M_2}{bw(n-2)} ; \sigma_g^c = 1/4 v_A ; 4 \cdot \sigma^c$$

$$\sigma_s^2 = \frac{M_2 - M_3}{wb} ; \sigma_s^c = 1/4 v_D ; 4 \cdot \sigma^c$$

$$\sigma_e^2 = \frac{M_3 - M_4}{w}$$

$$\sigma_w^2 = M_4 = v_G - \sigma_g^2 - \sigma_s^2 + v_{Ew} ; v_P = \sigma_g^2 + \sigma_s^2 + \sigma_e^2 + \sigma_w^2$$



Partial diallel crossing plan

This design may be distinguished from the complete and modified diallel plan in so far as a clone has not been crossed with all the other clones. The design can have a series of different conformations (Braaten, 1965) and in Figure 3 we indicate two different types.

Parents									10
1	x	x	x	x					
2			x	x	x				
3				x	x				
4					x				
5									
6						x	x	x	x
7							x	x	x
8								x	x
9									x
10									

Disconnected partial diallel design.

Parents	1	2	3	4	5	6	7	8	9	10	11
1					x	x					
2						x	x				
3							x	x			
4								x	x		
5									x	x	
6										x	x
7	x										
8	x	x									
9		x	x								
10			x	x							
11				x	x						

Brown's partial diallel design (Kempthorne and Curnow, 1961)

Fig. 3 Partial diallel crossing plans.

As may be expected, these designs are less efficient than the full design and the modified diallel design. However, to make up for this, a large number of offspring can be tested at a fairly low cost. Unfortunately, missing values, which cannot be avoided in large-scale crossing plans, considerably complicate the work of calculation.

As illustrated in Figure 3, there are various different designs in the group of partial diallel designs, and we give below an analysis of one of the most frequent, the disconnected partial diallel design.

Variance analysis

Source of variation	df	MS	Expected MS
Blocks	b-1		
Diallels	d-1		
Block x diallel	(b-1)(d-1)		
Families within diallels	d.(c-1)		
GCA	d.(p-1)	$M_1$	$\sigma_w^2 + w\sigma_e^2 + bw\sigma_s^2 + bw(n-2)\sigma_g^2$
SCA	dp(p-3)/2	$M_2$	$\sigma_w^2 + w\sigma_e^2 + bw\sigma_s^2$
Error	d(b-1)(c-1)	$M_3$	$\sigma_w^2 + w\sigma_e^2$
Within plots	dbc.(w-1)	$M_4$	$\sigma_w^2$

Genetic interpretation

$$\sigma_g^2 = \frac{M_1 - M_2}{bw(n-2)} \quad ; \quad \sigma_g^2 = 1/4 v_A \quad ; \quad v_A = 4 \cdot \sigma_g^2 \quad ;$$

$$\sigma_s^2 = \frac{M_2 - M_3}{bw} \quad ; \quad \sigma_s^2 = 1/4 v_D \quad ; \quad v_D = 4 \cdot \sigma_s^2 \quad ;$$

$$\sigma_e^2 = \frac{M_3 - M_4}{w} \quad ;$$

$$v^2 = M_4 = v_G = v_G - \sigma_g^2 - \sigma_s^2 + v_{Ew} \quad . \quad v = \sigma^2 + \sigma^2$$

Factorial crossing plan

In this design a number of mother clones are crossed with the same number of father clones. Often there is a small number of fathers, also called common testers. This design can also be considered a sort of full diallel design including all the combinations of one group of mothers and another group of fathers. See Figure 4.

Parents	1	2	3	4
5	x	x	x	x
6	x	x	x	x
7	x	x	x	x
8	x	x	x	x
9	x	x	x	x
10	x	x	x	x
11	x	x	x	x
12	x	x	x	x

Fig. 4 Factorial crossing plan.

The design is widely used in the United States under the name of North Carolina II. Normally four different fathers are used for the crossing plan, but as a general rule, the number of fathers in the plan must depend on the magnitude of the specific combining effects. If major specific combining effects are likely, the estimation of g.c.a. of the mothers may turn out to be highly erroneous if too few father trees are used.

Since the design often includes very few fathers and since the same clone does not appear as mother and father, it is difficult to compare the general g.c.a.'s of each parent.

It is also difficult to make a progeny selection for the next generation of seed orchards, since selected individuals, especially when only a few fathers are used, are very often already related to each other.

One advantage of this design is that its implementation is simple and therefore relatively cheap; at the same time it makes analysis of the results easier. We give below a diagrammatic summary of a factorial design.

Variance analysis

Source of variation	df	MS	Expected MS
Blocks	b-1		
Fathers	m-1	M <sub>1</sub>	$\sigma_w^2 + w\sigma_e^2 + bw\sigma_{mf}^2 + bwf\sigma_m^2$
Mothers	f-1	M <sub>2</sub>	$\sigma_w^2 + w\sigma_e^2 + bw\sigma_{mf}^2 + bwm\sigma_f^2$
Father x mothers	(m-1)(f-1)	M <sub>3</sub>	$\sigma_w^2 + w\sigma_e^2 + bw\sigma_{mf}^2$
Within plots	(mf-1)(b-1)	M <sub>4</sub>	$\sigma_w^2 + w\sigma_e^2$
	bmf - (w-1)	M <sub>5</sub>	$\sigma_w^2$

Genetic interpretation

$$\sigma_m^2 = \frac{M_1 - M_3}{bmf} \quad ; \quad \sigma_m^2 = 1/4 v_A \quad ; \quad v_A = 4 \cdot \sigma_m^2 \quad ;$$

$$\sigma_f^2 = \frac{M_2 - M_3}{bmm} \quad ; \quad \sigma_f^2 = 1/4 v_A \quad ; \quad v_A = 4 \cdot \sigma_f^2$$

$$\sigma_{mf}^2 = \frac{M_3 - M_4}{bw} \quad ; \quad \sigma_{mf}^2 = 1/4 v_D \quad ; \quad v_D = 4 \cdot \sigma_{mf}^2 \quad ;$$

$$\sigma^2 = \frac{M_4 - M_5}{\quad}$$

$$\sigma_w^2 = M_5 = v_G - \sigma_m^2 - \sigma_f^2 - \sigma_{mf}^2 + v_{Ew} \quad ; \quad v_P = \sigma_m^2 + \sigma_f^2 + \sigma_{mf}^2 + \sigma_e^2 + \sigma_w^2 \quad ;$$

Single pair pairings

In this system each clone is involved only once as mother or father.

The system works particularly well if the objective is to produce a population for selection of individuals for new seed orchards or for use in continuous breeding work.

Another advantage of the use of single pair pairing is that a large number of clones may be tested under the same plan and normally it is very expensive to produce offspring on the basis of controlled crossing.

On the other hand, the possibilities of estimating the g.c.a. and the variance of the general and specific combining abilities are normally not very good. If the specific combining effects are not important, a quick estimate of g.c.a. may, however, be made in order to set aside the worst of the clones tested. If, on the other hand, the specific combining effects are very important, this design may be used to select the best combinations of clones for use in two-clone plantations.

CHOICE OF CROSSING PLAN

The definitive choice of a crossing plan will depend mainly on the purpose of the controlled crossings, as described in the first paragraph of this article. The advantages and disadvantages of the different crossing systems and designs have been briefly discussed in the paragraphs above, and we provide a summary of all the most important aspects in Table 1. Lindgren (1977) and Buijtenen (1976) have given a more detailed analysis of the different designs.

Apart from the problems discussed, which are important in the choice of a crossing plan, a series of problems of a practical nature may arise in the implementation of large series of crossings; for example the differences between clones insofar as their time of flowering is concerned.

We may also mention problems related to the transfer of the crossing plan to a field design. If possible, a simple, sturdy test design, such as the random block, should be chosen. With many different offspring it might, however, be necessary to use an incomplete design. See Braaten (1965).

**Table 1.** Comparison of crossing plans

Crossing System	Determination of GCA	Selection of plus trees	Costs	Determination of variance of GCA and SCA
Free loss of flowers	Fair	Possible, but inefficient	Low	Difficult
Poly-crossing	Very good	Very little and only if the depression of intra-crossing is reduced	Very low	Good determination of the variance of GCA
Full diallel	Excellent	Excellent	Very high (impossible where there is a large number of clones)	Excellent
Modified diallel	Excellent	Excellent	Very high (impossible where there is a large number of clones)	Very good
Partial diallel	Good	Very good	Fair	Good determination of the variance of GCA. The variance of SCA can be determined but it is difficult from the point of view of data processing
Factorial	Good	Only in a few cases and where intra-crossing depression is low	Fair	Good
Single pair pairings	Bad	Good	Very low	Bad

GCA = General combining ability; SCA = Specific combining ability

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Participants visiting the CVG plantations  
of *Pinus caribaea* in Uverito

SEED ORCHARDS <sup>1/</sup>

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<sup>1/</sup> The text of this article has followed the structure and content of the book, "Seed Orchards", edited by R. Faulkner (1975) for the IUFRO (International Union of Forestry Research Organizations) Working Group S2-03-3, with additional information taken from lectures given by D.G. Nikles in Kenya in 1974 and A.G. Brown and K.G. Eldridge in Australia in 1977.

## INTRODUCTION

The modern trend of producing wood and wood products from plantation forests implies the availability of enormous quantities of seed, if extensive areas of forest are to be planted.

It is sometimes difficult to obtain enough high-quality seed in sufficient quantities for the increasingly large-scale expansion plans in the different forest regions of the world.

Moreover, the cost of forestry activities, from the preparation of the soil to the felling of the trees and extraction of the logs, and also the irrecoverable factor of the long wait until the trees are ready to harvest means the breeder must know in advance, that the seed will be good.

Seed orchards ensure a supply which is regulated by the foresters themselves, and which provides steady, reliable production for their plantation programmes.

The establishment of seed orchards is therefore accepted as a necessary forestry activity, which should be started as soon as possible in afforestation programmes relying on seed supplies.

### CONCEPT AND DESIGN

#### Definitions

According to the general definition by Faulkner (1975), seed orchards are the most important means the tree breeder has for mass-producing seed for large improved plantations, based on the best selected trees.

The classic definition by Zobel et al (1958) states that "A seed orchard is a plantation of genetically superior trees, isolated to reduce pollination from genetically inferior outside sources, and intensively managed to produce frequent, abundant, easily harvested seed crops. It is established by setting out clones (as graftings or cuttings) or seedling progeny of trees selected for desired characteristics".

In some cases, seed orchards are established to mass-produce seed of some population of which it is impossible to obtain seed in adequate quantities, without too much attention being paid to the genetic superiority of the individuals. For this reason, the Organization for Economic Cooperation and Development broadens the concept of the seed orchard for the use of international trade, as follows (Brown and Eldridge, 1977): "A seed orchard is a plantation of selected clones or progenies which is isolated or managed to reduce pollination from outside sources, managed to produce frequent, abundant, easily harvested crops of seed."

### HISTORICAL BACKGROUND

Although the concept of a seed orchard was applied before 1940 to other tree species such as rubber and quinine, it was only in 1949 that the first pine seed orchards were planted in Sweden. The use of this technique was intensified as from 1957 in the south-eastern United States, in line with the expansion of pine plantations in response to the establishment of many large paper factories in the region. The Cooperative Programme of the University of North Carolina alone in association with 32 forest industry ventures in the region, has a total of 1 700 ha of pine seed orchards (185 orchards in three States). This scale is justified by the seed needs of an annual afforestation programme of 180 000 ha (Sprague et al, 1978).

The United States Forest Service figures for 1972 (Wright, 1976) list about 3 000 ha of Pinus taeda and P. elliotii seed orchards that could produce seeds for at least 300 000 ha each year.

However, the Queensland Department of Forestry in Australia can claim the honour of having had the first fully productive seed orchard. The clonal orchard of Pinus elliotii near Beerwah has been producing at least 20 kg/ha/yr since 1966. This is the seed used by the Department for its plantations (Brown and Eldridge, 1977).



Another species that has been used intensively in afforestation programmes in Australia and New Zealand is Pinus radiata. These countries have 625 ha of clonal orchards from grafts, producing more than 4 000 kg of seed per annum (Brown & Eldridge, (1977)

In 1975, second generation seed orchards began to be planted in the United States and in Australia.

To date, almost all the information available concerns conifers, especially pines. Forest hardwood seed orchards are recent and on a smaller scale; Tectona has been grown in New Guinea, Thailand, Nigeria and India, and Gmelina in Nigeria. Mention should, however, be made of work on eucalypts in Australia, South Africa, Morocco, Portugal and more recently, Brazil, where private enterprises, with the collaboration and advice of IPEF (Instituto de Pesquisas e Estudos Florestais), are cooperating on a major effort in this field.

World experience (despite the fact that this technique is relatively new) and the results obtained with different species in different regions indicate enormous potential for seed orchards for better yields of forest crops, and, therefore, more effective use of sites and cheaper forest production.

#### PLANNING AND DESIGN

Generally speaking, the design of a seed orchard is based on the assumption that all the clones or progeny composing the orchard will flower at the same time, be completely inter-fertile with all their neighbors, produce the same amount of pollen and ovules, yield the same amount of seed, have the same degree of compatibility when grafted, the same type of growth and a similar form of crown, etc.

Experience shows that this is seldom the case, since for each species and each region, these characteristics must be studied in detail and all possible information collected on clonal behaviour, compatibility, combining ability and any other information inherent in the production of seed and its future behaviour, in order that the design of the next and subsequent orchards can make maximum use of the available data.

#### Clones or seedlings

There is a wealth of literature on whether to use clones or seedlings from selected trees, (Toda, 1964), but in general it is agreed that only in special circumstances is it desirable to use seedling progenies. Unless control pollinated seed is available, the offspring will very likely be genetically inferior to the parents. Secondly, selections in the orchard are applicable only to this environment. Nikles (1974) agrees that in certain cases the seedling seed orchard has a special place in improvement programmes when working with species that root with difficulty and that may flower and set fruit early. The same author maintains it is a mistake to believe that the seedling seed orchard is the low-cost solution for small breeding programmes, since great expertise is essential to a successful orchard.

Many aspects of the establishment, design and management of seed orchards are common to both clonal and seedling seed orchards. However, there has been more experience with the former, basically with grafting, although rooted cuttings have also been used.

In practice, very few seedling seed orchards from selected trees have been established. The decision is made not on genetic grounds but springs rather from a reluctance to use a little-known technique where the investment is bound to be long-term.

#### Number of clones or seedlings

It is generally agreed that the right number of clones or families to obtain the maximum genetic gain and avoid the bad effects of inbreeding, is between 15 and 20. There are, however, good reasons for establishing a greater number of pheno-types to start with. Possible incompatibility between the graft and the stock, flowering habits, and also the need to thin clones, (leaving those with better general combining ability), justify starting a seed orchard with a greater number of clones than is usual (in general practice 60 to 100 clones).

According to Lindgren (1974), genetic gain is maximized by using a smaller number of clones, provided they flower simultaneously and their orchard output is not used for further selection. Five clones provide enough genetic variation to ensure adaptation to different sites, resistance to diseases, changing uses for wood, and so forth.

An extreme illustration of this concept is the use of two clone seed orchards with high specific combining ability for maximum genetic gain of known geno-types.

On the other hand, for progenie of selected trees, Shelbourne (1969) has advocated starting the orchard with more than 200 families, with intensive intra- and inter-family selection.

#### Initial planting distance

On the assumption that the best final spacing for most cultivated species is 10 metres, depending on expected intensity of selection, or earlier fruit-setting through better pollination, the initial distance can vary from 2 to 6 metres. This spacing has been used successfully for pines. As a general rule, it may be said that the space between plants should be sufficient to allow free and complete crown development, with maximum sunshine, to ensure a plentiful crop of fruit for several years before thinning becomes necessary.

The minimum distance is often limited by the space needed for mechanical control of weeds and grass, applying herbicides and fungicides, and seed collection.

Planting can be in squares, rectangles or quincunxes; Nikles (1974) mentions a hexagonal distribution for better mechanical seed collection. However, after selection and culling of undesirable genotypes, the final distribution is completely irregular.

#### Experimental design

The design most widely used throughout the world for clonal orchards and seedling seed orchards is the randomised complete block. Shape and distribution within the block should be such as to ensure cross pollination in which all clones participate. To avoid selfing, it is desirable to alter the random design where ramets of the same clone are close together.

Some systematic distributions can be recommended within the block when the initial number of clones is maintained until the end, otherwise the thinning of clones disrupts distribution as much as random design.

The size of the orchard depends on the forester's need for seed; in other words, it is in direct proportion to the projected afforestation annual programme.

The number of blocks will depend on the quantity of seed that experience of the species and site dictate.

#### VEGETATIVE PROPAGATION

As indicated above, most orchards are established by using clone ramets. The technique commonly used is grafting, with various methods depending on the species and the region.

Some species, mainly due to incompatibility between stock and graft, cannot be successfully propagated by this method, and therefore other techniques must be used. This was the case with some widely cultivated species such as Pinus radiata, Eucalyptus grandis and Pseudotsuga menziesii, in different regions of the world. Sometimes, the decline and death of the clone take place over a fairly long period of time, complicating the operation of the orchard and post-poning definitions. With Pinus radiata, the problem was solved by making use of the ease with which its cuttings take root, and the same method was followed with Eucalyptus grandis, although seedlings from selected trees have also been used to establish seed orchards. Considerable efforts have been made with Douglas fir to improve grafting techniques, detect incipient incompatibility, replace defective grafts and find compatible rootstocks. With this species, seed orchards were often established from seedlings.

The methodology, techniques and problems of vegetative propagation have already been discussed in another lecture.

## ESTABLISHMENT

### Location

In deciding on the location of a seed orchard, the following factors should be borne in mind: climate and soil for high seed production; isolation from undesirable pollen sources; facility of access and nearness to work areas.

The ecology of the site where the seed orchard of a particular species, variety or provenance is planted, should be such as to encourage optimum development and maximum fruit setting. Where the species are native and the orchard is located within the range of the species, the best site can probably be identified quite easily. With the more extensively cultivated species, there is already sufficient knowledge available to reduce the danger of choosing a bad site. However, for species or provenances of recent introduction and little history of cultivation in other regions, choice of the seed orchard site should have top priority.

As regards climate, it is usually unwise to select sites exposed to extreme temperatures, or low areas exposed to frost. Some species, like Pinus elliottii and P. taeda, do not appear to be affected by slight changes, whereas P. caribaea is very sensitive to frost.

Although one may generalize with regard to the best texture, quality and fertility of soils for better fruit production, each species may have different requirements in this respect.

Concerning the isolation factor, it is difficult to achieve perfect isolation (which would be theoretically acceptable) and completely avoid contamination by undesirable pollen. The orchard would have to be situated outside the forest area or in a remote or not easily accessible place. Experience shows that, in orchards with normal flowering and fruiting, complete isolation can be sacrificed in favour of better siting as regards accessibility and nearness to working places. The minimum distance acceptable varies with species, topography, winds, etc. It has been found that for Pinus caribaea var. hondurensis a distance of 200 metres is sufficient (Nikles 1974) to achieve adequate isolation.

The site should be protected from wind, fire and animals, and near places of easy access and intensive work such as nurseries. The site must be visited after for management, fertilization, irrigation, pruning, collection of branches for propagation, pollination, and regular inspection. Pest and disease control are also easier. Proximity to labour force also facilitates seed collection, drying and extraction.

### Site preparation

The site selected for the orchard should be prepared according to normal afforestation practices, with no skimping on preventive control of rodents, ants and other pests. Clearing and weeding should receive the same care lavished on intensive agricultural crops.

Site preparation should facilitate mechanical work as much as possible. Paths, fire-breaks, etc., should be methodically laid out.

In clay or poorly-drained soils, it is desirable to chiselplough the planting rows. It is also desirable to use land with little or no slope; however, if no flat ground is available, contour ploughing, or, in extreme cases, terraces, to check or prevent soil erosion is recommended.

### Planting

The primary objective should be maximum survival of the material planted. If this material consists of nursery plants (seedlings of selected plants), or grafts in pots

or clumps of soil, planting should be timed to coincide with optimum weather and soil moisture conditions to ensure maximum success, as replanting in subsequent years has proved to be ineffective. It is therefore desirable to plant a greater number of ramets closer together.

On some occasions, good results have been obtained by planting the future root stocks straightaway in the spot where they will be growing permanently and later grafting in situ. This is particularly true for species that do not take well on transplanting. In this case it is advisable to plant 2 or 3 rootstocks in each spot, as a precaution against unsuccessful grafts or incompatibility, or in order to select the best graft, etc. This latter method has produced good results in Queensland, with 85 to 100% success in grafts of Pinus caribaea and Araucaria cunninghamii, and also in the southeastern United States with Pinus elliottii and P. taeda. It has the advantage of ensuring more rapid growth, earlier flowering and no root curling. (Nikles 1974). Among the disadvantages are the need for more experienced grafters and more frequent visits to tend the grafts in the field; also, weather conditions cannot be controlled (temperature, winds).

When dealing with little-known species, unpredictable climates or unskilled staff, it is therefore preferable to use material which has been grafted, or has already taken root, in shelters or nurseries.

## MANAGEMENT AND HARVESTING

### Cultivation techniques

#### Plant cover

It is advisable to weed the plantation the first year, especially around the shoots or seedlings, but experience has shown that later on it is better to let the grass grow naturally (provided there are no aggressive rhizomes) or to sow grass, which can be kept short. This practice reduces or prevents soil erosion; affords excellent fire protection, adds organic matter to the soil and keeps the orchard in excellent condition for work.

Weed killers or a mulch of straw and/or manure around the plants following superficial raking - never deep raking or hoeing that could damage the roots - are recommended when drought makes weeds over-competitive.

In areas with periodic droughts, or in dry years, it is preferable to irrigate the plantation to conserve soil moisture rather than leave the ground bare (Nikles 1974).

#### Fertilization

Fertilization can be very effective in increasing seed production on skeleton or poor soils. The type, rates and timing of fertilizer applications, vary according to species and site. Experiments described by Nikles (1974) are summarized below.

In the region of origin of Pinus elliottii, the equivalent of 1 kg of nitrogen (3 kg of ammonium nitrate) per tree is applied annually at the end of the spring or the beginning of the summer. On phosphorus deficient soils, (i.e., less than 8 to 10 kg of extractable  $P_2 O_5$ ) and potassium (less than 60 kg of  $K_2 O$  per hectare), 2.5 kg of super phosphate and 1 to 1.5 kg/tree/yr of potassium chlorate are applied. Lime is also used where acidity is high or there is a deficiency of Ca and Mg.

In Queensland, an appreciable increase in seed production has been achieved through NPK applications.

For Pinus taeda, the Cooperative Programme of the state University of North Carolina has reached the conclusion that the best way to achieve good seed production is to fertilize (NPK) in years of normal rainfall, and irrigate during periods of drought.

In Texas specific recommendations for fertilizer applications are made in the light of results of leaf analyses. It is a common practice to apply nitrogen to promote flowering.

### Pruning and thinning

Neither pruning nor crown reduction nor girdling have produced the anticipated increase in seed production of species with high apical dominance such as *Pinus elliottii*, *P. taeda* and *P. radiata*. On the other hand, bending down *P. radiata* branches has proved successful in facilitating cone collection; as has pollarding which forces the tree to produce cones lower down. Low branches are only pruned to facilitate access and movement within the orchard.

Clonal selection in the orchard will depend fundamentally on the result of the progeny tests, which will eliminate clones with poor general combining ability. The seed production of each clone should also be borne in mind. If the clone produces not seeds but male flowers (pines) and has good combining ability, it should not be culled. In the selection of clones, the degree of incompatibility and other factors producing weak or low-yield ramets should also be borne in mind.

### Protection

Seed orchards are highly specialized, expensive and very important for afforestation programmes, so they are far more carefully protected than ordinary forest plantations. This is not difficult, since the orchard is frequently visited by trained staff who can easily spot any problem that could affect the normal development of the orchard. Damage from diseases, insects, animals and birds, machine damage to trunks and branches and wind or frost damage can thus be remedied or prevented.

Fires should be prevented or controlled, by keeping fire-breaks clear, not allowing weeds to grow too tall, and having fire-fighting teams always ready for emergencies.

Measures should also be taken to avoid erosion and excessive compaction of the soil.

### Flowering, pollination and handling of pollen

The seed orchard manager needs a good understanding of the environmental factors controlling flowering and seed set, the movement of pollen and the degree of inbreeding and outcrossing. These are aspects that need to be studied in greater detail, and the reader is therefore referred to Chapters 7, 8, 9 and 11 of Faulkner's book (1975).

Until now, pollination has seldom been considered sufficiently reliable for proper seed setting to reduce selfing and avoid undesirable pollen. Brown and Eldridge (1977), hold that it is possible to pollinate 1 000 flowers with 6 of pollen. One man with simple equipment can pollinate 5 000 flowers daily. They also maintain that this technique, with some refinements, will soon become part of seed orchard management, particularly when the orchards are young.

### Harvesting of fruit and seed

Harvesting techniques depend on species, climate, site, size of the orchard, local or national economic conditions of seed. Mechanized harvesting is justified if labour is scarce or is expensive, or if very fast harvesting is necessary because the seeds ripen and are dispersed quickly in extensive orchards.

Some pines species have cones that fall very easily. These can be harvested by hand, or with mechanical tree shakers. However, in some serotinous species the cones are not easily detached from the tree. In these cases, elevating work platforms can be used. The Australian experience with *P. radiata* indicates that 6 kg per day can be harvested with this machine whereas only 1.8 kg of seed/man/day can be collected by hand (K. Willcocks in Brown and Eldridge 1977). In the southeastern United States, studies are being made on the use of a suction harvester to pick up the seeds of *Pinus taeda* from the ground. Where harvesting time is limited because of rapid dehiscence of the cones or fruits, they can be harvested green so long as the orchard staff are familiar with off-tree fruit ripening techniques.

With eucalypts, that coppice well and produce a lot of seed, Brown and Eldridge (1977) recommend felling the tree to facilitate harvesting. With serotinous cone species that have very little fruit, and where labour is expensive, harvesting is at two or three-year intervals to reduce costs.

### Seed production

This varies with the species, age of the trees, clonal composition, site, management, etc. It is important for any organization managing an orchard to determine production potential, so as to match orchard size to the forestry programme. Nikles (1974) reports that a high-yield seed orchard of Pinus elliottii in Queensland produced 145 lbs/acre (approximately 160 kg/ha); a normal yield for this species in Australia is 75 lbs/acre (83 kg/ha). With Pinus caribaea var. hondurensis the experience of the Byfield orchard indicates that between 13 and 34 lbs/acre/yr can be obtained, with an average over 8 years of 23 lbs (25 kg/ha). Other younger orchards obtained lower seed productions. The average yield of Pinus radiata, after 10 years, is 20 lbs/acre (22 kg/ha). In the United States, the average for Pinus taeda, a higher yielding species than P. elliottii is estimated at 55 kg/ha/yr.

Seeds from orchards are usually bigger, and have better germination and viability than seeds from natural forests or plantations.

### Seed extraction and utilisation

When cones are collected from an expensive seed orchard, maximum care should be taken in extraction and subsequent operations so as to maximize viability. The seed should be extracted at low temperature under dry conditions. Seed should be stored in accordance with the requirements of each species, with adequate protection from insects and rodents, and proper disinfection.

### Keeping records

Efficient seed orchard management and utilisation means keeping careful records, including: charts of ramet location, listing cultivation techniques, fertilization, costs, phenological observations, incompatibility, fruit production, relative seed production from each clone, etc. Experience has shown that the more information recorded, the better the management and future upkeep of the orchard.

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PROGENY TRIALS

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1. Variance analysis for a factorial genetic design in a completely random and equal replication statistical model.
2. Variance analysis for a modified diallel genetic design and a completely random statistical model.
3. Variance analysis for a genetic design of polymixia or free pollination in a completely random statistical model.

DEFINITION AND IMPORTANCE

The purpose of progeny tests is to estimate: (1) The genetic value of an individual on the basis of the behaviour of its offspring, or (2) the genetic value of individual half-siblings or full-siblings.

In programmes based on phenotypic selection, where environmental influence is unknown and where selection is consequently not very reliable, progeny tests are indispensable.

Progeny tests facilitate:

- (a) Evaluation of the crossing value (combining ability) of trees;
- (b) Estimation of genetic statistical parameters (variance, correlation, etc.);
- (c) Evaluation of sub-populations or lines for specific uses in plantations;
- (d) Evaluation of individuals for the purpose of continuous selection.

Crossing value <sup>1/</sup>

This is the value of a tree, determined by the average of its progeny obtained from crosses with one or several other trees, following a specific plan. The crossing value of individuals is determined by specific crossing systems (genetic designs). From this, we can determine the combining value of an individual which is a statistical parameter that indicates the ability of an individual to transmit certain of its characteristics to progeny resulting from crosses with one or more other individuals. This information is used as a basis for selective thinnings in seed orchards.

Estimation of genetic statistical parameters <sup>1/</sup>

This is done through a series of theoretical assumptions on the components of the phenotype and constitutes the mathematical basis of genetics. It involves the use of special types of genetic and experimental designs.

These require determination of the components of variance and co-variance, using Expected Mean Squares in Variance and Co-variants Analysis Tables.

The determination of such parameters as heritability ( $h^2$ ), makes possible eventual estimation of genetic gains or the response to breeding schemes as regards both how many in numerical value and how much improved.

Evaluation of groups or lines <sup>1/</sup>

In specific cases, the results of particular combinations between clones or families resulting in progeny outstanding for a specific characteristic (high value of specific combining) can be used.

Evaluation of individual trees <sup>1/</sup>

For the purposes of continuous selection, individual evaluation is made as and when advanced seed orchards are established, i.e. in future generations.

This requires continuous selection within progenies of the most outstanding individuals. It can lead to problems of inbreeding in orchards of an older generation, but this can be counteracted by having a sufficiently broad basis for initial selection, and separating the seed production population from the breeding population (see paper entitled "Planning and Strategies of a Forest Tree Improvement Programme").

TYPES OF PROGENY

The quantity of information that can be provided by trials depends on the type of progeny, among other things.

We may distinguish two principal types: semi-fraternal (half-sibs), and fraternal (full sibs).

Half-sibs are progeny with a known parent in common (the mother tree). They are typically freely pollinating, the exact degree of inbreeding is unknown.

Information obtained will depend on the value of the seed tree.

<sup>1/</sup> For more detailed information, see paper entitled "Quantitative Genetics".



Full sibs are progeny with two known parents in common. This can only be achieved through controlled pollination.

In this case, the tests will produce more information, as it is based on the values of both parents. However, most progeny tests made to date have been with half-sibs, since the establishment of full-sib tests involves considerable work and expenditure.

#### CROSSING SYSTEMS

The way in which parent trees are combined influences the results of tests, since it determines the type of progeny obtained.

There are two important general types of crosses in the field of forestry: (1) crossing systems with an unknown father, and (2) crossing systems with a known father.

In the first case the principal systems are: (a) free pollination and (b) poly-crossing; in the second (c) diallel designs (complete, modified, partial diallels), (d) factorial designs, and (e) mating of a single pair. For detailed information on these designs, see the paper entitled "Systems and Designs of Controlled Crossing".

#### EXPERIMENTAL DESIGNS <sup>1/</sup>

The environmental component in progeny tests is controlled by the use of experimental designs which seek to reduce the non-genetic effects. Randomization (random distribution), replication (repetition) and local control (blocks) should be taken into consideration.

The use of blocks facilitates control of local variability, exposing the progeny to fairly standard site conditions. Ideally, replication makes it possible to expose individual progeny to different site conditions, which occur quite frequently in the same plantation. The genetic and environmental components of the phenotype can thus be estimated. Randomization is indispensable for obtaining estimates not vitiated by experimental error.

The testing site should be representative of the area where the seed will eventually be used in a normal plantation. The best experimental design usually depends on the number of progeny, plot size, and site variability. The complete blocks design is often used for low numbers of progeny and trees per progeny, and sites of average to low variability. For a large number of progeny (more than 25), large plots and very heterogeneous sites, it is advisable to use incomplete block designs such as lattices.

Plot size can range from one tree per plot upwards. Low numbers, particularly in row plots, are desirable if the value of intra-progeny competition is to be ascertained. High numbers are desirable with square or rectangular plots in estimating genetic statistical parameters where the value of competition is a bias factor. In this case, one condition is a variable number of trees in the centre of each plot of a given progeny, that are not in direct contact with other progeny, or else are surrounded by buffer areas of trees of their own kind.

In order to cover the maximum intra-progeny variability, it is recommended that the number of replications be increased for smaller plots.

Replication can be spatial (control of local environmental variability) and temporal (control of climatic or biotic variations).

#### CULTIVATION TECHNIQUES

Spacing should be the usual planting distance in a normal programme. Tending should, as far as possible, be the same as for large-scale plantations. "Luxury tending" should be avoided.

Protection against fire, wild animals, etc., should be effective.

<sup>1/</sup> For more detailed information on experimental designs, see the paper on this subject.

### EVALUATION

The characters evaluated will depend on the actual and potential uses of the species under consideration. There are, however, several (general) characters common to the majority of uses, such as survival, growth and vulnerability to pests and diseases; other (specific) characters will depend on the use envisaged.

Evaluation in the field usually begins six months or a year after the test, with mortality and attack counts, and measurement of initial growth. Evaluation is usually repeated in the second and in the fifth, seventh and tenth years, including other characteristics in the measurement, as the individual trees develop. For most characters, the minimum age for making reliable evaluations is considered as equal to one-third of the final rotation of the species. For some characteristics, such as wood quality, it is usually necessary to wait until the end of the rotation, with periodic evaluations every three or five years.

Evaluations are also made in the nursery, for correlative comparisons with field behaviour. These evaluations can also be used for selecting within the nursery itself. Even more important, these studies can include seed characteristics such as weight and size.

### RECORDS

A detailed record of the material and the procedures used is indispensable, a file should be kept for every test made. This file should include a summary of the objectives of the test, and all observations made during the course of the test, data and analysis of evaluations, etc. This procedure will make it easier to come to the right conclusions at the end of the test.

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ANNEX I

Specific models

1. Variance analysis for a factorial genetic design in a completely random and equal replication statistical model

Source of variation	Degrees of freedom df	Mean square expectation E(MS)	Genetic interpretation
Male	$m - 1$	$\sigma e^2 + r m^2 h + r h m^2$	$\sigma m^2 = \text{Cov}(fm)$
Female	$h - 1$	$\sigma e^2 + r m h^2 + r m h^2$	$\sigma h^2 = \text{Cov}(fh) = \frac{1}{4} VA$
Male x Female	$(m-1) (h-1)$	$\sigma e^2 + r m^2 h$	$\sigma m^2 h = \text{Var}(f) - \text{Cov}fm$
Error	$mh (r-1)$	$\sigma e^2$	$-\text{Cov}_{fh}$  $= \frac{1}{4} VD$
Total	$mhr-1$		

$\sigma^2$ = Component of variance for the source of variation indicated by the letter(s) below.

$\text{Cov}_{fm}$ = Co-variance of half-sibs with a male parent in common.

$\text{Cov}_{fh}$ = Co-variance of half-sibs with a female parent in common.

$\text{Var}_s$  Sibling variance.

Additive component of genotype.

$VD$ = Non-additive component of genotype.

2. Variance analysis for a modified diallel genetic design  
in a completely random statistical model

Source of variation	Degrees of freedom df	Mean square expectation E(MS)	Genetic interpretation
General combining value	$p - 1$	$\sigma e^2 + r e^2 + r (p-2) g^2$	$\sigma g^2 = \text{Cov } f$
Specific combining value	$p(p-3) / 2$	$\sigma e^2 + r e^2$	$\sigma e^2 = \text{Var } f - 2\text{Cov } f$
Experimental error	$p(p-1) (r-1)/2$	$\sigma e^2$	$\frac{1}{4} V_D$

$P =$  Number of parents.

$\sigma^2 =$  Components of variance for the source of variation as indicated.

$\text{Cov } f =$  Half-sib co-variance.

$\text{Var } f =$  Full-sib variance.

$V_A =$  Additive component of genotype.

$V_D =$  Genotype component.

3. Analysis of variants for a genetic design of polymixia or  
free pollination in a completely random statistical model

Source of variation	Degrees of freedom df	Mean square expectation E(MS)	Genetic interpretation
Progeny	$(P - 1)$	$\sigma e^2 + r p^2$	$\sigma p^2 = \text{Cov } f = \frac{1}{4} V_A$
Experimental error	$f(r - 1)$	$\sigma e^2$	

$\sigma^2 =$  Component of variance for the source of variance indicated.

$\text{Cov } f =$  Co-variance of half-sibs.

$V_A =$  Additive component of genotype.

GENOTYPE-ENVIRONMENT INTERACTION

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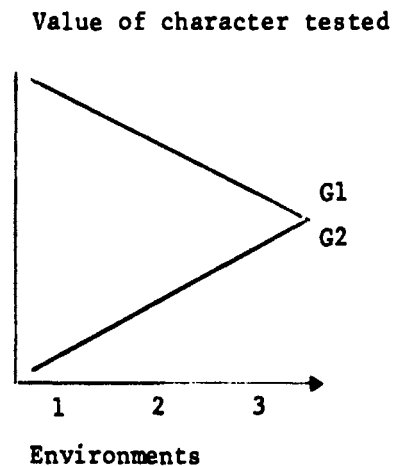
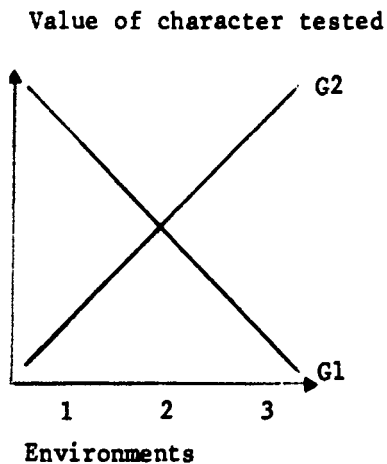
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EXISTENCE AND IMPORTANCE

Genotype-environment interaction may be defined as lack of uniformity in the response of two or more groups of plants grown in two or more environments; one group may show the best growth in one environment, but be mediocre in another.

The interaction may show itself in a change in the relative position of the groups in each environment, or in differences in the degree of superiority, even when the rank positions are equal in each environment.

In graph form, an interaction is represented by lines which cross or approach each other, as the environment varies, following a given gradient.



Since it is more apparent, the first makes it necessary to select a distinct group for each environment, in order to obtain the best gain in productivity.

The second is important as a guide for the extrapolation of data to environments different from those tested.

The presence of genotype-environment interaction reflects the existence of environmental variations, even over relatively small distances, and of variations in the requirements of different genotypes in both macro and micro environments. The same reasoning may be applied to seasonal variations.

This is the fundamental reason why experiments need to be repeated both in different areas (control of local environmental variation) and at different seasons (control of cyclical variation).

Different levels of genotype-environment interaction may be distinguished in forestry, due mainly to the genotypic constitution in question. Thus we note the existence of species x environment, provenance x environment and progeny x environment effects.

In terms of species, the differences with regard to adaptability to environments are greater, i.e. there are species which possess a wide range of adaptation, so that the detection of interaction necessitates tests over a wider range of environmental conditions. If the genetic spectrum, i.e. the provenances and progenies, is reduced, interaction tests become more sensitive, in that the ranges of tolerance narrow, and this sensitivity shows up in different reactions to minor variations in the environment.

Of the environmental factors that indicate interactions, the most tangible are soil conditions, since these can be detected within a plot, over relatively small areas. Climatic conditions have to be more extreme in order to be detected, e.g. variations due to extreme conditions of temperature (low or high), humidity (drought or flooding), etc.

The interaction may be considered as an indicator of the relative stability of a genotype. If the interaction is close to zero, the genotypes are sufficiently stable for the characteristics under consideration, i.e. their relative positions and the differences in magnitude of responses are similar in the different environments; the only thing that changes is the actual magnitude of the responses, which will depend on the particular genotypes (species, provenances, individuals) and sites under consideration.

Genotypes with a wide range of adaptability, as shown by zero or insignificant interaction, are called plastic, while those with a high susceptibility to marked variation in behaviour with slight variations in the environment are called rigid or strict.

Since the components of genotype and environment also play a part, though small, in the response of individuals (evaluated in the phenotypes), the interaction will never represent 100% of the variation observed; however, the nearer one comes to this value, the lower will be the stability of the genotype in different environments, and from the point of view of the breeder, the less reliable it will be for large-scale propagation under normal plantation conditions. It will be more suitable for plantations in limiting environmental conditions, since these are established in relatively small areas and under more homogeneous site conditions.

The present tendency of breeders is to produce sub-populations with a broad spectrum of adaptability, which, in the long run, can represent greater gains for lower costs.

If the interaction is not significant, selection will be made on the basis of the mean of the responses of the genotypes in all the environments. This same criterion may be adopted when the interaction is significant, but at levels very close to the lowest critical limit of probability (usually 5%), in which case it may be ignored in practice.

The practical problems of using interaction as a yardstick are highlighted by certain factors, the difficulty being to interpret it correctly. Very often the existence of interactions is reported on the basis of a very few tests, located very close to each other, which in practice would be of very dubious applicability from the point of view of costs. In these cases it is recommended that the interaction be considered as part of the experimental error and the average yields from the sites tested be taken as the basis for work.

Effective practical use of interaction requires essentially testing of the same genotypes in a range of environmental conditions which represent marked variations, with areas sufficiently large to be used for plantations.

DETERMINATION

Rank position

A simple, preliminary way of evaluating the presence of genotype-environment interaction is by using the rank position of each of various genotypes in each of various sites or environments.

The genotypes are graded from best to worst, according to their yield in each site, assigning them a number from 1 to n (according to the number of genotypes).

If there are noticeable changes in position from one site to another, this indicates interaction.

<u>Genotypes</u>	<u>Environments</u>		
	<u>1</u>	<u>2</u>	<u>3</u>
A	1	3	3
B	5	1	2
C	4	2	5
D	3	4	4
E	2	5	1

A disadvantage of this method is that rank classification gives us only an overall idea of the magnitude of the changes from one environment to another, since the changes will always be in constant units. In addition, there is no statistical information available on the significance of these changes.

A statistical approximation can be obtained by using rank correlation, using pairs of stations. These may be all the pairs possible according to the number of environments, or the environmental extremes in question.

Variance analysis

The importance and magnitude of the interaction are evaluated by using different methods of variance analysis. One method is to combine variance analysis with a specific experimental design (e.g. random complete blocks).

<u>Sources of variation</u>				
Sites	(L-1)			
Blocks/sites	L(r-1)			
Genotypes	(t-1)			
Genotypes x sites	(t-1)(L-1)	MSI	$\frac{MSI}{est. MS}$	$2 = 2$ $\sigma_e + K1 \delta I$
Errors	L(t-1)(r-1)	est.MS		$\sigma_e^2$
Total	Lrt-1			$\sigma_F^2$

The significance test gives us information on the overall importance of the interaction. We obtain its magnitude ( $\sigma I^2$ ) and effective participation in the total variation ( $\sigma F$ ) by estimating the variance components, using the means squares (E(MS)) anticipated from the variance analysis table.

### Regression analysis

Another way of using the principle of variance analysis is through the regression of the genetic values in the environments. For this it is necessary to establish the same genetic entities (normally progeny) in various well-differentiated environments (preferably more than two). The individual values of a given characteristic of each genetic entity (genetic values) are related to the overall means of each site (environmental values) adjusting simple lineal regressions. This results in various straight lines (as many as there are progeny), which are then compared with each other, analytically or graphically. The graphic form is the most usual, and the presence or absence of interaction is indicated by the arrangement of the lines. If they are more or less parallel, the genetic entities are said to be relatively stable (no interaction). If the lines cross or markedly diverge from the parallel position, this indicates the presence of interaction.

Analytical methods involve comparison of the lines to see whether they are to be considered as having the same slope, and involve, for each genetic entity quantifying the importance of the regression or deviation.

The most stable genetic entities are those whose regression approaches the unit and the deviations zero. If these stabilities are associated with acceptable productivity (best or nearly best), then they will have preference over others which, although the best in a given environment, are unstable as a whole.

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Participants visiting CVG Pinus caribaea plantations in Uverito



BREEDING FOR DISEASE RESISTANCE 1/

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INTRODUCTION

A disease involves harmful physiological changes in a plant. The changes may be caused by non-pathogenic agents such as adverse climatic or soil conditions, or by a pathogen (Tarr 1972). The most important biotic diseases of forest trees are caused by fungi (Cowling 1969). Research on the genetics of insect resistance and on resistance to bacteria and viruses has not been nearly so extensive as on the genetics of resistance to fungal diseases. Nevertheless, enough is known to indicate that the inheritance of resistance to these agents differs in no major way from inheritance of resistance to fungi (Allard 1964; Painter 1966). Major stress in this paper will be placed on infectious diseases caused by fungi. The term 'breeding' will be treated in the broad sense, thus including procedures of selection.

The general objective of a program to produce pest resistant trees is to reduce losses to a pest by genetic manipulation of the host trees (Callaham *et al.* 1966). The probabilities of success in a breeding program will, to a large degree, depend on the establishment from the outset of a clearly defined set of objectives and a realistic order of priorities. The prospects for significant improvement of disease resistance are better in forest trees than in most cultivated crops, because forest tree species generally represent natural cross-pollinated populations which provide a wide range of genotypes for basic selection (Schreiner 1966). Concurrently with improvement in disease resistance, it is necessary to provide for improvement in yield and quality of the crop. A realistic weight must be given to the importance of each factor in the breeding program (Borlaug 1966).

Selection and breeding for disease resistance does not vary fundamentally from breeding for any other character (Allard 1964; Dyson 1974). Consequently, any of the various methods of breeding appropriate for the crop or species in question can be used in developing disease-resistant varieties or population, once resistance-conferring genes have been found (Allard 1964). However, it must be kept in mind that disease

1/ Based on a paper presented at the Training Course in Forest Tree Breeding held in Canberra, Australia, 1977.

resistance involves two genetic systems, that of the host and that of the pathogen, each a result of the two basic variables of genotype and environment. The phenotypic expression of a disease will thus depend on the interactions between the host, the pathogen and the environment (McIntosh 1971). As the pathogen populations constantly react to changes introduced into the host populations (Dinoor 1975), resistance breeding is a dynamic rather than a static process. A full understanding of the pest complex, including the variability and genetic potential of the host, the biology of the pathogen and the interactions between host, pathogen and environment, is a necessary basis for a program on breeding for resistance.

#### VARIABILITY OF THE PATHOGEN

Diseases in forest trees can be grouped into two categories, those caused by obligate and those caused by facultative parasites. Obligate parasites are restricted to living tissue, whereas facultative parasites are able to colonise both living and dead organic matter (Tarr 1972). The rust fungi are examples of obligate parasites in forest trees (e.g. blister rust of pines and leaf rust of poplars), while facultative parasites, which often are limited to certain provenances, include blight diseases (e.g. needle cast disease of pines and stem canker of poplars) (Bjorkman 1966). The susceptibility of trees to facultative parasites is generally greatly affected by their physiological condition and growth vigour, and thus indirectly by the environment (Schreiner 1966).

Pathogenic organisms have enormous potential for developing new, virulent forms or races. Plant breeders must therefore be prepared to face new races of pathogen to which their formerly resistant varieties or populations are susceptible (Allard 1964).

Once a fungal race becomes established, its prevalence is determined by the varieties of the host plants being grown. An extreme case is the growing of a crop consisting of inbred lines or one single clone in which the individuals are genetically identical, possessing identical genes for resistance against prevailing races of the pathogen. A host population like this will exert a strong selection pressure, and is likely to give rise to highly specialised physiologic races of the pathogen which are able to overcome the resistance of the host (Borlaug 1966).

The key to understanding variability in fungi, including variability in pathogenic capabilities, lies in their reproductive systems. In addition to meiotic recombination of the genetic material, variation may be added to the population by non-meiotic recombination, by heterocaryosis, in which two or more nuclei occupy the same cell, by cytoplasmic inheritance, and by mutation which, itself, provides the initial genetic differences that are brought together in the various recombination processes (Buxton 1961). The majority of the species are haploid organisms in which nuclear fusions occur to give rise to a relatively short-lived diploid stage, but life-cycles ranging from completely haploid to completely diploid are also encountered (Allard 1964).

#### VARIABILITY OF THE HOST

Variability of the host leading to resistance can be either active or passive. Passive resistance is accomplished by structural barriers of a morphological or anatomical nature. Active resistance is due to vital processes initiated in the host as a reaction against a pathogenic agent, and is directed against the agent itself (Gäuman 1950).

Schreiner (1966) lists the following host characteristics as the most common ones contributing to disease resistance in forest trees:

- (1) Variation of the host in the uptake of minerals under similar field conditions;
- (2) Differences in water content of the host tissue;
- (3) The presence of metabolic products in the host tissue other than phytotoxins;
- (4) The presence of fungistatic or phytotoxic substances in the host;

- (5) The production in the host tissue of phytotoxins;
- (6) Pre-existence of formation of barriers that restrict the movement of the pathogen into and within the host tissue;
- (7) Effect of osmotic substances on germ tube growth and penetration of stomata;
- (8) Escape mechanisms such as drooping needles or densely pubescent leaf surfaces.

The genetic nature of host resistance can either be vertical (specific resistance) or horizontal (non-specific resistance, also called field resistance or tolerance) (van der Plank 1963). Vertical resistance acts against specific races or varieties of the pathogen; it is generally characterised by a close correspondence between the genes of the pathogen and those of the host, and is often controlled by single genes, although many genes may be involved. The genetic components that contribute to vertical resistance can generally be isolated and studied in appropriate crosses (Schreiner 1966; Watson 1971).

Horizontal resistance is generally polygenic and many factors, such as control of rate of growth of the hyphae through the host tissue and penetration through the tissue, may simultaneously control resistance. Horizontal resistance generally gives a certain amount of protection against a whole range of races of the pathogen (Watson 1971). No direct correspondence exists between host and fungal genes, and although generally more efficient against fungi and favoured both in agriculture and forestry, polygenic systems are more difficult to utilise in breeding than the major genes controlling vertical resistance (Heybroek 1969; Luig 1971; Watson 1971).

Present evidence for forest trees indicates that resistance may be due to a small number of major genes (e.g. in blight resistance of poplar hybrids; see Heimbürger 1966), monogenic resistance (e.g. in resistance of western red cedar to leaf blight; see Soegaard 1966), polygenic resistance (e.g. in resistance of western white pine to blister rust; see Bingham et al. 1960), and cytoplasmic inheritance (e.g. in resistance of larch to needle blight; see Lagner 1952). Both major genes and polygenes may simultaneously contribute to resistance (e.g. in resistance of eastern white pine to blister rust; see Heimbürger 1962).

While it has been generally accepted that different genetic systems operate in the case of vertical and horizontal resistance to a single disease, the same genes may be involved in both types of resistance (Watson 1966). A diversity of resistance genes in the population will reduce the chances of the pathogen overcoming existing resistance by a change in virulence or pathogenicity (Borlaug 1966; Watson 1971; Dinooor 1975).

In addition to being genetically controlled, horizontal resistance may arise from imperfect synchronisation of pathogen and host, as in diseases which appear late in the life of the plant or late in the growing season (e.g. poplar leaf rust). This verges on disease escape, in which vigorous individuals may be able to replace diseased leaves or other parts, and so produce a reasonable yield in spite of infection. Plants may also escape infection if their susceptible phase happens to come at a time when the pathogen is absent, present in insufficient amounts, or when environmental conditions are unfavourable to it (Tarr 1972).

#### PRINCIPLES OF BREEDING FOR DISEASE RESISTANCE

##### Assessing the control alternatives

Before embarking on a program to breed pest-resistant trees, alternative methods of disease control should be carefully assessed. These include: (1) exclusion, (2) avoidance, (3) eradication, and (4) protection through chemical or biological control (McNabb 1964; Gibson 1975).

Exclusion through quarantine, i.e. restricting the introduction of plants, parts of plants or soil into the country (as e.g. in Australia) may be effective against diseases not yet established, provided there are adequate means of enforcing the legislation. Exclusion through inspection and treatment of planting material and possibly tools and machinery before transferring them from one region to another pre-supposes good information on the spread and life-cycle of the pathogen (Gibson 1975).

Disease avoidance through a change of species is usually effective if an acceptable alternative species is available (e.g. the change from one species of cypress to another in East Africa discussed later in this paper; the change from spruce to pine or larch on some sites infested with root rot in Northern Europe; see Palmberg 1969). Adjustment of e.g. sowing and planting times to reduce the risk of infection can sometimes be successful, as can a change in management practices (e.g. a change in pruning routines of cypress in East Africa; see Rudd-Jones 1954).

Eradication of other than nursery diseases must be achieved at a very early stage of the disease outbreak, and calls for an exceptionally efficient survey organization to be effective, e.g. eradication of diseased individuals of elm to stop the spread of dutch elm disease have largely failed (Neely 1975). Eradication of the secondary host in rust diseases has, however, proved fairly effective (e.g. removing aspen in Northern Europe and *Ribes* spp. in USA from areas close to pine plantations to avoid damage by pine twist and fusiform rusts; Day 1972).

Protection by the application of fungicides is generally regarded as too costly outside the nursery. However, in diseases which attack the trees during a limited period of their life this approach can sometimes be economically acceptable (e.g. spraying of radiata pine against needle blight in New Zealand; see Gilmour and Vanner 1971). Protection by the application of insecticides is usually considered feasible during outbreaks of insect epidemics (Benedict 1964). Biological control has been very successfully employed against insects (Franz 1964) (e.g. control of the Sirex wasp in Australia; see Anon. 1974).

The above control methods are in many cases practiced parallel with programs on breeding for disease resistance, and some of them provide only short-term solutions to a problem. Generally the most economical and, in many respects, ideal method of achieving disease control is the development of resistant biotypes of the host (Gibson 1975).

#### Developing methods for evaluation of resistance

Once a decision to breed for resistance has been reached, the development of rapid and accurate methods for evaluating resistance in the host plant is the most important immediate problem. Resistance is not an intrinsic character, but is subject to environmental influences on the host, the pathogen and the host/pathogen relationship (Schreiner 1966). In addition to basic research on the establishment and progress of parasitism, the development of such evaluation methods will therefore require knowledge of the effects of environmental factors on host resistance and of the pathogenicity and virulence of the parasite (Callahan et al. 1966; Schreiner 1966).

As expression of resistance is phenotypic, the same expression may be the outcome of interaction between many different host and pathogen genotypes (Dinoor 1975). The identification of genes for resistance therefore involves crosses and genetic analyses, which in turn require the development of efficient techniques for selecting, propagating, breeding and progeny testing the host (Schreiner 1966).

Identifiable resistance genes depend on the pathogenic strains present; in the absence of the pathogen, resistant genotypes are indistinguishable from non-resistant (Allard 1964). Programs for identifying resistance should therefore always be based on artificial inoculation (Allard 1964; Dyson 1974). As immunity to a disease is usually an unrealistic objective, it is necessary to set up minimum practical standards of resistance for each host/pathogen relationship. For both economic and biological reasons these standards must be kept flexible (Schreiner 1966).

#### Selecting for disease resistance

After developing methods for recognising and identifying disease resistance, the next step is to locate resistant material in existing populations of the host (Allard 1964).

Resistance to disease in plants is more common than susceptibility, most wild plants being resistant to most diseases (Cowling 1969). Our most disastrous forest tree diseases have resulted from the introduction of foreign pathogens into populations which carry no effective genes for resistance to this pathogen (e.g. chestnut blight, dutch elm disease, white pine blister rust) (Borlaug 1966). Widespread planting of fast-growing exotics

sometimes under unfavourable ecological conditions and of populations possessing a very narrow genetic base, also easily leads to phytopathological problems (e.g. needle blight in radiata pine in East Africa, poplar leaf rust in Australia) (Björkman 1966).

Genes do not occur at random in populations (Qualset 1975). Long association between pathogen and host is likely to lead to the development of mutual tolerance, with consequent elimination of highly susceptible host genotypes through natural selection (Tarr 1972). Genes for resistance to pathogens and pests are therefore likely to be found in highest frequency in regions where the plant in question has been grown on a large scale in the presence of the pathogen, or by an extensive search of natural populations.

A large number of individuals should be screened at high levels of artificial inoculation to augment any search for resistant individuals in the forest. Resistance tests must be designed in consideration of the biology of the host and the biology of the pest; for example, the age of the host at which infection and diagnosis are to be made must be known. The trials should be replicated to sample a range of environments. The design must allow for statistical procedures to deal with variation in host, pest and environment, and their interactions. Tests on clone x environment interactions should not be considered conclusive until 1/3 to 1/2 of the estimated rotation elapses (Callaham *et al.* 1966). Screening for vertical resistance should be undertaken in each planting region separately, whereas screening for horizontal resistance often can be centralised. However, factors like climate and the amount of virulent inoculum present in various planting regions may alter the level of resistance found at a central testing site (Dinoor 1975).

If vegetative propagation is feasible for mass-production of planting material (as e.g. in poplars) and if the resistant trees have desirable phenotypes, they can be used immediately to develop pest resistant test populations. However, in the case of species reproduced by seed, it should be remembered that trees not only vary in resistance to a pathogen, but also in their ability to transmit resistance to their progeny (Wood 1966). It is therefore essential that phenotypically selected trees of these species are progeny tested. If resistant progenies emerge, their parents can tentatively be designated 'resistance transmitters' (Schreiner 1966), and after further tests propagated into orchards to produce resistant F<sub>1</sub> seed (Callaham *et al.* 1966). Trees exhibiting high general combining ability for resistance will be of greatest use. Specific combining ability can be utilised only through vegetative propagation or through controlled crosses.

### Breeding for disease resistance

Variation in the degree of resistance has been attributed to the kind and number of resistance genes present in the parent (Wood 1966). Breeding can be used to ensure that cultivars possess maximum genetic diversity for resistance genes (Watson 1966).

In polygenically controlled systems a selection plateau may be reached beyond which further advances are insignificant. This plateau may or may not confer a degree of resistance adequate for practical purposes. Introducing new variation through hybridization of the most resistant individuals and additional populations of the host which show some degree of resistance may overcome this plateau (Heimbürger 1962).

If sufficient disease resistance cannot be found in existing populations of the host species, genes for resistance can sometimes be introduced through inter-specific hybridization. If the resistant material thus developed is not commercially acceptable, two procedures are available: the F<sub>1</sub> hybrids can be crossed to produce an F<sub>2</sub> generation where segregation and recombination may result in acceptable resistant phenotypes, or the F<sub>1</sub> hybrid can be backcrossed to the desired parent species (Allard 1964). Renewed screening for disease resistance must be undertaken in these new populations.

Mass-producing inter-specific F<sub>1</sub> seed possessing both desirable phenotypic characteristics and disease resistance may be done either through controlled pollinations or, where the two species involved flower simultaneously, they may be interplanted in orchards to produce hybrid seed spontaneously. In some cases single clones of one species can be interplanted within stands of the other species; this procedure facilitates roguing of non-hybrid seedlings in the nursery (Callaham *et al.* 1966).

Both intra- and inter-specific hybridization may be used to transfer genes for resistance to desirable phenotypes.

#### Maintaining resistance in improved populations

There is evidence of sufficient variation in resistance between species, races and individuals to warrant the use of resistance breeding to combat practically all important plant diseases (Schreiner 1966). Whenever satisfactory disease resistant varieties are available they have been preferred over other means of control, because once developed they add little or nothing to the cost of production (Allard 1964). In crop plants which to a great extent consist of genetically homogeneous planting material and inbred lines, resistance breeding demands continuous study and mobilisation of new and different sources of resistance (Dinoor 1975). For example, the average maximum duration of effective protection by any given type of stem rust resistance in wheat in USA and Canada has been about 15 years; the situation has been even worse in respect of areas of the sub-tropics and the tropics, where the disease escape mechanism does not function effectively and where the gene pools for pathogenicity are broad and persist from year to year (Borlaug 1966).

As long rotations are the rule in forestry and effects of any long-term climatic changes on the host, the pathogen and their inter-relationships may be pronounced, the question of maintaining resistance is of vital importance (Schreiner 1966; Painter 1966).

The probability of attaining and maintaining resistance by breeding for extended periods of time is generally directly proportional to the diversity of germplasm available to the breeder (Painter 1966). Whereas the basic unit in crop plant breeding is an inbred line or a strain of the plant, the basic unit in forestry is generally the individual, and an infinite number of genotypes is involved in each population (Painter 1966). As long as the genetic base in forest plantations is not allowed to become too narrow through vigorous selection in limited populations and through inbreeding, problems are unlikely to develop on the same scale as in agriculture. Broadly based genetic reserves may be an additional safeguard for the future; by this means the capacity of the host populations to react to the changes in pathogen populations may be preserved (Dinoor 1975).

#### PRACTICAL IMPLICATIONS

Although breeding for disease resistance in forest trees is a long-term project, success stories are numerous.

Diseases attacking the leaves, limbs and stems of trees have been more thoroughly investigated than e.g. root rots. Although root rots are economically important, evaluation of resistance, screening of selections and progenies, and the development of effective inoculation methods cause difficulties when dealing with internal damage. In addition, root rot fungi usually invade the dead heartwood of the tree, in which the possibilities of introducing changes leading to resistance seem smaller than in living tissue. There have, however, been some positive results from altering by selection the toxic substances present in the heartwood (Björkman 1966; Cech et al., 1966).

Two examples, one entailing a change of species and subsequent selection, the other selection and further breeding, may serve to illustrate how the techniques on breeding for disease resistance outlined above can be successfully applied in practice.

Cupressus macrocarpa Hart. and C. Lusitanica Mill were introduced into East Africa in the early 1900s. C. macrocarpa was favoured in plantations because of its somewhat faster growth. However, problems were soon encountered with cypress canker, caused by the fungus Monochaetia unicornis (Cook & Ellis) Sacc. The pathogen was studied intensively in the early 1950s. It was found that it occurred on the indigenous species Juniperus procera Hook, in which it caused little damage. Three strains of the fungus were isolated, two unimportant and one virulent one; these were brought into culture to facilitate their study. Then an effective inoculation technique was developed, involving wounding the stem before the application of virulent inoculum. It was found that disease resistance of individual trees could be evaluated by measuring the rate of diameter increase of bark lesions on the trees over a period of three months after inoculation. Using this method it was demonstrated that C. lusitanica was only half as susceptible

as C. macrocarpa, and a change of species was therefore recommended and undertaken. The same inoculation technique was subsequently used to test open pollinated C. lusitanica progenies of select plus trees (Dyson 1974). Some 80% of the total reforestation area in Kenya is presently planted with C. lusitanica. All seed used originates in seed stands selected for good form, high yield and a high degree of disease resistance.

Western white pine (Pinus monticola Dougl.) is among the most valuable timber trees in USA. Blister rust, Cronartium ribicola Fisch., was first accidentally introduced into USA in the 1920s, and by 1941 the disease had reached epidemic proportions. Observations in natural populations of the pine showed that variation existed in disease resistance. Apparently resistant or immune phenotypes were selected, and resistance was tested by the response of grafts and progeny of selected trees over several years and at several sites. As the alternate host for the disease is Ribes spp. this plant was interplanted in the experimental plots to augment inoculum potential. Results from grafts and progeny trials indicated that both additive and non-additive gene effects were involved in resistance. The original selections were screened for high general combining ability by means of these trials.

The next step in the breeding program involved controlled crosses between promising phenotypes; these were tested for two years under intense artificial inoculation, using an "inoculation tent" which maintained humidity at levels favourable to the pathogen. It was found that no selection yielded progeny that were completely immune to the disease, and that a wide range of variation was apparent in the level of resistance transmitted by the selected trees (Bingham et al. 1960; Hoff 1966; Bingham 1969).

Practical breeding programs now utilise natural intra-specific variation in western white pine. The Forest Service of the Northern Region has embarked on a project to mass-produce  $F_2$  seed from screened intra-specific  $F_1$  hybrids of phenotypically resistant parents. Heritability studies have indicated a gain of some 20% of  $F_1$  stock in disease resistance under intense artificial inoculation conditions. Practical problems encountered involve seed orchard technology, size of gene pool needed for each planting area to assure adequate genetic variation for further improvement of desirable traits, and procedures to speed up selection and testing of new individuals (Hoff 1966).

During the last ten years there has been a growing interest of inter-specific hybridization in the white pine group. There are more than 20 species of 5-needled white pines exhibiting varying degrees of resistance to blister rust. The breeding programs have concentrated on those 14 species which possess the widest adaptation to varying site and climatic conditions and the strongest species-wide resistance. Comparative world-wide observations have been made on the relative resistance of the various species, and an international list of 'tentative rankings' has been drawn up. Resistant hybrids between a number of species have been produced and tested on an experimental scale; especially some of the Asiatic species (P. griffithii, P. Armandii, P. Koraiensis) and their hybrids have proved promising, exhibiting a much higher degree of resistance than e.g. P. monticola (Bingham 1972).

Steps in developing resistance through inter-specific crosses parallel those producing resistant strains within a species (Callahan et al. 1966).

The role of forest genetics will become progressively greater as forestry becomes more intensive. The growing of big, uniform plantations with stock often bred for non-fitness traits like growth and stem straightness in the absence of potential pathogens will increase the disease hazard. Efficient plant breeding programs should include plans to deal with the threat of undetected pathogens and new virulent races of existing ones before they can cause excessive damage. As stressed earlier in the paper, this can best be done by maintaining heterozygosity and a broad genetic base in the plantations as well as in the genetic reserves established or maintained in connection with the breeding programs.

International co-operation is essential for rapid progress in disease resistance breeding. The co-operation should include genetic conservation of natural stands to serve as gene pools for disease resistance, international gene banks of pest resistant genotypes for the use in breeding, and an increasing exchange of information.

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ECONOMIC CONSIDERATIONS IN FOREST TREE BREEDING PROGRAMMES

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INTRODUCTION

Tree breeding through genetic manipulation is one of several methods available for increasing forest production and the efficiency of processing procedures. The potential benefits and costs of tree breeding must therefore be considered within the overall framework of the task of reforestation and utilization as a whole.

Restocking programmes may be promoted by individuals, private companies, ministries or other public bodies. If the capital comes from private sources, the usual objective is to maximize annual benefits. Projects promoted by public bodies may be established for social purposes, but also to obtain direct economic benefits. In the latter case, the objective will be to achieve maximum production rather than to maximize the economic benefits, in order to ensure that the country has an adequate supply of wood, or to develop (or maintain) a strong forest products industry.

In this paper we shall deal only with considerations relating to financial cost-benefit models, but the breeder must bear in mind that an analysis of social costs and benefits may be necessary in certain cases, and may lead to entirely different conclusions (Reilly, 1977).

MARKET FACTORS

The market for genetically improved seed is like that of other commodities. Growers supply seed in accordance with existing demand.

The demand for genetically improved seed depends on the nature and level of the demand for the commodities grown from the seed, and this, in turn, reflects the demand for

products made from these. This is of great importance, since the price that the buyers are willing to pay for the improved seed will be equal to the price of the products grown and manufactured from this seed, less the costs of cultivation and processing.

Since the benefits of a tree breeding programme will extend beyond the first few years, it is advisable to have some idea of future trends in the market for the processed products. The level of demand forecast will influence the amount of seed to be produced, while the nature of the demand will influence the characters to be selected and the intensity of selection.

In a stable market situation in which supply and demand, and hence prices, do not vary, the point at which the supply of genetically improved seed is in balance with demand will be mirrored in the market price of the seed. If the amount available on the market is excessive and demand does not change, the price will fall, but will eventually return to its original level as supplies are reduced. An increase in the demand for improved seed owing to an increase in the annual planting rate will result in a rise in the price.

This very simplified description of the market relates to the prices of a surplus offered to other seed growers. If the surplus seed production of the organization's programme represents a considerable proportion of the total market, the price will fall. This must be borne in mind when evaluating the seed. Likewise, if the organization decides to buy genetically improved seed from other growers instead of starting its own programme, the increased demand may be sufficient to provoke a considerable rise in prices. However, if the effect on supply and demand is not very great, no great changes in price will occur.

Markets for genetically improved seed are sometimes highly specialized. Breeding programmes cover a wide range of species, selected characters and selection intensities. The market is often dominated by one or a few producers, and the price will be based, not on market forces, but on the cost of production plus a margin of profit. The cost of producing genetically improved seed on the basis of one's own programme may be very different from the market price, or the price that an organization was willing to pay for the seed.

#### CHOICE OF PROCEDURE

There are two kinds of alternative procedures or strategies: those arising from the decision on whether or not to undertake the programme, and those arising from having chosen the improvement programme. The strategies in the first category are as follows:

- 1st to continue using unimproved seed;
- 2nd to buy genetically improved seed from other sources;
- 3rd to participate in a cooperative tree breeding programme;
- 4th to undertake one's own genetic improvement programme.

Before undertaking a comparison of these strategies, it is necessary to ascertain whether it is technically possible for the organization to undertake a genetic improvement programme. This will depend essentially on the existing demand for genetically improved seed, the resources available to the organization, the size of the programme proposed, and the objectives of the directives. The resources available include not only highly skilled breeders and other labour, but also capital, land and, above all, the size and nature of the population available for selection purposes. Research may also prove necessary to establish flowering models, vegetative propagation techniques and other operational procedures for seed orchards.

The kind of genetic improvement programme will depend mainly on the available data on the heritability of important improvement characters, the additional genetic gain at different levels of selection intensity, the genetic relationship between various characters, etc. The size of the programme will depend on the organization's seed requirements and the demand for seed surpluses.

Initially, most organizations will not have sufficiently detailed information to undertake big programmes, and analysis will be limited to a comparison of these programmes

with one or another of the above alternatives. As the programme proceeds and more is known about the genetic improvement characters of the species, more advanced strategies may be contemplated.

#### EVALUATION CRITERIA FOR A GENETIC IMPROVEMENT PLAN

Economic experts have not yet completely solved the problem of choosing the right economic criterion for comparing the benefits and costs of alternative procedures over a period of years, or for accepting an individual project. But most now agree that it is necessary to have some method of discounting to reduce benefits and costs of different dates to a common denominator at any given moment. A dollar is worth more to an organization today than at a future date, because it can be used to produce additional income. The following two evaluation criteria are the ones most frequently used:

1. The current net value of a project is defined as the difference between the costs and benefits attributed to the project actualized at the appropriate rate. If the actual net value is positive, the project can be considered economically feasible and may be accepted. If there is more than one project, preference should be given to the one which offers the highest positive actual net value.
2. The rate of internal yield is the type of actualization which gives an actual net value equal to zero, i.e. the actualized value of the benefits is equal to the actualized value of the costs. An individual project may be accepted if the rate of internal yield proves higher than the minimum acceptable rate adopted for investment purposes. The choice between projects will be determined in favour of the project with the highest rate of internal yield.

In some cases, the project that offers the highest actual net value does not necessarily offer the highest rate of internal yield. In such a case, the criterion of the actual net value is the one that should be followed.

The actual net value of a programme (CNV) may be expressed in algebraic form through the following equation:

$$CNV = \sum_{t=0}^t (B_t - C_t)/(1 + i)^t, \quad \text{where:}$$

$B_t$  denotes the benefits generated by the programme in the year  $t$ ,

$C_t$  denotes the costs incurred by the programme in the year  $t$ ,

$i$  denotes the rate of interest for actualizing benefits and costs, expressed as a decimal.

In calculating the rate of internal yield it is not necessary to have any predetermined rate for actualization purposes. In order to decide whether the programme should be accepted or not, one needs an estimate of the minimum rate of yield acceptable for the organization contemplating the investment. This rate will be equal to that which the organization should have earned in alternative investments, i.e. the in timely placement cost of its capital.

Most privately-owned organizations expect new investments to generate as a minimum a rate of profit equal to the weighted average profits from other sources (capital shares and loans, undistributed profits and external investments), according to the relative proportions of these resources used by the organization.

#### EVALUATION OF COSTS AND BENEFITS

The simplest method of analysing costs and benefits is to limit the analysis to actual cash transactions. The costs will therefore include wages and salaries, the price of purchasing land and other fixed assets, such as buildings, plant and equipment, and the costs of the raw material. Values must be assigned to the fixed assets and land at the end of the time horizon and included as benefits.

Two aspects of the cost/benefit ratio must be examined. At what point in the production process should the costs and benefits connected with the genetic improvement programme be evaluated? And how should they be planned over the years?

The costs must be charged to the account at the time they occur. The benefits are usually evaluated at the time the seed is collected. All the costs relating to the selection of parent trees and the establishment and management of the seed orchard are naturally included in the analysis, while those relating to progeny and provenance trials, hybridization programmes, etc., are neither partially nor fully attributed to the main improvement programme, and it may therefore be necessary to earmark funds for these items in some way. It is preferable that this be from profits generated by the different programmes. Sometimes, however, it is necessary to adopt an arbitrary procedure based on the breeder's own assessment.

The value of genetically improved seed is based on its price on the free market (if there is one) or the value of profits generated by sale of the products obtained from the seed using a method called residual value price. This implies deduction of the costs of cultivation, harvesting, processing and distribution from the price of an end (or intermediate) product derived from the seed. The prices of sawnwood and pulp are appropriate starting points for an evaluation of the benefits of a forest tree breeding programme.

### COSTS

#### Fixed costs

As in any other form of technological change, the costs of tree breeding may be fixed, or may vary in accordance with the size of the seed harvest produced. They are fixed if they are not affected by the size of the harvest, and variable if they vary in direct accordance with it.

Selection and progeny trials of parent tree for the seed orchard constitute the main sources of fixed costs connected with the management of seed orchards. This is because the number of phenotypes selected to be propagated in the orchard is normally independent of the size of the orchard.

#### 1 Cost of selection per parent tree

The cost of selection per parent tree for a seed orchard depends on the selection intensity and the criteria or characters on which selection is based. Van Buijtenen and Saitta (1972) showed that the initial selection cost per tree tends to increase at a relatively more rapid rate as selection intensity increases. Per example, the cost of initial selection per tree at high selection differentials of 3 or 4 standard deviations above the average was almost five times greater than with relatively little deviation from the standard.

The cost of initial selection also increases greatly in proportion to the number of characters to be selected. For a selection intensity of one percent and assuming that the characters are not correlated and that the costs of the search amount to \$1 per 100 trees studied, the selection cost would be as follows:

Number of characters to be selected	Number of trees studied per parent tree	Cost per parent tree selected (\$)
1	100	1
2	10 000	100
3	1 000 000	10 000

The selection cost increases 100 times for each additional character selected.

## 2 Progeny trials

A progeny trial may represent one of the most expensive aspects of the genetic improvement programme, and its costs are very difficult to figure. If progeny trials are designed to provide information for the purpose of roguing a first-generation seed orchard, the total cost of the trials will be assigned to this phase of the improvement programme. If they are also designed to provide the basis for a second-generation selection, a method is required for assigning the costs between the first and second generation orchards. The ideal would be to base cost assignment on the profits generated by each generation, but it may prove impossible to quantify these. In this case, a general factor is needed to cover most circumstances, such as the relative costs of selection.

## 3 Other fixed costs

The annual costs of administration and research constitute the other most important categories of fixed costs. The costs of administration may be assigned pro rata among the costs of wages, salaries and materials directly generated in each phase of an improvement programme, but it is more convenient to treat them as a fixed annual cost.

If the research programme is not designed to benefit the improvement programme carried out in combination with it, the costs must be changed to the future improvement programmes on behalf of which they are designed, when these programmes are produced.

### Variable costs

The remaining costs of establishing and managing a seed orchard are closely connected with its area or size. For any management system, they also depend directly on the seed yield. They include the costs of preparing the site, planting, vegetative propagation, fertilization, pruning, roguing, overall maintenance and protection.

Establishment costs will vary according to the number of clones, the method of propagation and the initial density of the forest. The per hectare seed production of a species depends on the extent of site preparation, particularly the amount of fertilizer used, and the density of the forest. Keiding (1975) has given a detailed summary of the costs of establishing seed orchards.

The larger the area of the seed orchard, the lower the costs per kilogramme of seed produced. However, a moment may come when the orchard is too large and diseconomies of size or scale become apparent, owing mainly to a disproportionate increase in the costs of administration, or perhaps because the collection of graft material is very expensive or more parent trees are required.

Thus the production cost of seed in an orchard will follow the well-known U-shaped curve of production theory, i.e. it will fall at the beginning as the area of the orchard increases, and rise at the end as the fixed costs start to rise. Similar relations may be observed in individual operations, particularly between the average cost of fertilizers per kilogramme of seed produced and seed production per hectare; and between the spacing of ortets and seed production per hectare.

## BENEFITS

Tree breeding can benefit forest production in four ways: first, by increasing the yield of wood per hectare ("yield effect"); second, by inducing a rise in the prices of the different products harvested ("price effect"); thirdly, by reducing costs ("cost reduction effect"); and fourthly, by decreasing the economic rotation for the forest ("rotation effect").

### 1 Yield effect

This effect can be obtained by cultivating genetically improved trees which give a higher yield, or by reducing losses in yield by cultivating trees better adapted to the environment, e.g. trees more resistant to wind in areas with cyclones or trees resistant to diseases, insects, damage produced by frost or snow or drought. One of the problems in trying to increase the inherent speed of growth, however, is the relatively low heritability of this character.

## 2 Price effect

If we assume that the price of the improved seed will include any economic surplus from harvesting and processing of the trees grown from the seed, the following factors will influence the value or price of the seed:

- a) Higher yield of processed articles. For sawn logs, longer trees, with straighter trunks and improved form, and less compression wood and twisted grain, provide a higher yield of saw timber per unit of roundwood volume. For pulpwood, a higher yield is obtained from trees with greater basic density, little compression wood and better fibre properties. A reduction in the variability of these properties of the wood also produces a higher yield.
- b) Improvement in the class or quality of the processed articles. Higher classes of saw timber, with consequently greater value, can be achieved by reducing the size of the branches and the amount of twisted grain and compression wood, improving branch angle, etc. Higher classification of the pulp can be obtained by cultivating trees with appropriate fibre properties.
- c) Reduction of felling costs. These costs can be reduced through higher yields per hectare, larger average trunk size at time of felling, wider spacing at time of planting, and better branch characteristics (reduction in snedding time).
- d) Reduction of processing costs. For saw logs, straighter, larger trees of improved form and uniform size reduce sawing time; improved wood properties can reduce drying time in the sawmills and cooking and grinding time in the pulp plants.

## 3 Cost reduction effects

Faster-growing, better quality trees enable forestry directors to space tree plantings more widely, which means fewer seedlings per hectare and easier access. Many operations are thus shortened.

## 4 Rotation effect

Higher prices and yields and lower cultivation costs mean economic rotation can be considerably reduced. This also offers the advantage of a reduction in the amount of land necessary.

The benefit side of the budget is the most difficult aspect in any genetic improvement programme. How can the benefits deriving from the programme be evaluated? As we have already indicated, evaluation can be done in two ways: one based on the market price of the seed produced, and the other based on the residual value price method.

If the market price method is adopted - which is the exception rather than the rule, since the improved seed, even of the same species, is rarely of the same genetic quality - the problem is to identify any change in price deriving from the increase in the supply of seed.

If the residual value method is adopted, the procedure used will depend on the products cultivated or processed from the seed of the seed orchard and the characters selected.

The benefits to a plantation from genetic improvement can be evaluated in terms of the seed produced, actualized to the time the seed was collected and from the time profits begin to accumulate, using data relating to the initial planting density, the germinative capacity of the seed and the rate of roguing in the nursery to express the benefits in terms of dollars per kilogramme of seed.

### DUBIOUS POINTS IN EVALUATION

Most studies imply that physical production inputs and outputs and their prices can be estimated without error. But this is not so.

An analysis which takes into account the doubts inherent in probability distributions for basic inputs and outputs and their values is much more exact with regard to the collection and analysis of data than one based on average or probable values. Also, it is very often impossible to make reasonable subjective estimates of the probability distribution of many variables, particularly in the analysis of investments that imply technological changes, such as the genetic improvement of trees, in which even the average increase in benefits is very often unknown.

One possible way of resolving this difficulty is to assume that each option evaluated will have the worst possible result, and to select the one that gives the highest value for the economic criteria selected. This is a highly conservative method and may result in projects with high potential benefits not being considered.

In projects with investments of a biological type the costs can usually be evaluated fairly accurately, but the benefits raise difficulties. Tree breeding is a project of this kind. Lundgren and King (1965) and Davis (1967) resolved the problem by calculating the levels of genetic gain that should be obtained in a tree-breeding programme based on known costs and then comparing these gains with data available from progeny trials. Another method is to limit the studies to gains that can be evaluated easily, as, for example, in the analysis by Swoford and Smith (1971) of the national forests in southern U.S.A.

Finally, it may prove more satisfactory to make a sensitivity analysis of the key parameters, such as prices, or of those which are the object of subjective evaluation or are subject to big fluctuations. This requires an evaluation of each project on the basis of the most probable floor and ceiling values of the key variables. The main objective of the analysis is to judge whether it is to be assumed that a project is unacceptable in terms of its assumed floor, or whether the order of the competing projects should be modified.

#### OPTIMIZATION OF IMPROVEMENT PROGRAMMES

According to the traditional production theory, the optimum result of a project is defined by the point at which the marginal cost is equal to the price of the production, where the marginal cost is defined as the cost of producing an additional production unit. For a project with a life of one year or less, this is relatively easy; but for long projects like tree-breeding programmes, the situation is complicated by the additional variable represented by time.

The simplest solution to this problem is to assume that there are no restrictions on resources and then submit all the feasible genetic improvement options to separate cost-benefit analysis. The one that generates the maximum economic benefits will be chosen. Options may vary according to the number and nature of the characters to be selected, selection intensity, the number of plus trees propagated in the seed orchard, its area and the management system adopted. For each set of characters to be selected, there will be a range of production possibilities based on the above factors.

This method may prove extremely complicated and require much time as the number of feasible improvement programmes increases. Owing to inadequate data this very rarely happens; but if sufficient information is available, mathematical programming techniques may prove appropriate.

Linear programming was used by van Buijtenen and Saitta (1972) to derive optimum solutions based on the size of the harvest, the area of the seed orchard and whether or not the orchard had to be rogued. The technique is very appropriate for the optimum earmarking of scarce resources between competing requirements, in terms both of individual programmes and of time. The process can be performed rapidly and exactly by computers.

A more recent development is Porterfield's study (1974) on potential gains in genetic improvement programmes for Pinus taeda in the southern U.S.A. using goal programming. This is simply a modification of lineal programming, but here the restrictions are replaced by the goals. Many goals can be included in this technique, while there is only one in lineal programming, i.e. maximization of the net returns in a single objective function. Characters which it was considered would affect the volume and specific weight were incorporated in the model. Only characters affecting the volume were taken into consideration for sawlogs, but both characters were taken into account for pulpwood.



The main advantage of the model is that the goals can be modified, absolutely or relatively, according to changes in the market. It can provide for the genetic selection reaction of indigenous populations, roguing and progeny trials. By specifying the selection intensity for a given character and the percentage of improvement desired, a solution is obtained which gives the minimum deviation from the given genetic goal subject to restriction under the capital expense budget.

• The purposes of any optimization will depend on the organization contemplating the investment. In view of the rapid changes in the market for wood products, many organizations prefer to adopt a conservative genetic improvement strategy which maintains maximum flexibility. Greater importance may be attributed to characters that may be important for various generations in a range of different environmental and economic conditions. As a general rule, an increase in the yield of wood per hectare and greater resistance to diseases are two characters of this kind, while it may be assumed that wood properties such as grain are not so important.

Other organizations are more concerned with improving first-generation characters which are obviously inferior but which might provide large gains rapidly, and concentrating more on other characters in later generations.

Great care must be taken in applying very advanced optimization procedures, since they depend entirely on the data on which they are based. The benefits or gains deriving from the tree breeding constitute a major problem. Very little is yet known of the gains obtained through genetic improvement of trees in a complete rotation of a plantation regenerated by genetically improved seed, particularly in cases in which other cultural techniques, such as pruning and thinning, are used. For plantations that produce only one product, e.g. pulpwood, have a short rotation and are not thinned, the gains can be forecast with more accuracy than for those which are regularly thinned and which produce both logs and pulpwood in long rotations.

#### FINAL COMMENTS

Genetic improvement is an expensive programme that must be justified by its potential benefits.

Nikles (1973) gives a series of examples of the economic considerations relating to the genetic improvement of forest trees.

Breeders usually choose the improvement programme which provides the biggest and most rapid gains and has the shortest improvement cycle.

Smith and Zobel (1974) have shown that there will be enormous losses in potential gains if the source of the seed is unknown, and it is important that this source be considered and thoroughly investigated before a genetic improvement programme is formalized.

They also considered that important gains in straightness of trunks, specific weight, length of tracheid and resistance to rust can be confidently assumed, as they are highly inheritable.

As regards costs, they proved that, when all the costs of a representative seed orchard were updated to a common point in time, the selection of parent trees with the subsequent progeny trials represented only 10 percent of the total costs. Hence an improvement in selection standards may produce only a relatively small increase in costs. This bears out the results of van Buijtenen and Saitta (1972), who showed that selection was the most effective phase in the tree-breeding programme they were studying, in terms of the profitability of investment in a first-generation seed orchard. Most (89 percent) of the total costs of the seed orchard programme concern preparation of the site, cost of the land, supervision, fertilizers, protection, harvesting and extraction of seed, and it is important to realize that these costs do not vary with the genetic quality of the tree selected.

Some characters may compete with each other. This seems to be characteristic of characters of quality, such as straightness of trunk and branches, when these are selected in conjunction with fast growth.

The profitability of tree breeding is considerably increased by progeny trials and roguing of the seed orchard (Smith and Zobel, 1974). Consequently, if it is desired to obtain maximum economic benefits, progeny trials and high selection standards must be used.

The seed yield per hectare of the seed orchard must also be maximized through appropriate use of fertilizers and proper spacing.

Owing to the variety of species and the doubts regarding benefits, it is difficult to generalize about the most appropriate method of formulating a tree improvement programme. Perhaps all we can do is to repeat the conclusion of Smith and Zobel (1974) that the most profitable tree improvement programmes usually have the following characteristics:

- 1 One species is grown over a wide area;
- 2 The desired characters have moderate to high heritability;
- 3 Crossing of the species can be easily controlled, and the species is a prolific seed producer;
- 4 The values of the wood products are high and it is to be assumed will remain high.

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Participants visiting the CONARE Pinus caribaea plantations in Chaguaramas.

PLANNING AND STRATEGIES OF A TREE IMPROVEMENT PROGRAMME 1/

PalMBERG, Paul and Willan

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1/ This lecture is a revision of the one originally presented by Dr D.G. Nikles at the FAO/DANIDA Training Course in Kenya in 1973, and published in the Report of that Course (FAO/DEN/TF-112. FAO, Rome 1974).

## INTRODUCTION

Planning a tree improvement programme involves many considerations. A primary factor is the stage in development of the reforestation project. A common situation, and the one adopted for reference in this lecture, is where a species with considerable known or suspected geographic variation is already being successfully planted on a moderate scale. The aim of the reforestation project is to meet the needs for a variety of products for local use and/or export. The scale of operations is sufficient to justify a continuing, multi-generation improvement program

Many more and less advanced variations of this reference model can be readily envisaged, and details of appropriate associated tree-breeding programmes would vary accordingly. It is not possible to consider many such situations here, so only the principles of planning a tree improvement programme are emphasized in this lecture.

## PRELIMINARY CONSIDERATIONS

The first step in planning a tree improvement programme is to ascertain the types of products likely to be required and the aims of forest management now and in the future.

Such an investigation and consideration of the following points will be needed in order to develop a strategic plan for the tree improvement programme: at step two the following are examined.

### A. Administrative considerations

(i) Formulation and statement of the aims of the tree improvement programme in order that they will contribute most effectively to the overall objectives. Aims must be expressed as simply and precisely as possible.

(ii) Assurance of possibilities to provide funds, equipment, facilities, and qualified personnel. Provision for extra training may be required.

(iii) Assurance of programme continuity. It is desirable that suitable personnel be encouraged to make a career of tree breeding. If there are doubts about continuity of competent staff, it is essential to choose simple, robust strategies for the programme.

(iv) Possible reorganization of administrative resources to locate tree breeder and staff in suitable headquarters together with colleagues working on silviculture, soils and nutrition, wood quality and products, forest management, etc.

(v) Consideration of cooperation in improvement work at local, regional, national and international levels. This can lead to cost sharing of technical assistance and research, exchange of ideas and generation of enthusiasm.

### B. Technical considerations

(i) Determination of the factors limiting forest production in the region and ways and means of manipulating these to meet stated overall objectives. It is essential to build a tree improvement programme on a base of sound silviculture, management and utilization. The relatively long time scale of tree improvement work and the possibility of rapid technological change in other techniques of forest management and utilization should also be borne in mind.

(ii) Choice of species and provenances to provide the desired type of products. Identification of the best species and provenances for each major site type in potential planting areas is essential.

The availability of basic biological information on the species (i.e. their ecological and morphological variability, individual variation and ease of regeneration by seed and vegetative means), as well as of possible techniques for improvement based on experiences in other countries should be investigated. Special characteristics of individual species can often be used to advantage.

(iii) Determination of the characteristics which are best manipulated by genetic means. Basic studies to secure reliable estimates of genetic parameters will provide information of great value in improving efficiency of selection and of breeding strategy.

The development of simple assessment methods, efficient record keeping and data handling procedures will often be required in connection with these studies.

(iv) Specification of the number of generations and number of years needed to achieve a certain degree of improvement in important characteristics. This information should be critically examined in the light of urgency for the improved material.

(v) The gathering, throughout the programme, of data for the evaluation of costs and benefits.

Evaluation of costs and returns have been discussed in the literature i.e. by Van Buijtenen (1975); Porterfield (1978); Reilly and Nikles (1978); Reich and Carlisle (1978); and van der Meiden (1978).

### SELECTION CRITERIA AND THE BASIS FOR SELECTION

#### Selection Criteria

In choosing characteristics to be included in the programme, one should concentrate on a few traits which have high potential for economic gain and which cannot be more cheaply improved by cultural or technological means. Consideration should be given to inclusion of a trait if one or more of the following factors are relevant.

- (i) economic value is high;
- (ii) the trait is likely to be of continuing value even if product demands change in the future.
- (iii) variability and heritability are high, giving potential for considerable genetic gain;
- (iv) the trait is positively correlated with, or is independent of, other desirable traits;
- (v) genetic and management and non-genetic improvement methods interact favourably, or combine positively to improve the trait.

Some traits are desirable for virtually all end products, and they may be expected to retain their prime importance for a long time. These are good health, high growth rate, lack of malformation, straight stem, large branch angle. Several other traits are of great value for specific products, e.g. special wood properties, branch pattern, branch diameter, branch longevity, and stem defects such as cone holes.

In planning a programme, attention must be given to ranking the possible selection criteria in order of likely economic importance many years hence, and adjusting this ranking for expected genetic improvement. Each tree selected as a candidate for the breeding programme can then be assessed for overall merit.

#### The Basis for Selection

The degree of genetic improvement in the desired traits through selection and breeding is dependent on three components. These are (i) variation; (ii) heritability and (iii) proportion of trees selected. The degree of improvement is expressed by the Genetic Gain,  $\Delta G$ , which is computed as the heritability  $\times$  selection differential.

(i) Variation in the traits to be improved is a prerequisite and a starting point for any programme. Initial selection should be done in large populations in which the genetic base has not been narrowed down by e.g. collecting the seed for the establishment of the stand from only a few trees.

(ii) Heritability ( $h^2$ ) is a measure of the degree to which a character influenced by heredity as compared to environment, and is expressed as the proportion of genetic to genetic plus environmentally caused (phenotypic) variation (see paper on quantitative genetics for more detail). If selection is carried out in even-aged, regularly-spaced stands growing on uniform sites, the masking effects of the environment will be minimized, and accuracy of determining the genetic proportion of the variation will increase. This accuracy can be further increased by stratifying the plantation into site class areas, by comparing candidate superior trees to neighbouring trees growing on similar sites, applying adjustments to total volume for crown size effects, etc.

(iii) Proportion of Trees Selected. The gain component most amenable to influence by the breeder is the proportion of the population selected. The intensity of selection is measured by the selection differential ( $s$ ), i.e. the difference between the mean of the selected trees for a certain characteristic and the mean of the original population for the same characteristic. In theory, the larger the selection differential the larger the genetic gain. In practice, however, to increase the selection differential becomes increasingly more costly as the area to be searched increases in dimension logarithmically for a given increase in selection differential (Shelbourne 1973). Thus, a costly search for the '1-in-a-million tree' will not achieve a correspondingly large selection differential, and less rigorous selection of individuals for inclusion in the first-round breeding programme may be called for (say, 0.1-1%). In practice, countries with rather small plantations will have to select even less intensively (probably about 1 percent of the trees).

### STRATEGY

Determining the most efficient system of managing the various parts of a breeding programme within the constraints of time and other resources available can be complicated and compromises are necessary to resolve conflicts of interest. The scheme that is developed as a result of all the conditions necessary is termed the breeding strategy. The process by which the strategy is implemented is termed the breeding method, while the biological procedures such as grafting, controlled pollination, planting, etc., are the breeding techniques. Thus, a breeding strategy is an approach to securing the greatest improvement with the species, resources and conditions prevailing.

#### General principles

Tree improvement has three major objectives, namely, to provide:

- (i) genetically improved seed or other material for immediate use;
- (ii) suitable select breeding material for future use;
- (iii) adequate genetic information for immediate and future use.

In addition, the need to conserve the gene resources of the original populations and land races of the species concerned must be recognized.

#### Populations

The principal objective of the tree breeder is the generation of optimum breeding populations to create cumulatively better genotypes for advanced-generation seed orchards (Namkoong 1972). This involves the reduction of the genetic base of the population, thus creating a serious conflict between short-term and long-term gains through reducing effective populations size. The conflict can be mitigated by maintaining a hierarchy of separate populations side by side, representing a series of decreasing selection intensity but increasing effective population size (Burdon, Wilcox and Shelbourne 1978). These

populations include the following:

- (i) Gene pool - a population in which the full range of genetic variation is maintained; it may sometimes equal the original selection population.
- (ii) Selection population (base population) - a large population within which superior trees are selected; about 1 million trees is suggested (500 - 1 000 ha).
- (iii) Breeding population - a selected population, containing perhaps 200-300 trees chosen for their superiority within the selection population. It is used in whole or in part to generate the next selection population.
- (iv) Seed production population - a population of 30-100 trees established to produce seed for forest plantations (or, for the wood-producing population).

There are many variations of this pattern. Mass vegetative propagation would eliminate the seed-producing population as a separate entity, while a seedling seed orchard combines (ii) and (iii).

The classic seed-producing population is the clonal orchard, giving very high selection intensity but still large enough, say 25 unrelated clones, to give genetic "insurance". Maximum outcrossing is desired in the seed-producing population although the parents could be inbred themselves. The breeding population, which would include the seed-production genotypes, represent a compromise between maximum selection differential and full population size, but would also allow recruitment of individuals which are superior for particular traits. A gene pool of standing trees, although existing for gene conservation, cannot be shielded from all selective processes. Mild and non-specialized silvicultural selection seems reasonable, while preservation in several contrasting environments should help maintain genetic diversity (Burdon, Shelbourne and Wilcox 1978).

#### Considerations in choice of breeding methods

Gains likely to be achieved through tree improvement can be substantial and will be of a lasting nature. If breeding populations are kept variable and reasonably large (never fewer than 50 unrelated individuals), steady progress can be made for many generations through selection.

An understanding of the following biological principles and technical guidelines may facilitate decisions when carrying out the improvement programme:

(i) Most individuals of most forest species being used in large reforestation projects suffer depression of growth upon inbreeding. It is therefore essential to maintain a large genetic base in the selection and breeding populations to allow for mating between non-relatives.

(ii) With small selection populations, say, only 1 000 individuals, a sacrifice in gain will be necessary; in order to maintain a large enough population (i.e. selecting a large proportion of the trees), selection intensity will have to be relatively low.

(iii) Some individuals may have a very high general combining ability (GCA), which can only be utilized through controlled crosses. Provision for controlled crosses at an experimental scale should therefore be made at a fairly early stage of the programme. Choice of appropriate mating designs is of fundamental importance for this step in the strategy.

(iv) Establishment of early trials is necessary to enable estimation of the effects of family-by-environment interactions.

(v) Family experiments should normally contain a large number of entries and of the order of 100 siblings per family. The number of trees per plot should be small and replications numerous.

(vi) Exploitation of the biological characteristics of the species with ingenuity is part of the art of tree breeding, for example, by means of clonal propagation, mass pollination, hybridisation, etc.



(vii) Where breeding programmes lack a sufficient number of desirable clones the situation can be rectified by selecting locally, or importing, additional material for injection of "new blood" into the breeding population.

#### Breeding methods and their application

Essentially, there are only two main strategies: one using sexually reproduced progeny and the other, vegetatively reproduced progeny.

##### (i) Selection with Regeneration through Seed

(a) Simple or recurrent mass selection. Example: Selection of phenotypically superior trees, collection of open-pollinated seed and bulking of the seed. Seed from the original, select trees is harvested continually (simple mass selection), or selection and seed collection is eventually carried out within their progeny (recurrent mass selection). The method is cheap, and it can be quite effective where the selection differential is large and phenotypic selection is accurate (high heritability and environmental effects minimized within the selection population). It has been used successfully in many countries and for many species.

(b) Selection and simple progeny testing, with or without further control of pollination. Example: Culled seedling seed orchards (pollination control achieved by isolating the progeny from major sources of contaminating pollen).

(c) Selection, full control of pollination, without progeny testing. Examples: Clonal and control-pollinated seedling seed orchards.

(d) As above but with periodic progeny testing, recurrent roguing and subsequent selection. Examples: Clonal and control-pollinated seedling seed orchards (a) with roguing of clones or of families and individuals; or (b) using test results to select material for new orchards. Note that roguing clonal seed orchards may give limited gain unless they contain a relatively large number of clones (50+) and the orchards have originally been established using relatively close planting distances. In some cases, where specific combining ability has been found to be high, bi-clonal orchards may be established for seed production.

(e) Hybridization of species or provenances. Examples: Larch species hybrids in Europe and Japan; P. elliotii and P. caribaea var. caribaea in Queensland. This method is attractive in some special circumstances (Brown, 1972).

##### (ii) Selection with Clonal Propagation:

(a) Without testing. Example: Some poplar and willow culture; P. radiata in New Zealand to a limited extent.

(b) With clonal testing. Example: Poplar and willow culture; Cryptomeria in Japan proposed for P. radiata for future in New Zealand and for Eucalyptus hybrids in Congo. This is a high gain but "dead end" procedure unless a crossing programme is included to produce new selection populations periodically.

#### A DYNAMIC BREEDING PROGRAMME

Current seed requirements. Possible sources of improved seed for immediate use include the following:

(i) Phenotypic selection and seed collection in local stands of good provenance generally assures well-adapted populations and gives modest genetic improvement. Genetic gain is limited by the unselected nature of the pollen parents.

(ii) Collection of seed from thinned seed production areas; ideally, these should be chosen in stands of superior provenance.

(iii) Imported seed. This may be from good phenotypes of suitable provenance in natural stands or excess seed from an external breeding programme using an appropriate provenance grown in similar conditions. Improved imported seed should only be used to enrich a locally selected gene pool, it can never substitute local selections.

Base for future selection. At an early stage in the breeding programme, it is appropriate to begin the importation of select genes (as seeds, scions or pollen) to broaden and improve the genetic base available locally for second generation selection. There are several examples of success in this procedure: scions, open-pollinated seeds and pollen of some 85 select trees of Pinus pinaster imported into W. Australia in the mid-sixties; vigorous exchange of select genes of P. radiata among several countries; scions and seeds of many P. caribaea var. hondurensis select trees exported from Queensland, Australia, to enrich gene pools elsewhere; seeds from selected orchard clones and ortets of P. eliottii and P. taeda in the U.S.A. exported to several countries in the southern hemisphere.

It is necessary to watch closely for diseases and insects in any exchanged material and especially in scions. Watch for potential undesirable hybridization when planting important breeding material; interspecific crossing has caused a lot of trouble with eucalypts in Brazil.

#### Progressive improvement of seed through successive orchards and clone banks

The above means for providing somewhat improved seed to meet immediate requirements should be implemented as soon as possible in the programme. However, such techniques give relatively small gains. Higher gains are achieved in classical seed orchards, although the time-lag is longer.

(i) Production orchards. A compromise and a useful strategy to gain time, is the establishment of clonal (or seedling) seed orchards (annually using the best material available each year.

(ii) Progeny populations. Controlled crossing is used for the production of families for second-generation selection. Information for roguing the orchards is obtained from progeny tests established soon after parental selection, as well as from the full-sib progeny studies in which selection is carried out.

(iii) Breeding population in clone banks: As explained earlier the seed production population is continually reduced to a superior nucleus (never less than some 25 clones per production orchard); the roguing is based on progeny trials. Parallel with these orchards it is essential to create highly variable, high-quality new selection populations for successive generations of selection. This requires the mating of large numbers of unrelated trees. It can be accomplished by vegetatively propagating select trees and making the crosses in a clone bank established for this purpose. Thus, large diverse selection populations and relatively narrow seed production populations are continuously generated and selected. Special measures may be required to maintain diversity in breeding and selection population such as importation of new material or production of "wide crosses" (Zobel and McElwee, 1964; Zobel et al, 1972). If adequate precautions are taken to keep a "sufficient" number (>50) of unrelated individuals in the breeding population, one would expect to be able to make steady progress for many generations without needing to add comparatively unselected new stock simply to restore lost genetic variability.

Conservation of gene resources. The tree breeder must be concerned with conservation of the diversity found in the natural populations, both for future research and as a source in the future of gene combinations not currently required (Kemp et al, 1972; Nikles 1973-b; Yeatman, 1973; Zobel, 1973). Strategies are discussed in the lecture on conservation.

Demonstrating progress. Libby (1973) listed 'political demonstration' as useful forms of planting. These are conveniently located plantings of simple design, the purpose of which is to show the achievements of the programme in as unambiguous a manner as possible. It may be desirable to deliberately include poor material, e.g. unsatisfactory provinces as well as 'routine' controls and 'improved' material.

## STAFF ORGANIZATION, FACILITIES AND ADMINISTRATION

Staff and facilities: It is essential to appoint an interested, well-trained and capable professional tree breeder to plan and develop the breeding programme in consultation with senior managerial and utilization personnel. For a large-scale programme, the tree breeder should be supported by well-trained technicians and labour of high quality.

At the headquarters, or within easy access, there should be biometrical services and library facilities. It may be necessary to take special steps to develop or obtain efficient techniques and computer programmes designed to facilitate the collection, processing and analysis of data. The tree breeder and the biometrics team should keep abreast of modern developments in mating and field designs and work on their application to local problems. Opportunity should be provided for the tree breeder to participate in regional, national and international scientific meetings, workshops and refresher courses from time to time. The local group or team of workers at headquarters should be encouraged to hold occasional seminars and discussions at which progress and problems being encountered in their programmes, each contributing to the overall aims of management, are reviewed.

Cooperation with other tree breeders working with the same species under similar conditions is most worthwhile, and periodic reciprocal visits by the breeders among programmes should be arranged.

All these aspects help to ensure constant review of the direction and aims of the work and a vitality and sense of purpose in the personnel.

Revisions of plans and publication of results: The tree breeder plan should be revised periodically when thorough re-examination of objectives and approaches is made. Annual reports and work programmes should be prepared for consultation with administration officers and review by colleagues or willing experts.

Publication of results should be seen as an obligation to colleagues, as a means of informing sponsors and administrators of progress (positive and negative results) and problems, and as an intellectual discipline for the tree-breeding team.

### SUMMARY

Planning an efficient tree improvement programme tailored to the requirements of forest management and utilization and resources available will involve the following main activities and decisions:

- (i) Define appropriate aims for the programme, especially concerning its duration, the improvements sought and the characteristics that are best manipulated by genetic means.
- (ii) Ascertain the resources that will be made available at least for the first several years. Appoint and encourage an interested tree breeder to help plan and run the programme with appropriate assistants.
- (iii) Locate suitable populations, in terms of provenance, size, age, sites, etc., for selection.
- (iv) Assemble relevant information on the biology of the species and decide the areas in which further research is required. Confirm or develop suitable techniques for grafting, pollinating, raising plants, etc.
- (v) Choose appropriate selection criteria, and limit their number.
- (vi) Develop methods for rapidly obtaining seeds of better quality.

(vii) Work out long-term dynamic, flexible breeding strategies so that a sufficiently large number of trees can be established in the breeding population, taking into consideration the planned programme and the number of generations for which improvement programmes are planned.

(viii) Work out dynamic long-term and flexible breeding strategies having regard to aims, resources, time-scale, seed requirements, species characteristics, other institutes, regions and countries working on the same species should be carefully considered.

(ix) Set up efficient administrative arrangements and make provision for periodic reviews of the programme and its modifications as necessary.

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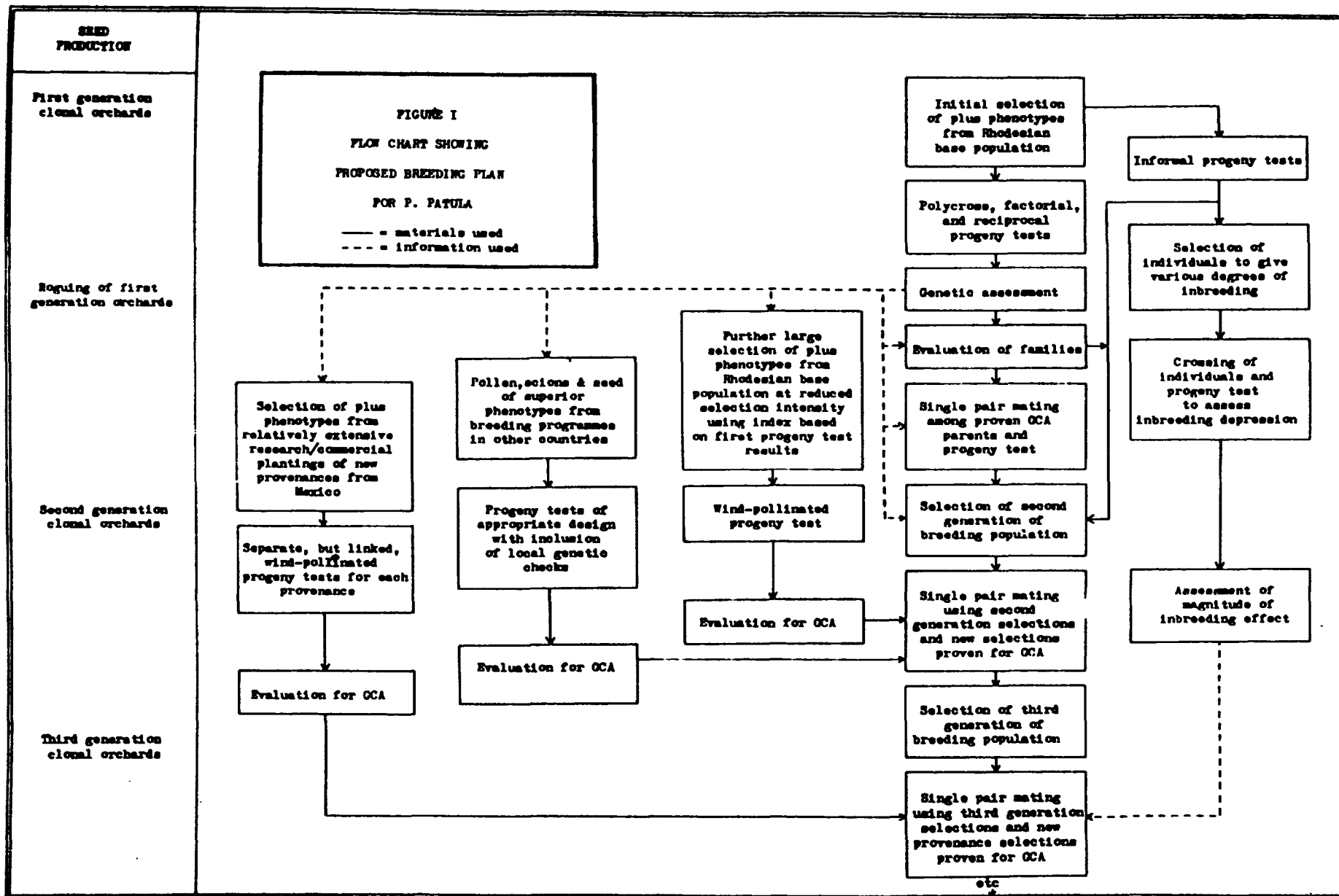
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The references marked with an asterisk (\*) have already been quoted in the text of the report.

Figure 1. Flow chart showing proposed breeding plan for *P. patula*



SIMPL ED CHART OF BREEDING STRATEGY FOR RADIATA CENTRAL NORTH SLAND Z

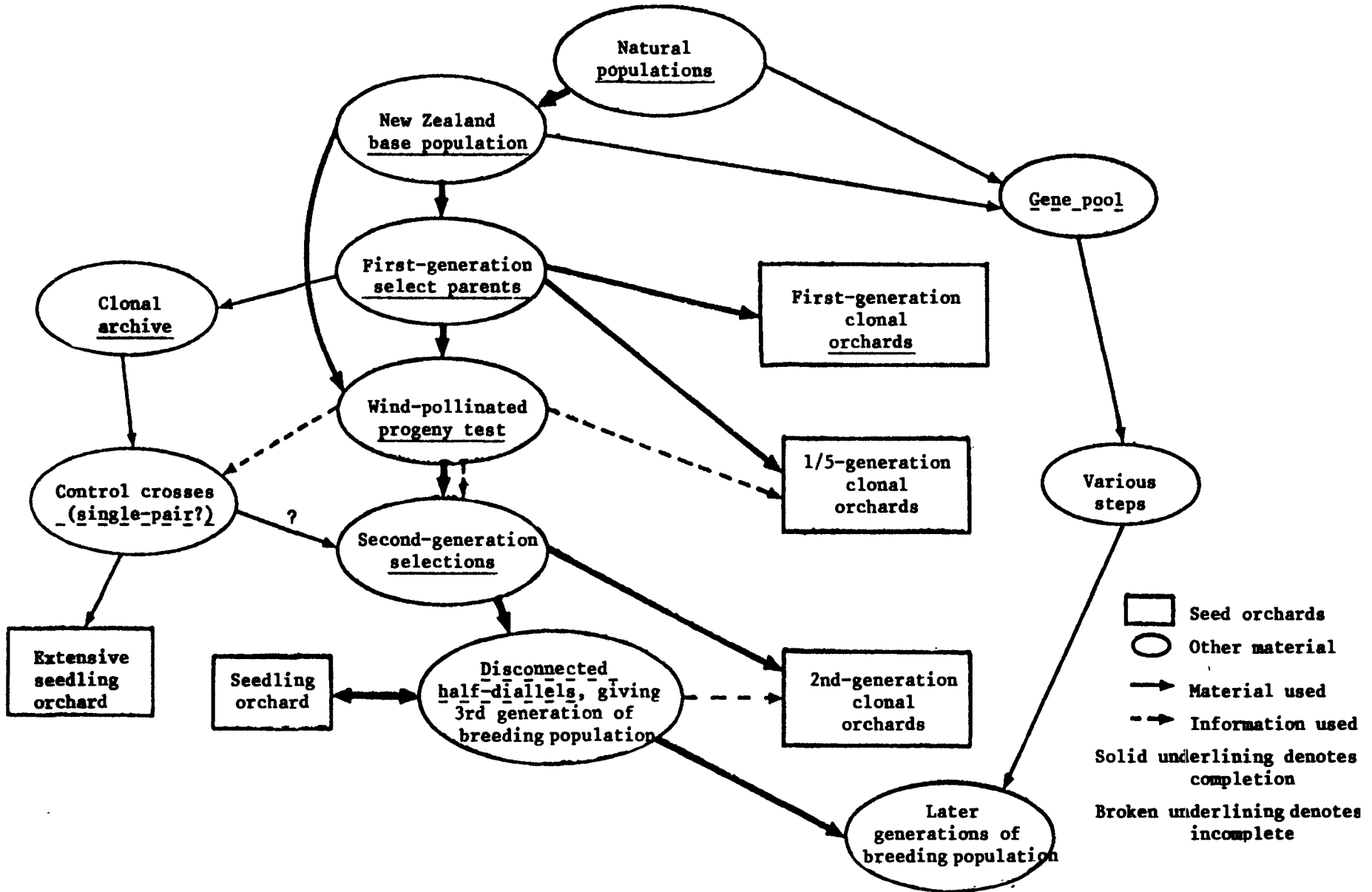


Figure 3 Strategy of the improvement of *Mangifera indica* in the Congo-Brazzaville

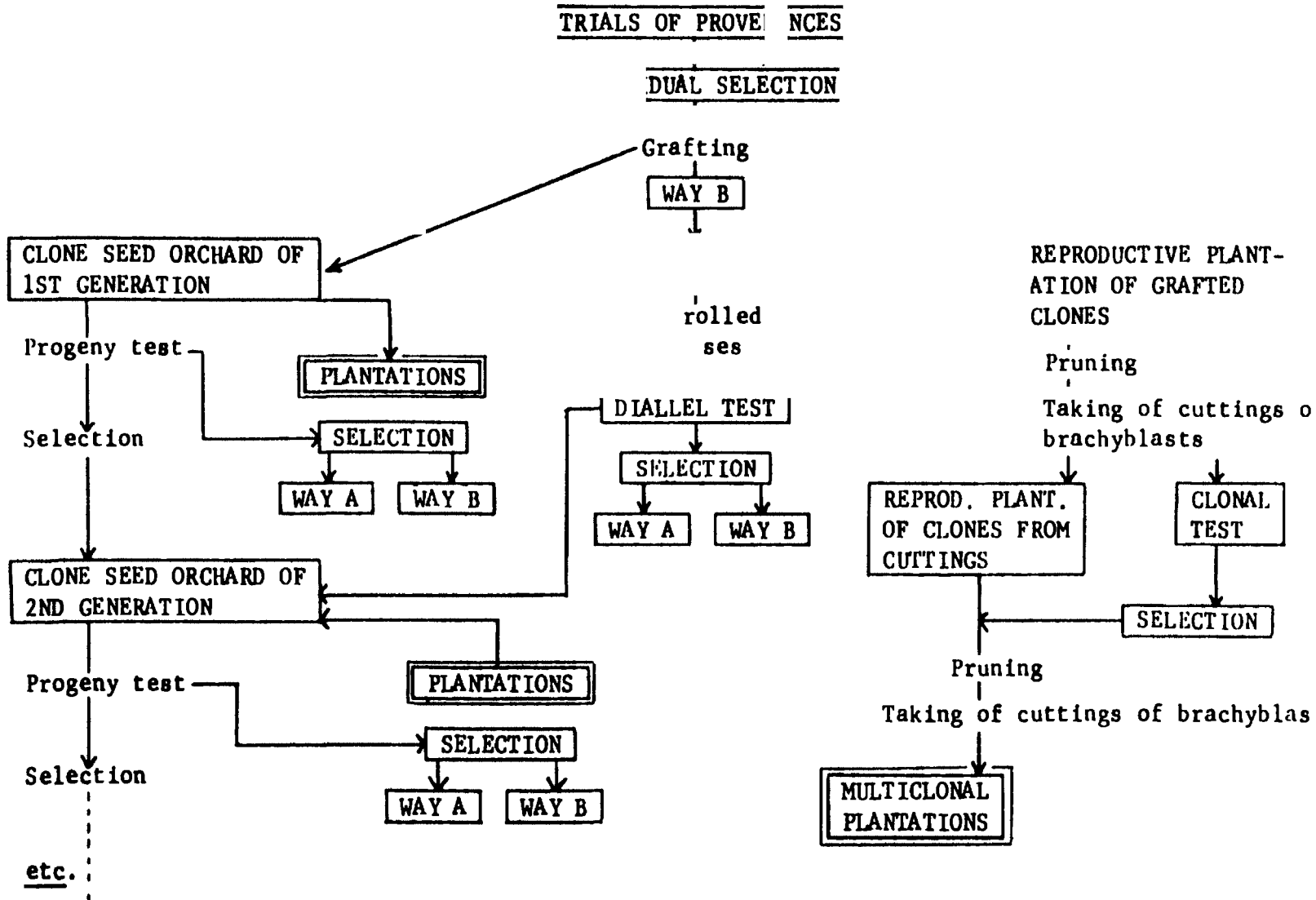
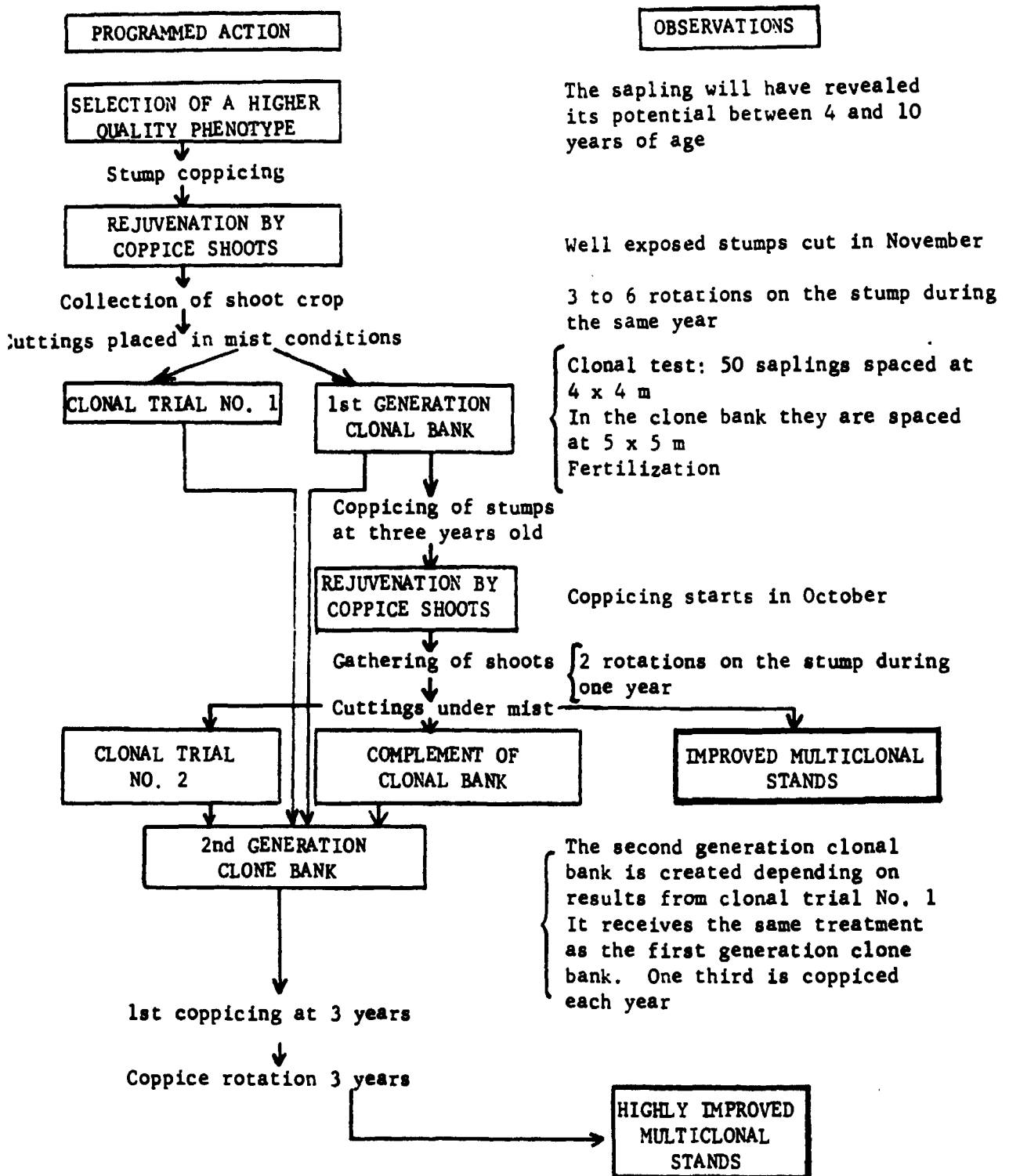
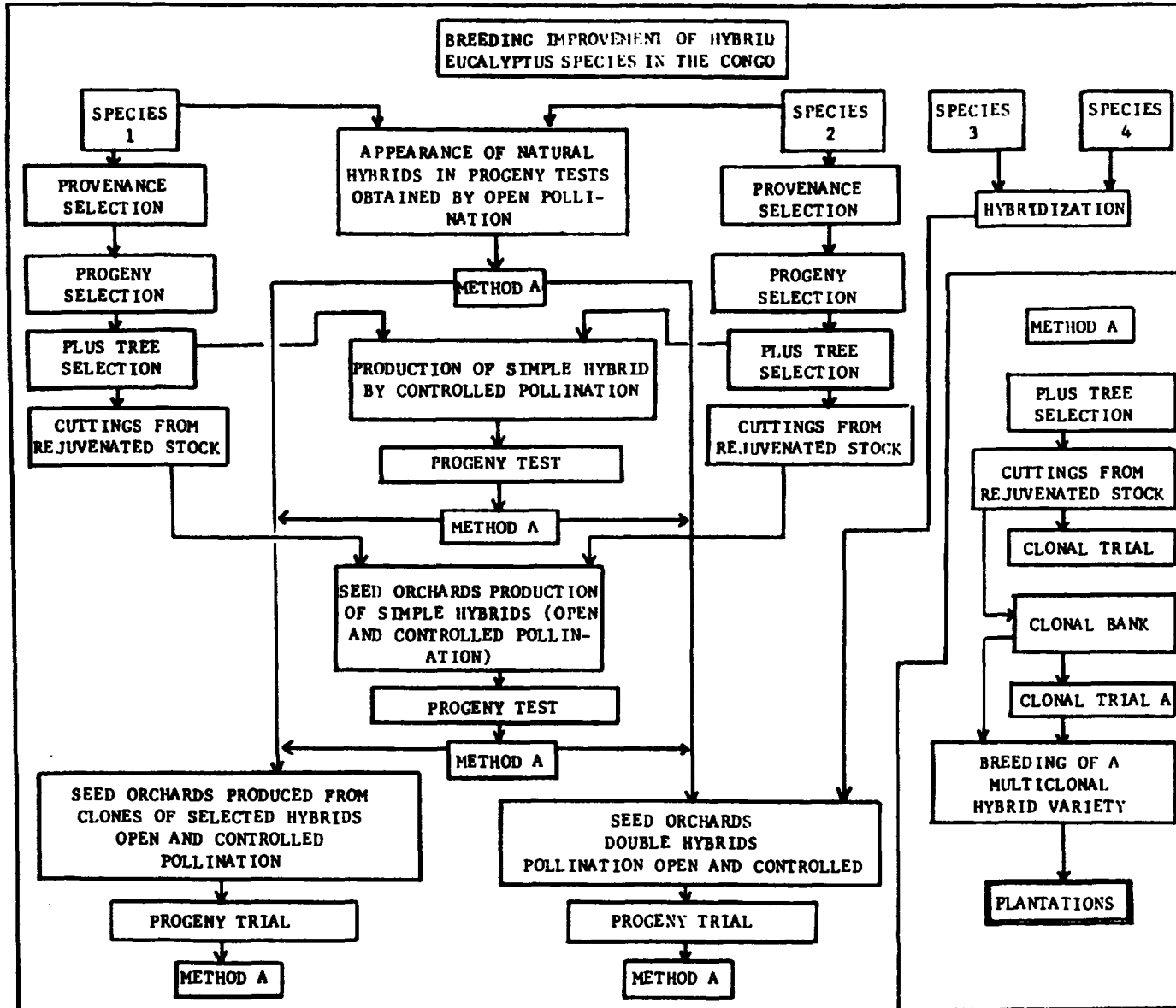




Figure 4. Stages in the use of Eucalyptus cuttings





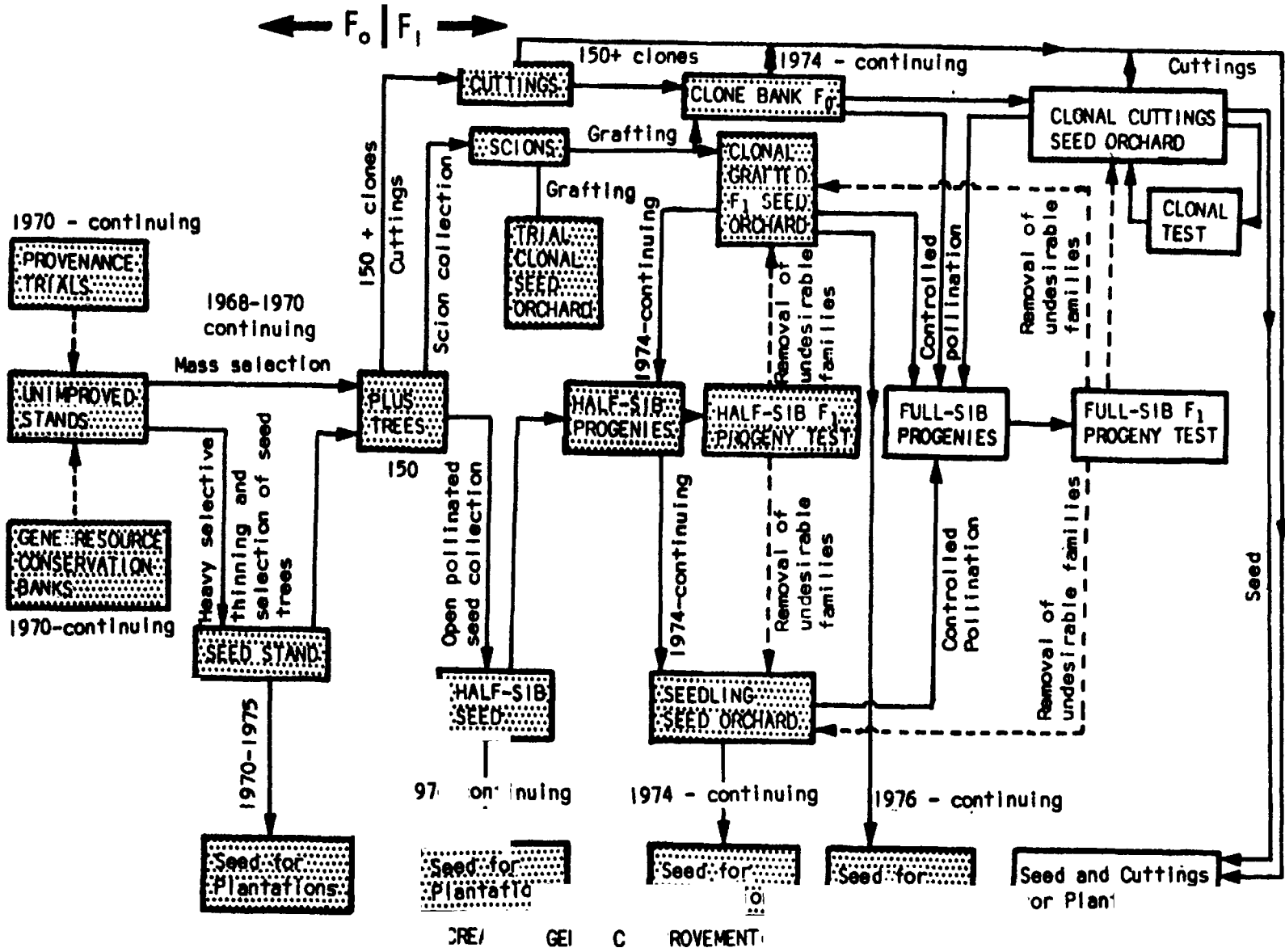


Figure 1. The breeding program for the improvement of the genetic base of the tree species. The arrows indicate where significant genetic changes are expected to occur.

SOME ASPECTS OF THE PROBLEM OF GENETIC IMPROVEMENT OF

HARDWOOD SPECIES NATIVE TO VENEZUELA

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OVERALL SITUATION

In Venezuela, as in many Latin American countries, hardwood species have not played a very important role in plans for genetic improvement, most of which are only in their initial stages. This is due largely to the fact that the natural forests, which are rich in flora, particularly broadleaved trees, have so far been expected to meet only local requirements, one species being replaced by another as time goes on. Another factor is the relatively low demand, particularly as regards quality, in many tropical regions. The weakness of the forestry sector within national economies has also had an effect: the forest enterprises are usually small, and though they use forest resources, they do not generate them. The larger enterprises have been centred around the coniferous species, particularly those belonging to the genus Pinus, for pulp and paper making.

The history of the native broadleaved species can therefore be summed up as follows:

a) Deterioration of the genetic base of species which have been of commercial importance at one time or another. Typical examples are the species of the Meliaceae family. This situation is due basically to continued dysgenic selection in the natural range of these species. This kind of negative selection has well been called trader's selection since the best trees in the forest have been logged, leaving as a source of regeneration the trees with the worst phenotypic characteristics.

b) Ignorance of the inherent and cultural properties of the species. This is due in large part to the feeling that the natural forests are inexhaustible, and to the problems in the initial utilization of some species. The latter is influenced by the use of genetically poor basic material and the application of cultural techniques developed specifically for temperate-zone species. However, the situation has begun to change in many places, due to the following factors among others:

- 1) exhaustion of natural sources of wood, particularly near large population centres;
- 2) an increase in demand owing to the growth in population;
- 3) the need to diversify economies traditionally dependent on a few resources, particularly non-renewable resources. Here forestry economics is particularly important;
- 4) the emergence of a desire to recuperate natural ecosystems and create recreation areas.

Some countries have proposed as a solution the use of introduced broad leaved species, such as Tectona, Gmelina and Eucalyptus, in view of their favourable productivity characteristics.

Even so, it has become necessary to increase the use of native species, either as means of recuperating and preserving the autochthonous ecosystems, or because of the fear that after a time the introduced species may present problems which outweigh the advantages they offer. The main advantage of the native species, in any case, is biological adaptation they have achieved in certain sites through generations of natural selection.

#### SPECIFIC CASES

If greater use is to be made of native species in genetic improvement programmes, it is essential that a minimum amount of knowledge on these species be available, covering:

a) Natural variation in those areas of the country where the species of interest are still found, in order to know the morphological, anatomical, physiological and technological variants that imply hereditary adaptation to various site conditions for selection purposes.

b) Phenology of the species, in order to assess the seed production capacity for supplying plantation programmes. Flowering habits also need to be known for the purpose of controlled pollination.

c) Cultural habits, from the nursery production phase to plantation techniques and methods and subsequent tending. The purpose is to reduce the influence of this component as much as possible, maximizing the genetic potential for use of plantation sites. Of particular interest in this phase, for the purposes of improvement, is the species vegetative propagation habit.

d) Development habits under cultivation, including quantitative and qualitative growth and technological properties. This knowledge serves as a basis for estimating gains in the possible selection systems that may be applied.

Once this knowledge is available, genetic improvement would be directed towards aspects of a general nature and of a particular nature. The first category, common to all species, includes the growth phase, which is essential for a greater yield per unit of area and for enabling native species to compete with introduced ones - an aspect which is very commonly emphasized in justifying the introduction of species. In this connection the programmes would be directed towards the formation of quick-growing subpopulations, through the selection and testing of vegetative propagules or seed progeny.

In the second category account would be taken of particular problems of species or groups of species which might result, through appropriate crossing, in a more effective use of the product. In this connection special mention should be made of the following, which are among Venezuela's most valuable timber species.

a) Bombacopsis quinata. Efforts are being made to control the development of buttresses, in order to increase the amount of utilizable bole wood for sawmilling. Since the buttresses, like the thorns, seem to be a character inherently linked with the evolution of the species, the aim is not to eliminate them completely, but to reduce their development to a minimum, through a process of selection and crossing specific individuals, on the basis of observations and preliminary results with forest trees and progeny.

b) Meliaceae species. Of particular interest are species of the genera Cedrela and Swietenia, because of their resistance to Hypsipyla. Since in most part of the world where these species grow naturally they have been subjected to intensive dysgenic selection, the genetic base seems to be fairly weak. A possible improvement strategy would be to effect intra-species selection followed by inter-species hybridization, with possible subsequent backcrossing. Crosses between Cedrela odorata, C. angustifolia, C. fissilis and C. montana deserve particular attention, and knowledge of the floral biology of these species should be intensified. Crosses between Swietenia macrophylla, S. humilis and S. mahogany are also being considered. Spontaneous inter-specific hybridization in this genus has already been reported. The possibility of intergeneric hybrids, e.g. Cedrela x Toona, is not to be rejected. The problems involved may be considerable, but the genes are morphologically so similar that until fairly recently Toona ciliata was classified under the genus Cedrela.

c) Tabebuia rosea. Efforts will be made to correct ramification habits, particularly the typically polydichotomic bifurcation of the main trunk. This phenomenon appears to be connected with inadequate individual sources of seed and high heritability of the characteristic. Strict individual selection, particularly since stands with very good individuals are now available, should lead to important achievements in the near future.

d) Phitecelobium saman. The attractive feature of this species is its trunk-crown ratio. In the open, under a silvo-pastoral system, the tendency is towards the development of a very broad crown, to the detriment of the bole quality. This tendency has also been observed in the natural forest, where, however, the trunks are better. Through a process of continuous individual selection, with interprovenance crossings, a broad crown with better trunk quality can be sought in the open field, and a smaller crown and thicker trunk in dense plantations.

ANNEX V

TRIP REPORT

ANNEX V/1

FLOWERING, SEED PRODUCTION AND ARTIFICIAL  
POLLINATION OF BOMBACOPSIS QUINATA IN VENEZUELA

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INTRODUCTION

Bombacopsis quinata is one of the most important dry tropical forest timber species in Venezuela. It is found on various kinds of soils ranging from well drained terrace soils to poorly draining swamp soils.

Rainfall distribution in the Bombacopsis quinata range oscillates between 1 000 and 2 000 mm/yr, with a 3-4 month dry season from December to March. The mean annual temperature is roughly 27°C, with maxima of 32°C and minima of 22°C. B. quinata wood is widely used in construction, interiors, exteriors, furniture, cabinet making, carpentry, etc. The wood density is roughly 0.40, based in kiln dry weight and volume in green wood.

B. quinata has been planted on a moderate scale to enrich natural forest, particularly in the forest reserves. Various trials have indicated open field planting as a promising technique, assuming proper site selection.

Studies on B. quinata were begun in 1961 to gain a better understanding of this species for breeding purposes. Initially, vegetative propagation habits were studied. Bombacopsis quinata responded so well to these trials that it came to be considered an easily propagated species. Other studies on the flowering and fruit setting habits were begun in 1968 with the establishment of seed orchards, including open and guided pollination.

FLOWERING AND FRUIT SETTING HABITS

Bombacopsis quinata are monoic, with hermaphrodite, generally erect flowers. The stamens surround a pistil with stigma slightly protruding beyond the anthers.

The flowers, 10-15 cm long, are night-blooming. They usually open after 6 p.m., mostly from 8-10 p.m., when the temperature drops below 25°C and the relative humidity rises above 60 percent. The morning after the flowers open, they drop their floral covers and stamens. The style remains, even after the fruit has formed. The flowering season runs from the end of October to March and sometimes April, depending on how long the dry season lasts. The best flowering periods are January and February, which are usually the driest months. Observations in seed orchards and natural forests indicate great variability in flowering. Some trees have a prolonged flowering period which lasts throughout the season. Some flower early in January and some flower late, from February onwards. This is very important in planning the lay-out of seed orchards. The initial age of flowering, seems to indicate early flowering. Trees not yet 10 years old have been observed to flower. Extreme cases of plants grown from seedlings, flowering after only six months in the field, have also been observed.

Fruit setting begins in January, with a lapse of 50-60 days from flower opening and pollination to dehiscence.

The fruit is dehiscent. The seeds are fuzz-covered and therefore easily dispersed by wind.

Seeds from open pollination in seed orchards average 47 per fruit, ranging from zero (empty pods) to 140. The average in the natural forest is 30 seeds per fruit, with heavy insect attacks on fruit and seeds. Viable seeds are usually smooth and fairly resistant when pressed flat with the hand. Non-viable seeds are usually rough and are easily flattened with a slight pressure of the fingers.

Colouring ranges from light to dark brown with various degrees of segregation within the ramets of a clone, which seems to be linked to the source of pollen.

Size is heavily influenced by the mother tree, and is reflected in the number of seeds/kg: 20 000 to 40 000, averaging 32 000 seeds/kg.

Studies indicate that the species is highly resistant to selfing, which favours cross-pollination. The low occurrence of selfing seems to be facilitated by the fact that as the flower is hermaphrodite, the stigma is receptive at the moment the flower opens but before it scatters its pollen. Pollen dispersal usually takes place 10-15 minutes after the pollen is exposed to wind. Some system of reproductive incompatibility, likewise favouring cross-pollination is also conceivable.

The findings of several years of seed germination trials on seeds from over 100 seed orchards and natural forest trees, suggest that B. quinata can be classed as a genetically clean species inasmuch as negative traits such as albinism or dwarfism have not appeared to date.

#### CONTROLLED POLLINATION

The size and open floral structure of the B. quinata flower has made it much easier to artificially pollinate the species.

When the flower reaches normal size, both the bud and the flower are isolated in a cloth sack to avoid damage from insects looking for nectar in the flowers. For artificial pollination, breeders allow the flower to open naturally. When it opens, the stamen is cut away with small scissors, carefully avoiding contact with the stigma of the pistil. The breeder takes advantage of the fact that at this stage, the pollen is still not easily dispersed.

Once the plant has been emasculated, the stigma is introduced into the appropriate pollen source, and completely saturated. The cross is then identified and the pollinated flower is again covered with a cloth bag, perhaps until the fruit falls off but in any case until such time as the fruit is clearly formed.

The pollen is collected at emasculation. The stamens are placed in a Petri dish and allowed to dry for at least one hour after which the breeder shakes the dish to release the pollen. The pollen is stored in the same container. It has been stored in an ordinary refrigerator for up to two weeks, with no great loss of viability, as long as the Petri dish was kept tightly closed and excessive accumulation of moisture within the container avoided. Controlled pollination has been 50 percent successful, with figures of up to 60 percent for cross-pollination and 4 percent for selfing. Variations have been observed in inter-crossing different clones, with the highest percentage of success from inter-crossing clones of different provenances.



Success in cross-pollination has varied greatly: very poor years with rates as low as 25 percent and very good years with rates as high as 80 percent, apparently related to environmental determinants affecting floral development.

Seed production under controlled pollination can go as high as 87 seeds per fruit, which is 1.9 times the yield from open pollination in seed orchards. Here also there have been extreme variations, ranging from empty pods to 150 seeds per fruit.

No great qualitative differences have been noted in the viability of selected seed with either method. Germination rates have averaged about 90 percent.

Seed has been maintained in the laboratory in paper envelopes for as much as six months and remained highly viable. At temperatures of around 5°C, the seed can remain under ground in a closed glass container for more than a year without any visible signs of deterioration. Seed has been stored for about two years in a 40-80 percent sulphuric acid environment in a chemical drier, the only precaution being to check that the paper or cloth packages in which the seed was stored had not been corroded by the acid, and to change them every six months.

ANNEX V/2

PLANTATION PROGRAMME  
LLANOS ORIENTALES, VENEZUELA

Climatic feature 1/

Coordinates: 62°W, 8°N

Altitude: 50 m above sea level

Temperature: Mean max. 32°C  
Mean min. 20°C  
Mean annual 26°C

Rainfall: 1150-1200 mm/yr, with the main rainy season from June to September and the shorter rainy season from November to mid-January

Winds: Average wind speed 7.8 km/hr, with occasional gales of 60-80 km/hr

Evaporation: Mean annual values: 2000-2100 mm.

Plantation Programme (Pinus caribaea var. hondurensis; Eucalyptus spp. <1%)

Company	Site	Reserved area (ha)	Planted area (1978) (ha)	Anticipated annual planting (ha)
1. State				
- CONARE	Coloradito	60 000	7 000	5 000
	Chaguaramas	100 000	22 000	5 000
	Cadupo	805	-	-
	Centella	12 000	4 000	10 000
- CVG	Uverito	150 000	50 000	7 000
Sub-total		322 805	83 000	
2. Mixed				
- Forestor		60 000	2 600	10 000
- Sipas		30 000	3 000	1 500
- Guayamure		60 000	7 000	1 500
Sub-total		150 000	12 600	
3. Private			4 000	
TOTAL Llanos Orientales 2/		472 805	99 600	

1/ "Uverito - un bosque en la Sabana". División de Relaciones Públicas, Corporación Venezolana de Guayana, CVG. Publicación No.1078-652; Tomo I, Folio 20; October 1978.  
2/ For country-wide information, see Appendix VI, "Venezuela".

ANNEX V/3

CVG, VENEZUELA: ACTIVITIES AND HUMAN RESOURCE

FOR THE PLANTATION PROGRAMME

(P. caribaea var. hondurensis, Uverito)

Operation	Human Resources	Total Production
<b><u>Seedbeds:</u></b>		
Prepare terraces	1 foreman	360 000 plants/day
Weed	8 workmen	
Sow		
Irrigate		
<b><u>Prepare containers:</u></b>		
Cut cardboard	1 supervisor	
Staple containers together	1 foreman	
Fill, weigh	10 cutters 60 helpers 6 fillers	
<b><u>Transplant:</u></b>		
Extract seedlings	4 foremen	
Move to terraces	1 helper	
Open seed holes	6 hoers	
Sow in containers	32 sowers 6 hole-diggers	
<b><u>Field work:</u></b>		
Sprinkler irrigation	1 foreman	
Fertilizing	14 workers	
Fungicide treatments		
Weeding		
Fumigation		
<b><u>Terraces:</u></b>		
Transport containers	3 foremen	
Line up containers	6 people to line up containers	
Fill containers with sand	36 helpers	
Compact sand	27 people to fill containers 9 people to pack sand	
<b><u>Planting:</u></b>		
<b><u>Land preparation:</u></b>		
	4 supervisors	7 000-10 000 ha/yr
	8 foremen	
Demarcation of stands	64 people to fill boxes	(area planned for 1980 - 7 000 ha;
Soil preparation	90 planters	5 000 ha in containers,
Insect control	20 people to spray insects 24 tractor drivers	2 000 ha directly rooted)

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ANNEX V/3 (cont'd)

Operation	Human Resources	Total Production
<u>Planting:</u> (cont'd)		
<u>Plantation:</u>		
Fill boxes and trucks Transport plants Plant	(See previous page)	(See previous page)
<u>Maintenance:</u>		
Open up and weed firebreaks Prevent and fight fires Control weeds Insect control		
	<u>Additional personnel,</u> to staff dining rooms, infirmary, machine shop, carpentry shop, etc.	
TOTAL HUMAN RESOURCES:	180 workers	

## CALENDAR OF ACTIVITIES

GENERAL OPERATIONS	SPECIFIC OPERATIONS	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
Plant production	Seeding in seedbeds	/-----/											
	Prepare containers	/-----/											
	Prepare terraces	/-----/											
	Transplant seedlings		/-----/										
Cultivation activities in nursery	Sprinkler irrigation	/-----/											
	Fertilization			/-----/									
	Trimming roots					/-----/							
	Weeding			/-----/									
	Insect control	/-----/											
Soil preparation	Staking out stands					/-----/							
	Raking			/-----/									
Planting	Fill crates and trucks									/-----/			
	Actual planting									/-----/			
Tending plantations	Firebreaks	/---/			/---/								/---/
	Weeding					/-----/							
	Insect control	/-----/											

CORPORACION VENEZOLANA DE GUAYANA: CALENDAR OF ACTIVITIES  
(Pinus caribaea var. hondurensis, Uverito)

APPENDIX VI - COUNTRY STATEMENTS

COUNTRY STATEMENTS: ARGENTINA

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 2 790 000 km<sup>2</sup>
- 1.2 Location: longitude: 53° - 73°W; latitude: 21° - 55° S.
- 1.3 Population: 26 000 000
- 1.4 Main climatic and vegetative zones: "Selva Misionera" (Misiones Forest) - "Selva Tucumano Boliviana" (Bolivian Tucuman Forest) - "Selvas en Galería" (Riparian Forests) - "Bosques Subantarticos" (Subantartic Forests) - "Parque Chaqueño" (Chaco Park) - "Parque Puntano-Pampeano" (Puntano Pampas Park) - "Parque Mesopotamico" (Mesopotamian Park) - "Estepa Pampeana" (Pampas Steppe) - "Estepa Patagonica" (Patagonian Steppe) - "Monte Occidental" (Western Forest) and "Estepa Puneña" (Puno Steppe) (see Annex I).

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 60 300 000 ha (productive forests: 39 000 000 ha).
- 2.2 Proportion of land under forest: 20.54%.
- 2.3 Does the country have a written statement of National Forest Policy? YES
- 2.3.1 If a National Policy exists, what are the main objectives stated in it?
- a) Rational utilization in accordance with forestry plans.
  - b) Utilization with special emphasis on the most valuable end product.
  - c) Encouragement of reforestation and improvement of national forests.
  - d) Encouragement of afforestation, encouraged by development credit.
  - e) Conservation of protective forests.

2.4 Legislation available to implement policy?

YES - Law No. 13.273 of 1948

2.5 Ownership of forests (out of the 39 000 000 ha of productive forests)

Under State control: 18 150 000 ha (46.16%)

Private ownership: 20 850 000 ha (53.84%)

Community ownership: -

No effective control: -

2.6 Major forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):

In 1977:

Saw-wood	21 000 000 m <sup>2</sup>	Plywood	54 000 t
Veneer logs	58 000 m <sup>3</sup>	Charcoal	278 000 t
Logs for fibreboard	225 000 m <sup>3</sup>	Fuelwood	1 095 000 t
Logs for sleepers	61 000 t	Pulp for paper	703 000 t
Posts	199 000 t	Tanin (extract)	87 000 t

- 2.7 Staff
- |  | <u>State</u> | <u>Others</u> |
|--|--------------|---------------|
| Professional   | 96 1/        | ?             |
| Sub-professional<br>(with diploma or<br>certificate of training) | no 1/        | ?             |

2.8 Gross annual budget for forestry: US\$ 47 680 000 2/.

1/ Only under the National State.

2/ Only under the National State, including incentive subsidies (US\$ 1.00 = \$a 1.630).

3. AFFORESTATION AND REFORESTATION

3.1 Areas

3.1.1 Net total area <sup>1/</sup> of plantations at the end of 1978: 530 000 ha <sup>2/</sup>.

3.1.2 Planned annual target of afforestation/reforestation: 90 000 ha/year (1979) <sup>2/</sup>

3.2 Organization and administration of planting schemes:

3.2.1 State forest services: 100%

3.3 Principal product or purpose envisaged (for example, saw-wood, posts and stakes, pulpwood, fuelwood, protection, etc.).

3.3.1 Indigenous species

Product/Purpose	Species	Net area (ha) <sup>1/</sup>	Rotation (years)	Mean annual increment (without bark) at the end of the rotation (m <sup>3</sup> /ha/year)
Saw-wood Pulpwood	Araucaria angustifolia	30 000 <sup>3/</sup>	40	17 (man-made planta- tions)
Tanin and sleepers	Schinopsis sp.	12 000 000	120	6 for the stand, 0.5 for the species
Saw-wood	Nothofagus sp.	1 000 000	90	3-4 (homogeneous forest)
Saw-wood	( Cedrela sp. ) ( Cordia sp. ) ( Balfourodendron sp. )	2 500 000	60	0.5 0.15 (for the stand) 0.3 (heterogeneous forest)

3.3.2 Introduced species

Product/Purpose	Species	Net area (ha) <sup>1/</sup>	Rotation (years)	Mean annual increment (without bark) at the end of the rotation (m <sup>3</sup> /ha/year)
Paper pulp and resin	Pinus elliottii)	150 000	10-25	30
	Pinus taeda )		10-25	30
Wood and pulp	Pseudotsuga menziesii		32	20
	Pinus radiata		30	25
	Pinus ponderosa		35	18
Containers pulp	Populus sp.	170 000	10	22
	Eucalyptus sp.	100 000	20	30

4. SEED AND PLANT SUPPLY

4.1 Service and control of seed supply

4.1.1 Have seed zones been defined for indigenous species (i.e., is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)?

YES (only with Araucaria angustifolia in Misiones)

4.1.2 Is there a national seed certification system? NO <sup>4/</sup>

4.1.3 Are there facilities for storing seed at controlled temperatures? YES

4.1.4 Does the supply of seed cover the demand for the species listed in 3.3.1? NO in 3.3.2? NO

<sup>1/</sup> The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

<sup>2/</sup> Approximate dates.

<sup>3/</sup> Corresponds to range of the species in Argentina.

<sup>4/</sup> In process; status: preliminary draft law.

5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement programme? YES 1/

5.1.1 If yes, list the species concerned:

Pinus elliottii	Populus sp.
Pseudotsuga menziesii	Salix sp.
Pinus ponderosa	Eucalyptus saligna/grandis
Araucaria angustifolia	Melia azedarach

5.1.2 Most important characters to be improved or bred for:

- 1) Productivity
- 2) Ecological adaptability
- 3) Disease resistance
- 4) Seed quality
- 5) Wood quality

5.2 Brief outline of improvement methods already applied.

5.2.1 Species/provenance trials (indicate in parentheses the number of provenances being tested):

- a) Pinus elliottii and P. taeda (38 and 29 provenances) 2/
- b) Eucalyptus camaldulensis, E. viminalis (33 and 22 provenances) 2/
- c) Pinus in northwest Argentina (19 species) 2/
- d) Pinus on the Argentine coast (17 species) 2/

5.2.2 Area of seed stands in each of the main species: 3/

Pinus ponderosa	8 ha
Pseudotsuga mensiesii	15 ha
Araucaria angustifolia	414.5 ha

5.2.3 Plus trees of the main species (indicate in parentheses the number of trees): 3/

Pinus ponderosa (24)  
Pseudotsuga menziesii (17)

5.2.4 Seed orchards (species, area and number of clones or mother trees): 3/ NO

5.2.5 Progeny testing? (species and area): 3/

Pinus ponderosa (1979)  
Pseudotsuga menziesii (1979)

5.2.6 Other methods of improvement (specify): 3/ NO

6. MOST SUCCESSFUL METHODS OF VEGETATIVE PROPAGATION FOR MAIN SPECIES

<u>Species</u>	<u>Method</u>	<u>% of success</u>
Pinus elliottii	Stakes (horm. treatment and treatment of mother tree)	Started on 12.12.79
Eucalyptus saligna	"	Started on 12.12.79
Pseudotsuga menziesii	"	Starts on 1.2.80
Pinus ponderosa	"	Starts on 1.2.80

7. REFERENCES TO TREE IMPROVEMENT

Please list the references to tree improvement in the country, in publications, reports, etc.

IDIA (Suplemento Forestal No. 6)- INTA - Bs.As. 1970  
IDIA (Suplemento Forestal No. 8)- INTA - Bs.As. 1973  
IDIA (Suplemento Forestal No. 5)- INTA - Bs.As. 1966  
IDIA (Revista No. 12) - Buenos Aires

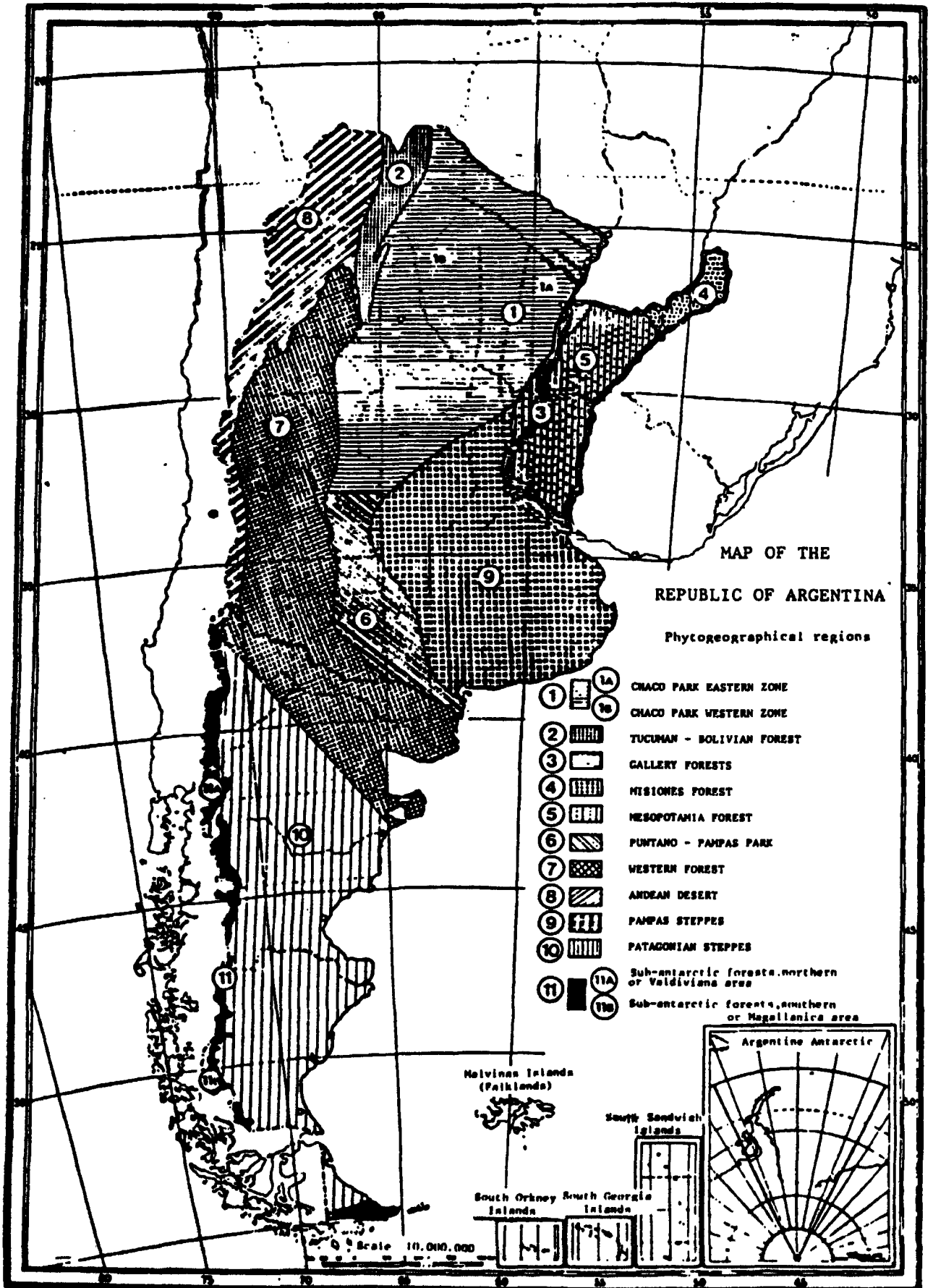
1/ By 1980 at national level.

2/ Instituto Nacional de Tecnología Agropecuaria (INTA) - Natl. Institute of Agricultural Technology.

3/ Only under the jurisdiction of the National Forestry Institute.



# PHYTOGEOGRAPHICAL REGIONS OF ARGENTINA



COUNTRY STATEMENT: BOLIVIA

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 1 058 000 km<sup>2</sup>
- 1.2 Location: longitude: 57°26' - 60°38'W; latitude: 9°38' - 22°53'N
- 1.3 Population: 4 647 816 (September 1976)
- 1.4 Main climatic and vegetative zones: mountain-building in the area has produced four different zones: warm valleys, valleys, high plateaux and plains.

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 56 468 000 ha
- 2.2 Proportion of land under forest: 51%
- 2.3 Does the country have a written statement of National Forest Policy? YES
- 2.3.1 If a National Policy exists, what are the main objectives stated in it?
  - a) To formulate the country's forest policy and its plans for implementation.
  - b) To manage national forest resources on a permanent basis.
  - c) To promote and/or make a forest inventory for Bolivia.
  - d) To authorize, guide and supervise forest utilization, in accordance with the provisions of the law.
- 2.4 Legislation available to implement policy? YES
- 2.5 Ownership of forests:
  - Under State control: 99.9 percent
  - Community ownership: 0.1 percent
- 2.6 Principal forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):  
Veneer logs, sawn-logs, sleepers, posts, planting for mines, building timber, charcoal fuelwood, rubber and chestnut.
- 2.7 Staff

	<u>State</u>	<u>Other</u>
Professional	28	5
Sub-professional (with diploma or certificate of training)	21	5
- 2.8 Gross annual budget for forestry: US\$ 1 000 000.

3. AFFORESTATION AND REFORESTATION

- 3.1 Areas
  - 3.1.1 Net total area 1/ of plantations at the end of 1978: 10 000 ha.
  - 3.1.2 Planned annual target of reforestation: 1 500 ha/year.
- 3.2 Organization and administration of planting schemes:
  - 3.2.1 State Forest Services: 90 percent
  - CÁMARAFOR: 3 percent
  - Other private owners: 7 percent
- 3.3 Principal product or purpose envisaged (for example, saw-wood, posts and stakes, pulpwood, fuelwood, protection, etc.).

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

3.3.1 Indigenous species

<u>Product/Purpose</u>	<u>Species</u>	<u>Net area (ha) 1/</u>	<u>Rotation (years)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Saw-wood	Swietenia macrophylla	200	80	
Sulphate	"Quina"	42	10	
Latex (rubber)	Hevea brasiliensis	230	10-20	
Fuelwood	Others	228		

3.3.2 Introduced species

<u>Product/Purpose</u>	<u>Species</u>	<u>Net area (ha) 1/</u>	<u>Rotation (years)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Posts	Eucalyptus spp			
Charcoal		9 000	10	20
Stakes				
Posts		300	20	

4. SEED AND PLANT SUPPLY

4.1 Service and control of seed supply

- 4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? YES
- 4.1.2 Is there a national seed certification system? NO
- 4.1.3 Are there facilities for storing seed at controlled temperatures? NO
- 4.1.4 Does the supply of seed cover the demand for the species listed in 3.3.1? NO  
in 3.3.2? NO

5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement progr. ? NO

5.2.5 Progeny or testing? (species and area):

Eucalyptus rostrata	Pinus radiata
E. viminalis	P. elliotii
E. saligna	P. taeda
E. Globulus	Cupressus lusitanica
E. citriodora	
E. tereticornis	

COUNTRY STATEMENT: BRAZIL

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 8 511 970 km<sup>2</sup>
- 1.2 Location: longitude: 34°S-74°W; latitude: 5°N-33°S
- 1.3 Population: 119 670 000
- 1.4 Main climatic and vegetative zones: See Annex I

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 352 000 000 ha
- 2.2 Proportion of land under forest: 41%
- 2.3 Does the country have a written statement of National Forest Policy? YES
- 2.3.1 If a National Policy exists, what are the main objectives stated in it?
  - a) Forest production to meet the National Programmes for pulp and paper and for the charcoal fueled steel industry
  - b) Reforestation Programme for small and medium-sized rural holdings
  - c) Settlement and rational utilization of the forest resources of the Brazilian Amazon region
- 2.4 Legislation available to implement policy? YES
- 2.5 Ownership of forests
  - Under State control: 75%
  - Private ownership: 15%
  - Community ownership: -
  - No effective control: 10%
- 2.6 Principal forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):

Saw-wood	16 325 000 m <sup>3</sup>	Charcoal	17 618 000 t
Sawn wood	7 400 000 m <sup>3</sup>	Paper	2 045 969 t
Pulp	1 253 784 t	Veneer	695 000 m <sup>3</sup>
Fibre board	574 000 m <sup>3</sup>	Particle board	461 000 m <sup>3</sup>
Plywood	659 000 m <sup>3</sup>	Fuelwood	140 000 000 m <sup>3</sup>
- 2.7 Staff

	<u>State</u>	<u>Others</u>
Professional	1 200	-
- 2.8 Gross annual budget for forestry: US\$ 30 266 343.83

3. AFFORESTATION AND REFORESTATION

- 3.1 Areas
  - 3.1.1 Net total area <sup>1/</sup> of plantations at the end of 1978: 3 319 034 ha
  - 3.1.2 Planned annual target reforestation: 335 442 ha/year
- 3.2 Organization and administration of planting schemes
  - 3.2.1 State forest services: 5%
  - Others: 95% (most of this due to tax incentives)
- 3.3 Principal product or purpose envisaged (for example, saw-wood, posts and stakes, pulpwood, fuelwood, protection, etc.).

<sup>1/</sup> The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

3.3.1 Indigenous species

<u>Product/Purpose</u>	<u>Species</u>	<u>Net area (ha) <u>1/</u></u>	<u>Rotation (years)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
	Araucaria angustifolia	73 074.91	40	13
	Indigenous species	39 744.75	40	

3.3.2 Introduced species

<u>Product/Purpose</u>	<u>Species</u>	<u>Net area (ha) <u>1/</u></u>	<u>Rotation (years)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
	Pinus spp.	05 533.82	7	19
		39 781.35	7	20

4. SEED AND PLANT SUPPLY

4.1 Service and control of seed supply

- 4.1.1 Have seed zones been defined for indigenous species (i.e., is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? YES
- 4.1.2 Do special seed production areas exist? YES
- 4.1.3 Are there facilities for storing seed at controlled temperatures? YES
- 4.1.4 Does the supply of seed cover the demand for the species listed in 3.3.1? YES  
in 3.3.2? NO

5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement programme? YES

5.1.1 If yes, list species involved:

Eucalyptus grandis	Pinus caribaea var. hondurensis
E. urophylla	P. caribaea var. caribaea
E. saligna	P. elliotii var. elliotii
Araucaria angustifolia	P. oocarpa

5.1.2 Most important characters to be improved or bred for:

Volume (dbh and height)	Wood quality
Form	Resistance to diseases

5.2 Brief outline of improvement methods already applied:

5.2.1 Species/provenance trials (indicate in parentheses the number of provenances being tested):

Eucalyptus spp.	43 species, 1-37 provenances of each species
Pinus caribaea var. hondurensis	(7) <u>1/</u>
P. caribaea var. caribaea	(2) <u>1/</u>
P. caribaea var. bahamensis	(2) <u>1/</u>
P. oocarpa	(19) <u>1/</u>

1/ Provenances introduced by PRODEPEF between 1971 and 1977.

5.2.2 Seed stands: area of seed stands in each of the main species:

Eucalyptus grandis	114.99 ha
E. urophylla	36.46 ha
E. saligna	2.30 ha
E. citriodora	8.15 ha
E. paniculata	10.45 ha
E. viminalis	215.28 ha
Pinus oocarpa	1 069.58 ha
P. caribaea var. hondurensis	1 202.96 ha
P. elliottii var. elliottii	30.90 ha
P. taeda	106.50 ha
P. caribaea var. caribaea	346.16 ha
P. caribaea var. bahamensis	185.48 ha
P. kesiya	117.87 ha
P. strobus var. chapensis	6.98 ha

5.2.3 Plus trees of main species (indicate in brackets the number of trees):

Eucalyptus grandis (200)	P. caribaea var. hondurensis (300)
E. saligna (50)	P. caribaea var. bahamensis (300)
Pinus oocarpa (100)	P. caribaea var. caribaea (300)
	P. taeda (50)

5.2.4 Seed orchards (species, area and number of clones or mother trees):

Eucalyptus grandis (100 clones)  
E. saligna (50 clones)  
Pinus caribaea (300 clones)

5.2.5 Progeny testing?

Eucalyptus grandis (15 tests)	P. caribaea var. hondurensis (22 tests)
E. saligna (5 tests)	P. kesiya (10 tests)

5.2.6 Other methods of improvement (specify):

Area of seed collection  
Grafted seed orchard  
Obtaining and use of hybrids

6. MOST SUCCESSFUL METHODS OF VEGETATIVE PROPAGATION FOR MAIN SPECIES

<u>Species</u>	<u>Method</u>	<u>% of success</u>
Eucalyptus camaldulensis	Estaquia	60
E. tereticornis	Estaquia	50
E. grandis	Enxertia	60
E. dunnii	Enxertia	70
E. dunnii	Estaquia	50
P. kesiya	Enxertia	80
P. caribaea	Enxertia	70

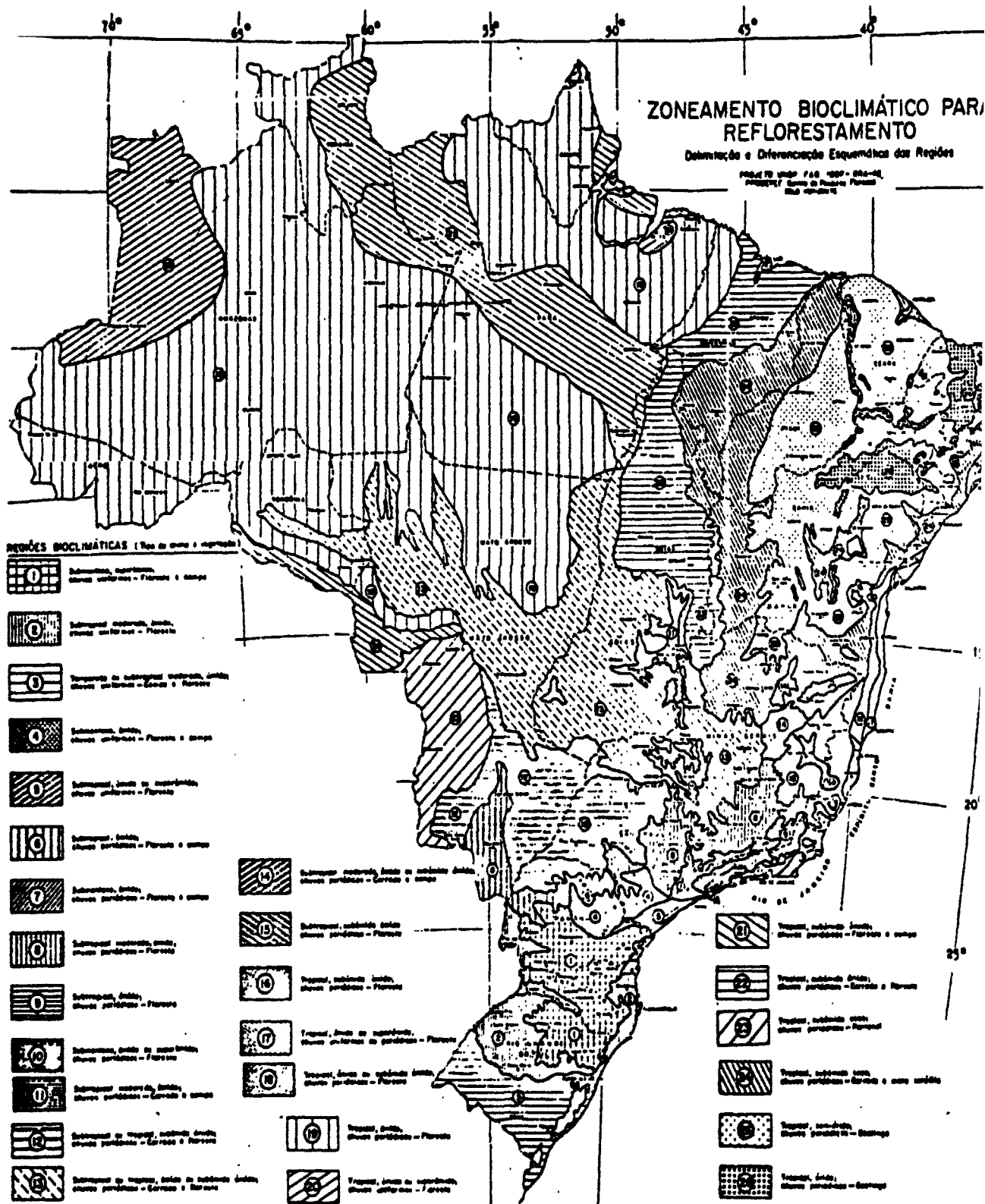
7. REFERENCES TO TREE IMPROVEMENT

Please list the references to tree improvement in the country in publications, reports, etc.

IPEF Revista	IUFRO Proceedings
SIF Boletín Técnico	Revista Arvore
IPEF Circular Técnica	PRODEPEF Série Técnica
Silvicultura en São Paulo	

COUNTRY STATEMENT: BRAZIL

ANNEX 1



Country statement: CHILE

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 2 007 000 km<sup>2</sup> - 757 000 km<sup>2</sup> mainland and islands, and 1 250 000 km<sup>2</sup> Antarctic.
- 1.2 Location: longitude: 67°30' - 75°30'W; latitude: 17° - 56°S (mainland). However, it stretches down to the Antarctic.
- 1.3 Population: 11 000 000
- 1.4 Main climatic and vegetative zones:

Climatic

- a) Sub-tropical arid
- b) Warm temperate with adequate humidity
- c) Rainy temperate
- d) Tundra
- e) Cold steppe
- f) Freezing climates

Vegetative

- a) Xeromorphic zone
- b) Mesomorphic zone
- c) Hygromorphic zone
- d) Andean zone

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 20 000 000 ha
- 2.2 Proportion of land under forest: 26 percent - taking into account both mainland and island Chile.
- 2.3 Does the country have a written statement of National Forest Policy? YES
- 2.3.1 If a National Policy exists, what are the main objectives stated in it? .

To achieve accelerated growth and development of the forest sector through conservation, protection, management and utilization of forest resources, bearing in mind the nation's interests and the country's economic and ecological limitations.

- 2.4 Legislation available to implement policy? YES
- 2.5 Ownership of forests:
- 2.5.1 Under State Control: 60 percent
- 2.5.2 Private ownership: 40 percent
- 2.6 Principal forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):
- Chemical pulp, mechanical pulp, newsprint, other papers, cardboard, fibreboard, particle board, plywood, veneers, logs, sawn timber, posts, stakes, sleepers, honey, bark, leaves, mushrooms.

2.7	Staff	State	Others
2.7.1	Professional:	60	300
2.7.2	Subprofessional (with diploma or certificate of training):	100	360

2.8 Gross annual budget for forestry: US\$ 20 000 000.

3. AFFORESTATION AND REFORESTATION

3.1 Areas

- 3.1.1 Net total area 1/ of plantations at the end of 1978:  
712 000 ha
- 3.1.2 Planned annual target/reforestation: 70 000 ha/year

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.



3.2 Organization and administration of planting schemes

3.2.1 State Forest Services: -

3.2.2 Others (specify):

Small private owners: 45 percent  
Large companies: 55 percent

3.3 Principal product or purpose envisaged (for example, saw-wood, posts and stakes, pulpwood, fuelwood, protection, etc).

3.3.1 Indigenous species:

<u>Product/ Purpose</u>	<u>Species</u>	<u>Net area (ha) 1/</u>	<u>Rotation (years)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Sawn wood	Nothofagus spp.	500 annual 2 000 total	80	14
Forage	Atriplex repanda	400 annual 2 000 total	-	-
Bark	Quillaja saponaria	100 annual 800 total	40	7

3.3.2 Introduced species:

<u>Product/ Purpose</u>	<u>Species</u>	<u>Net area (ha) 1/</u>	<u>Rotation (years)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Paper, sawn wood, pulp	Pinus radiata	62 000 annual 640 000 total	20-25	22
Firewood, posts, parquet	Eucalyptus globulus	3 500 annual 40 000 total	15-20	25-30
Matches, cases, sawn wood	Populus spp.	2 200 annual 22 000 total	15-20	25-30
Sawn wood	Pseudotsuga menziesii	700 annual 2 000 total	80	13
Forage	Atriplex nummularia	600 annual 3 000 total	-	-

4. SEED AND PLANT SUPPLY

4.1 Service and control of seed supply

4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? For very few species.

4.1.2 Is there a national seed certification system? YES

4.1.3 Are there facilities for storing seed at controlled temperatures? YES

4.1.4 Does the supply of seed cover the demand for the species listed:  
in 3.3.1? YES  
in 3.3.2? YES

5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement programme? YES

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

5.1.1 If yes, list species involved:

- Pinus radiata, through the establishment of seed orchards.
- Various species involved in the provenance trials (see item 5.2.1).
- Nothofagus alpina, an indigenous species, through a variability study.

5.1.2 Most important characters to be improved or bred for:

Growth rate	Volume
General form	Wood density
General adaptability	Resistance to Dothistroma pini

5.2 Brief outline of improvement methods already applied:

5.2.1 Species/provenance trials (indicate in parentheses the number of provenances being tested):

Eucalyptus delegatensis (12)	Pinus radiata (14)
E. regnans (6)	P. ponderosa (6)
E. obliqua (4)	P. contorta (3)
E. bicostata (4)	P. muricata (2)
E. camaldulensis (3)	Pseudotsuga menziesii (2)

5.2.2 Area of seed stands in each of the main species:

Pinus radiata: 120 ha

5.2.3 Plus trees of main species (indicate in parentheses the number of trees):

350 plus trees, with a selection intensity of 1 in 120 000.

5.2.4 Seed orchards (species, area and number of clones or mother trees):

Only pinus radiata. There are two types: (1) clonal: There are 8 of these, with 42 clones each and areas fluctuating between 11 and 30 hectares, 20 being the average; (2) from seedlings: there are 3 of these, with 200 families as a basis, 20 hectares each.

5.2.5 Progeny testing? (species and area):

In May 1980, 55 hectares on 14 different sites, will be put under progeny trials of Pinus radiata.

5.2.6 Other methods of improvement (specify):

38 000 seed trees of Pinus radiata have been selected, which have produced 7 000 kg of seed, with an expected improvement of roughly 5-6 percent.

6. SUCCESSFUL METHODS IN VEGETATIVE PROPAGATION FOR MAIN SPECIES:

<u>Species</u>	<u>Method</u>	<u>% of success</u>
Pinus radiata	Lateral grafting	80

7. REFERENCES TO TREE IMPROVEMENT

Please list the references to tree improvement in the country, in publications, reports, etc.

Burdon, R. Mejoramiento genético forestal en Chile. Documento de trabajo No.11. FO:DP/CHI/76/003 Investigación y desarrollo forestal. Santiago de Chile, 1978.

Delmastro, R. Proposición de un programa cooperativo de mejoramiento genético entre la Universidad Austral, instituciones y empresas forestales. Facultad de Ingeniería Forestal, Universidad Austral de Chile, Valdivia. 1976.

Delmastro, R. Informe de genética forestal. Proyecto CONAF/PNUD/FAO/CHI/76/003. Código III - 1.1 Facultad de Ingeniería Forestal, Universidad Austral de Chile, Valdivia, 1977.

Moreno, D.G. Consideraciones preliminares para un programa de mejoramiento genético. (To be published in May 1980 in the Supplement to "Chile Forestal").

Moreno, D.G. and Stutz, C. Informe de la gira a Nueva Zelanda sobre mejoramiento genético. Documento interno presentado a la Dirección Ejecutiva de CONAF a la Dirección del Proyecto CONAF/PNUD/FAO/CHI/76/003. Chillán, Chile, 1979.

Delmastro, R. Primer informe anual. Convenio de mejoramiento genético UACH - empresas forestales. Facultad de Ingeniería Forestal, Universidad Austral de Chile, Valdivia, 1977.

Delmastro, R. Segundo informe anual. Convenio de mejoramiento genético UACH - empresas forestales. Facultad de Ingeniería Forestal, Universidad Austral de Chile, Valdivia, 1978.

Delmastro, R. Manual para los ensayos de progenie de polinización abierta. Convenio de mejoramiento genético UACH - empresas forestales. Facultad de Ingeniería Forestal, Universidad Austral de Chile, Valdivia, 1979.

Smith, V.N. Selección de árboles plus en Constitución, provincia de Maule. Actas V jornadas forestales. Asociación Chilena de Ingenieros Forestales. Los Angeles, Chile, 1969.

Aparico, J. and Siri, A. Estudio de variación en plántulas de *Pinus radiata*. D. Don. en Chile. Tesis Facultad de Agronomía, Escuela de Ingeniería Forestal, Universidad de Chile, Santiago, 1970.

Garrido, F. Ibarra, M. Steinmetz, J. and Seron, J. Variación de poblaciones naturales de Raulí (*Nothofagus alpina* (Poepp. et Endl.) Oerst). Revisión bibliográfica. CONAF-FAO. FO DP/CHI/76/003. Documento de trabajo No. 28, Santiago de Chile, 1979.

Country statement: COLOMBIA

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 1 138 914 km<sup>2</sup>
- 1.2 Location: longitude 74°04'41''; latitude 4°35'56''
- 1.3 Population: 28 000 000
- 1.4 Main climatic and vegetative zones:

There are various areas in the country; they include humid and very humid tropical forest on the Pacific coast and in Amazonia; dry tropical forest on the Atlantic coast and in the east of the country; and premontane and montane forests in the Andean area.

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 36 426 000 ha (1977)
- 2.2 Proportion of land under forest: 38 percent
- 2.3 Does the country have a written statement of National Forest Policy? YES
- 2.3.1 If a National Policy exists, what are the main objectives stated in it?

To rationally manage forest areas, which are classed as productive, productive-protective and protective. To encourage watershed management and conservation in the Andean region. To develop, through support services, such aspects as: forestation, protection, technical assistance, research and marketing of products.

- 2.4 Legislation available to implement policy? YES

- 2.6 Principal forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):

Pulp, paper, cardboard - sawn wood - veneers, triplex, particle board, fibreboard - roundwood - posts, poles, fencing, cross-pieces, charcoal, rubber, balata, balsam of Tolu, essential oils, gum, etc.

2.7	Staff	State	Others
2.7.1	Professional:	270	650
2.7.2	Subprofessional (with diploma or certificate of training):	30	90

3. AFFORESTATION AND REFORESTATION

3.1 Areas

- 3.1.1 Net total area 1/ of plantations at the end of 1978:  
80 000 ha

- 3.1.2 Planned annual target/reforestation:  
40 000 ha/year

3.2 Organization and administration of planting schemes

- 3.2.1 State Forest Services: 20 percent
- 3.2.2 Others (specify):

Forest corporations: 30 percent  
Private companies: 50 percent

- 3.3 Principal product or purpose envisaged (for example, saw-wood, posts and stakes, pulpwood, fuelwood, protection, etc.)

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

3.3.1 Indigenous species:

<u>Product/ Purpose</u>	<u>Species</u>	<u>Net Area (ha) 1/</u>	<u>Rotation years</u>
Cabinet- making	Tabebuia rosea	250	30
Cabinet- making	Alnus jorullensis	500	30
Cabinet- making Interiors	Cordia alliodora	650	25-30
Cabinet- making	Cariniana pyriformis	700	30

3.3.2 Introduced species:

<u>Product/ Purpose</u>	<u>Species</u>	<u>Net area (ha) 1/</u>	<u>Rotation years</u>	<u>Mean annual increment (with- out bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Pulp	Pinus petula	25 000	15-20	20m <sup>3</sup> /ha/year
Roundwood	Eucalyptus globulus	18 000	8-15	22m <sup>3</sup> /ha/year
Pulp	Cupressus lusitanica	21 000	15-25	18m <sup>3</sup> /ha/year
Pulp	Pinus radiata	3 000	15	15m <sup>3</sup> /ha/year
Construction	Tectona grandis	1 000	40	15m <sup>3</sup> /ha/year
Round wood	Eucalyptus spp.	4 000	12-15	18m <sup>3</sup> /ha/year
	Other species	6 000	various	

4. SEED SUPPLY AND CONTROL

4.1 Service and control of seed supply

4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? YES

4.1.2 Is there a national seed certification system? YES

4.1.3 Are there facilities for storing seed at controlled temperatures? YES

4.1.4 Does the supply of seed cover the demand for the species listed in 3.3.1? NO  
3.3.2? NO

5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement programme? YES

5.1.1 If yes, list species involved:

Pinus patula	Pinus kesiya
Cupressus lusitanica	Eucalyptus globulus
Pinus oocarpa	Eucalyptus grandis
Pinus caribaea	Gmelina arborea
Cordia alliodora	Cariniana pyriformis

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

5.1.2 Most important characters to be improved or bred for:

Upward growth	Form of the trunk
Specific weight	Angle and thickness of branches
Fibre length	Crown size
	Ease of pruning

5.2 Brief outline of improvement methods already applied:

5.2.1 Species/provenance trials (indicate in parentheses the number of provenances being tested):

Cupressus lusitanica (20)	Eucalyptus globulus (32)
Pinus caribaea (14)	Gmelina arborea (11)
Pinus oocarpa (19)	Cariniana pyriformis (4)
Pinus kesiya (25)	Tectona grandis (5)
Pinus patula (?)	Cordia alliodora (13)
	Ochroma lagopus (5)

5.2.2 Area of seed stands in each of the main species:

Cordia alliodora  
Ochroma lagopus  
Jacaranda copaia

5.2.3 Plus trees of main species (indicate in parentheses the number of trees):

Cupressus lusitanica (43) pre-selected species  
Pinus patula (20)

5.2.4 Seed orchards (species, area and number of clones or mother trees):

Cupressus lusitanica (5 ha, 43 clones)

5.2.5 Progeny testing? (species and area):

Cupressus lusitanica  
Pinus patula  
Cariniana pyriformis

5.2.6 Other methods of improvement (specify):

6. SUCCESSFUL METHODS IN VEGETATIVE PROPAGATION FOR MAIN SPECIES:

<u>Species</u>	<u>Method</u>
Bombacopsis quinata	Large cutting
Tabebuia rosea	Large cutting
Cupressus lusitanica	Lateral grafting
Pinus patula	Grafting

7. REFERENCES TO TREE IMPROVEMENT

Logros genéticos con Cupressus lusitanica a través de 6 años de mejoramiento genético en Colombia. Cartón de Colombia: Investigación Forestal.

Documentos de Trabajo del Proyecto sobre Investigaciones y Desarrollo Industrial Forestales, INDERENA/PNUD/FAO/CONIF COL/74/005:

König, A. & Melchior, G.H. Propagación vegetativa en árboles forestales;

König, A. & Melchior, G.H. & Venegas T.L. Ensayos de procedencias con Pinus caribaea;

König, A. Ensayos de procedencia con Pinus oocarpa y Pinus kesiya en Colombia; Melchior, G.H. Bases y posibilidades del mejoramiento de árboles forestales en Colombia.

Country statement: COSTA RICA

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 50 851 km<sup>2</sup>
- 1.2 Location: Longitude: 82°34' - 85°59'; latitude: 8°02' - 11°13'
- 1.3 Population: 2 125 620
- 1.4 Main climatic and vegetative zones:
- Climatic zones: Valle Intermontano (Inter-montane valley), Vertiente Pacifica (Pacific slope), Vertiente Atlantica (Atlantic slope) and the north.
- Vegetative zones: Tropical forest (dry-humid), sub-tropical forest (humid-very humid), low montane forest (humid-very humid- rainy), montane forest, sub-alpine forest.

2. FOREST AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 2 088 200 ha
- 2.2 Proportion of land under forest: 40.9%
- 2.3 Does the country have a written statement of National Forest Policy? YES
- 2.3.1 If a National Policy exists, what are the main objectives stated in it?
- A. To transform productive forests into an efficient system for the supply of raw material to industry.
- B. To conserve protective forests.
- C. To encourage large-scale reforestation as a better land use measure. To strengthen the State institutions for forest planning and control.
- 2.4 Legislation available to implement policy? YES
- 2.5 Ownership of forests:
- Under State control: 11.5%
- Private ownership: 35.0%
- Community ownership: 0.3%
- No effective contro: -
- 2.6 Principal forest products (for exemple, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):
- Sixty-five percent of the country's forest production is saw-wood to meet internal needs, and some for furniture for export. The remainder is processed as plywood and particle board for export. A low percentage is used for the preparation of sleepers and souvenirs.

2.7 Staff

State

- 2.7.1 Professional: 20
- 2.7.2 Subprofessional (with diploma or certificate of training): 127 29
- 2.8 Gross annual budget for forestry: US\$ 2 264 655.40

3. AFFORESTATION AND REFORESTATION

3.1 Areas

- 3.1.1 Net total area <sup>1/</sup> of plantations at the end of 1978: 810 ha
- 3.1.2 Planned annual target/reforestation: 6 200 ha/year

<sup>1/</sup> The net area is the gross area of plantation, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

3.2 Organization and administration of planting schemes

3.2.1 State Forest Services: 8%

Others (Specify): Private ownership: 92%

3.3 Principal product or purpose envisaged (for example, sawwood, posts and stakes, pulpwood, fuelwood, protection, etc.)

3.3.1 Indigenous species:

<u>Product</u>	<u>Species</u>	<u>Net area (ha) <sup>1/</sup></u>	<u>Rotation (year)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Saw-wood	Cordia alliodora	20	25	18-20
Saw-wood	Bombacopsis quinata	50	25	15
Saw-wood	Alnus acuminata	50	18	35

3.3.2 Introduced species:

<u>Product</u>	<u>Species</u>	<u>Net area (ha) <sup>1/</sup></u>	<u>Rotation (year)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Saw-wood	Pinus caribaea	200	8	30
Posts	Eucalyptus deglupta	50	5-6	30
Saw-wood	Cupressus lusitanica	100	25	20-22
Pulp	Gmelina arborea	20	25	25
Saw-wood	Tectona grandis	300	40	10

4. SEED AND PLANT SUPPLY

4.1 Service and control of seed supply

4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? YES

4.1.2 Is there a national seed certification system? YES

4.1.3 Are there facilities for storing seed at controlled temperature? YES

4.1.4 Does the supply of seed cover the demand for the species listed  
in 3.3.1? NO  
in 3.3.2? NO

5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement programme? NO

7. REFERENCES TO TREE IMPROVEMENT

Please list the reference to tree improvement in the country, in publications, report, etc.

There is no literature on this specific subject. The only publications are a few short information booklets on identification of seed trees, published by the Forest Service of Costa Rica.

<sup>1/</sup> The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.



Country Statement: CUBA

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 110 922 km<sup>2</sup>
- 1.2 Location: longitude: 74 and 85°; latitude: 19 and 24°
- 1.3 Population: 9 405 000

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 1 691 131 ha
- 2.2 Proportion of land under forest: 15%
- 2.3 Does the country have a written statement of National Forest Policy? YES
- 2.3.1 If a National Policy exists, what are the main objectives stated in it?  
Reforestation of all potential forest areas to cover an estimated 27 percent of the country.

Well-managed forests for the purposes of production, protection of the environment and wildlife, and recreation.

- 2.4 Legislation available to implement policy? YES
- 2.5 Ownership of forests: Under State control: 100%

4. SEED AND PLANT SUPPLY

- 4.1 Service and control of seed supply
- 4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? YES
- 4.1.2 Is there a national seed certification system? YES
- 4.1.3 Are there facilities for storing seed at controlled temperatures? YES
- 4.1.4 Does the supply of seed cover the demand for the species listed  
in 3.3.1? YES  
in 3.3.2? YES

5. TREE IMPROVEMENT

- 5.1 Does the country have an official tree improvement programme? YES

- 5.1.1 If yes, list species involved:

Pinus caribaea var. caribaea	Hibiscus elatus
P. tropicalis	Cedrela odorata
P. cubensis	
P. maestrensis	

- 5.1.2 Most important characters to be improved or bred for:

Vigour  
Stem straightness  
Remification

- 5.2 Brief outline of improvement methods already applied:

- 5.2.1 Species/provenance trials (indicate in parantheses the number of provenances being tested):

Pinus caribaea var. caribaea (13)	Hibiscus elatus (23)
P. tropicalis (6)	Cedrela odorata (13)
P. cubensis (10)	Tectona grandis (16)
P. maestrensis (14)	Eucalyptus saligna (16)
Swietenia macrophylla (8)	P. caribaea var. hondurensis (9)

5.2.2 Area of seed in each of the main species:

Pinus caribaea var. caribaea (1 280 ha)	P. maestrensis (147 ha)
P. tropicalis (175 ha)	Hibiscus elatus (130 ha)
P. cubensis (572 ha)	Cedrela odorata (19 ha)

5.2.3 Plus trees of main species (indicate in parentheses the number of trees):

P. caribaea var. caribaea (270)	P. maestrensis (72)
P. tropicalis (120)	Hibiscus elatus (90)
P. cubensis (150)	Cedrela odorata (220)

5.2.4 Seed orchards (species, area and number of clones or mother trees):

Pinus caribaea var. caribaea (200 ha) (108 cl.)  
P. cubensis (45 ha) (98 cl.)  
Hibiscus elatus (13 ha) (48 cl.)

5.2.5 Progeny testing? (species and area):

Pinus caribaea var. caribaea (27,5 ha)	P. maestrensis (7 ha)
P. tropicalis (21,5 ha)	Hibiscus elatus (3 ha)
P. cubensis (6 ha)	Cedrela odorata (15 ha)

6. SUCCESSFUL METHODS IN VEGETATIVE PROPAGATION FOR MAIN SPECIES:

<u>Species</u>	<u>Method</u>	<u>% of success</u>
Pinus caribaea var. caribaea	Grafting	80
P. cubensis	"	65
P. maestrensis	"	70
Hibiscus elatus	"	90
Cedrela odorata	"	85

7. REFERENCES TO TREE IMPROVEMENT

Please list the references to tree improvement in the country, in publications, reports, etc.

- 7.1 Betancourt, A. and Gonzales A. (1972) "Trabajos realizados en Cuba sobre mejoramiento genético de P. caribaea Mor. var. caribaea". In: Special Papers from Cuba at the Seventh World Forestry Congress, p.7-26.
- 7.2 Gonzales, A. (1974) "Algunos aspectos sobre mejoramiento selectivo de árboles" (mimeographed) CIF, La Habana, 19 pp.
- 7.3 Thomsen, J. (1974) "Genética forestal y manejo de semillas forestales (ditto) CIF. La Habana, 246 pp.
- 7.4 Zayas, A. and Burley, J. (1973) "Estudio de progenies de P. caribaea var. caribaea" Cajálbana, in Cuba, 7 pp.

Country Statement: DOMINICAN REPUBLIC

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 48 442 km<sup>2</sup>
- 1.3 Population: 5 200 000
- 1.4 Main climatic and vegetative zones:
  - Low montane humid forest
  - Sub-tropical dry forest

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 1 100 000 ha
- 2.2 Proportion of land under forest: 23%
- 2.3 Does the country have a written statement of National Forest Policy? NO
- 2.4 Legislation available to implement policy? NO
- 2.5 Ownership of forests:
  - Under State control: 70%
  - Private ownership: 20%
  - Community ownership: -
  - No effective control: 10%

- 2.6 Principal forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):
  - Fuelwood
  - Piles for fencing
  - Poles for power lines

2.7	Staff	State	Others
2.7.1	Professional:	2	4
2.7.2	Subprofessional (with diploma or certificate of training):	30	5

- 2.8 Gross annual budget for forestry: US\$ 3 000 000

3. AFFORESTATION AND REFORESTATION

3.1 Areas

- 3.1.1 Net total area 1/ of plantations at the end of 1978: 2 000 ha
- 3.1.2 Planned annual target/reforestation: 1 200 ha/year

3.2 Organization and administration of planting schemes

- 3.2.1 State Forest Services: 95% Others (specify): 5 mining and private companies

- 3.3 Principal product or purpose envisaged (for example, saw-wood, posts and stakes, pulpwood, fuelwood, protection, etc.):

3.3.1 Indigenous species:

<u>Product/ Purpose</u>	<u>Species</u>	<u>Net Area (ha) 1/</u>	<u>Rotation (years)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Protection	Pinus occidentalis	1 000	30	- -

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

3.3.2 Introduced species:

<u>Product/Purpose</u>	<u>Species</u>	<u>Net area (ha) 1/</u>	<u>Rotation (year)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Protection and saw-wood	Pinus caribaea	800	20	
Fuelwood	Eucalyptus robusta			

4. SEED AND PLANT SUPPLY

4.1 Service and control of seed supply

4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? NO

4.1.2 Is there a national seed certification system? NO

4.1.3 Are there facilities for storing seed at controlled temperatures? YES

4.1.4 Does the supply of seed cover the demand for the species listed  
in 3.3.1? YES  
in 3.3.2? NO

5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement programme? NO

Country Statement: ECUADOR

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 2 745.4 km<sup>2</sup>
- 1.2 Location: longitude 78°30'; latitude: 0°0'
- 1.3 Population: 7 000 000
- 1.4 Main climatic and vegetative zones:  
From tropical desert to perennial snowfields

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 17 734 000 ha
- 2.2 Proportion of land under forest: 64.45%
- 2.3 Does the country have a written statement on National Forest Policy? YES
- 2.3.1 If a National Policy exists, what are the main objectives stated in it?  
Domestic utilisation of forest raw materials and conservation of renewable natural resources.

- 2.4 Legislation available to implement policy? YES

2.5 Ownership of forests:

Under State control: 12.41%  
Private ownership: 0.12%  
Community ownership: 0.02%  
No effective control: 87.45%

- 2.6 Principal forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):

Saw-wood; logs for triplex and plywood sleepers; posts; stakes; fuelwood and charcoal.

2.7 Staff

	State	Others
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2.7.1 Professional	53	20
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2.7.2 Subprofessional (with diploma or certificate of training)	114	33
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- 2.8 Gross annual budget for forestry: US\$ 600 000

3. AFFORESTATION AND REFORESTATION

3.1 Areas

3.1.1 Net total area 1/ of plantations at the end of 1976: 25 425 ha

3.1.2 Planned annual target reforestation: 5 000 ha/year

3.2 Organization and administration of planting schemes

3.2.1 State Forest Services: 70.0%  
Others (specify): 30.0%

- 3.3 Principal product or purpose envisaged (for example, saw wood, posts and stakes, pulpwood, fuelwood, protection, etc.):

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

3.3.1 Indigenous species:

<u>Product/ Purpose</u>	<u>Species</u>	<u>Net area (ha 1/)</u>	<u>Rotation (years)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Saw-wood and fuelwood	Eucalyptus globulus	17 405	20	18
Saw-wood	Pinus radiata	5 177	30	14
Saw-wood and plywood	Tectona grandis	646	30	12
Saw-wood and fuelwood	Eucalyptus saligna	156	20	16
Saw-wood and stakes	Eucalyptus camaldulensis	132	20	14
Various uses	Various species	129	variable	variable

3.3.2 Introduced species:

<u>Purpose/Product</u>	<u>Species</u>	<u>Net area (ha) 1/</u>	<u>Rotation (years)</u>	<u>Mean annual increment (without bark) at the end of (m<sup>3</sup>/ha/year)</u>
Saw-wood and plywood	Cordia alliodora	1 408	25	14
Conservation	Prosopis juliflora	173	indefinite	10
Saw-wood and poles	Centrolobium patinense	39	40	14
Conservation	Pseudosamanea guachapele	38	indefinite	18
Various	Various species	122	indefinite	variable

4. SEED AND PLANT SUPPLY

4.1 Service and control of seed supply

4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? NO - It is collected for local reforestation.

4.1.2 Is there a national seed certification system? NO

4.1.3 Are there facilities for storing seed at controlled temperatures? NO

4.1.4 Does the supply of seed cover the demand for the species listed in 3.3.1? YES in 3.3.2? For Eucalyptus globulus and Tectona grandis.

5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement programme? NO

1/ The net area is the gross area of plantations, less the area occupied by roads, paths firebreaks, buildings and other areas not covered by trees.

Country Statement: GUATEMALA

1. GENERAL GEOGRAPHIC INFORMATION

- 1.1 Area of country: 108 900 km<sup>2</sup>
- 1.3 Population: 7 045 800
- 1.4 Main climatic and vegetative zones:
  - a) South coast: Tropical and sub-tropical forests
  - b) Western high plateau: Cold, humid and very humid, mixed and coniferous forests.
  - c) Central region: Conifers in the western cold humid zone, tropical and dry sub-tropical forests in the east.
  - d) Eastern high plateau: Cold, dry, conifers and mixed forests.
  - e) Northern intermediate: Humid and very humid tropical, conifers and hard woods.
  - f) North (Petén): Tropical forests of valuable species, very humid.

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 3 610 000 ha
- 2.2 Proportion of land under forest: 39.7%
- 2.3 Does the country have a written statement of National Forest Policy? YES
- 2.3.1 If a National Policy exists, what are the main objectives stated in it?
  - a) To conserve the existing forest area;
  - b) To extend the forest area through afforestation and managed artificial reforestation; and
  - c) To encourage the rise of forest industries.
- 2.4 Legislation available to implement policy? YES
- 2.5 Ownership of forests: Under State control: 100%
- 2.6 Principal forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):  
Saw-wood (palo blanco, mahogany, cedar, pine);  
logs for veneering, for posts and for fuel wood.
- 2.7 Gross annual budget for forestry: US\$ 11 000 000

3. AFFORESTATION AND REFORESTATION

- 3.1 Areas
  - 3.1.1 Net total area 1/ of plantations at the end of 1978: 3 610 000 ha
  - 3.1.2 Planned annual target reforestation: 12 000 ha/year
- 3.2 Organization and administration of planting schemes
  - 3.2.1 State Forest Services: 100%
- 3.3 Principal product or purpose envisaged (for example, saw-wood, posts and stakes, pulpwood, fuelwood, protection, etc.):

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

3.3.1 Indigenous species:			Mean annual increment (without bark) at the end of the rotation <u>(m<sup>3</sup>/ha/year)</u>
<u>Product/Purpose</u>	<u>Species</u>	<u>Net area (ha) <u>1/</u></u>	<u>Rotation (years)</u>
Reforestation	Conifers	3 000	
	Hardwoods	9 000	

3.3.2 Introduced species:			Mean annual increment (without bark) at the end of the rotation <u>(m<sup>3</sup>/ha/year)</u>
<u>Product/Purpose</u>	<u>Species</u>	<u>Net area (ha) <u>1/</u></u>	<u>Rotation (years)</u>
Reforestation	Leucaena leucocephala		Recently introduced
	Sesbania aculeata		Recently introduced

#### 4. SEED AND PLANT SUPPLY

##### 4.1 Service and control of seed supply

4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected? YES - Government Decree of 8 March 1979.

4.1.2 Is there a national seed certification system? YES, BANSEFOR

4.1.3 Are there facilities for storing seed at controlled temperatures? YES, BANSEFOR

4.1.4 Does the supply of seed cover the demand for the species listed  
in 3.3.1? YES  
in 3.3.2? YES

#### 5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement programme? NO

5.2.2 Area of seed stands in each of the main species:

Conifers 1 295 ha  
Hardwoods 200 ha

5.2.3 Plus trees of main species (indicate in parentheses the number of trees):

Conifers (155)  
Hardwoods -

5.2.4 Seed orchard (species, area and number of clones or mother trees):

Leucaena leucocephala 3 ha (1 000)  
Sesbania aculeata 1 ha (100)

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.



Country Statement: HONDURAS

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 113 000 km<sup>2</sup>
- 1.2 Location: longitude: 85°; latitude: 14°
- 1.3 Population: 4 million
- 1.4 Main climatic and vegetative zones: Tropical

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 7.4 million ha
- 2.2 Proportion of land under forest: 65%
- 2.3 Does the country have a written statement of National Forest Policy? YES
- 2.3.1 If a National Policy exists, what are the main objectives stated in it?  
To preserve for the nation the inestimable flora, fauna and soil resources in forest areas;  
To ensure the protection and improvement of the above;  
To rationalize the utilization, industrialization and marketing of forest products.
- 2.4 Legislation available to implement policy? YES
- 2.6 Principal forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):  
Saw-wood, veneers and sleepers, fuelwood.
- 2.7 Staff 

	<u>State</u>	<u>Others</u>
Professional:	76	
Subprofessional (with diploma or certificat of training):	196	
- 2.8 Gross annual budget for forestry: US\$ 80 million

3. AFFORESTATION AND REFORESTATION

- 3.1 Areas
  - 3.1.1 Planned annual target area of afforestation/reforestation: 12 600 ha/year
- 3.2 Organization and administration of planting schemes
  - 3.2.1 State Forest Services: 100%

4. SEED AND PLANT SUPPLY

- 4.1 Service and control of seed supply
  - 4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? NO
  - 4.1.2 Is there a national seed certification system? YES
  - 4.1.3 Are there facilities for storing seed at controlled temperatures? YES
  - 4.1.4 Does the supply of seed cover the demand for the species listed in 3.3.1? YES  
in 3.3.2? Very little work

5. TREE IMPROVEMENT

- 5.1 Does the country have an official tree improvement programme? YES

5.1.1 If yes, list species involved:

Pinus oocarpa	Liquidambar styraciflua
Pinus caribaea	Didymopanax morototoni
Pinus pseudostrobus	Quercus sp.
Cordia alliodora	Leucaena leucocephala

5.1.2 Most important characters to be improved or bred for:

Shape of stem	Basic density
Resin production	
Fibre length	

5.2 Brief outline of improvement methods already applied:

5.2.1 Species/provenance trials (indicate in parentheses the number of provenances being tested):

Pinus oocarpa (29)	Pinus pseudostrobus (18)
Pinus caribaea (26)	Cordia alliodora (6)

5.2.2 Area of seed stands in each of the main species:

Not yet decided.

5.2.3 Plus trees of main species (indicate in parentheses the number of trees):

Selection has not yet been completed.

5.2.4 Seed orchards (species, area and number of clones or mother trees):

The first one will be established this year; there are no data as yet.

5.2.5 Progeny testing (species and area):

To be started in 1980.

7. REFERENCES TO TREE IMPROVEMENT

Please list the references to tree improvement in the country, in publications, reports, etc.

We are trying to publish some experiences.

Country Statement: NICARAGUA

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 130 000 km<sup>2</sup>
- 1.2 Location: longitude: 10°45' - 15°05'; latitude: 83°30' - 87°20'
- 1.3 Population: 2 500 000
- 1.4 Main climatic and vegetative zones:  
Tropical dry forest. Tropical humid forest. Montane and pine wood savanna.  
Tropical rain forest, monsoon forest, tropical savanna and sub-tropical montane climate.

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 4 550 000 ha
- 2.2 Proportion of land under forest: 35%
- 2.3 Does the country have a written statement of National Forest Policy? YES
- 2.3.1 If a National Policy exists, what are the main objectives stated in it?  
Nationalization and rational use of forests.
- 2.4 Legislation available to implement policy? YES
- 2.5 Ownership of forests:  
Under state control: 20%  
No effective control: 80%
- 2.6 Principal forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):  
Saw-wood: 1 000 000 m<sup>3</sup>/year
- 2.7 Staff
- |  | State | Others |
|--|-------|--------|
| Professional:  | 7     | 3      |
| Subprofessional (with diploma or certificate of training): | 12    | 3      |
- 2.8 Gross annual budget for forestry:  
US\$ 1.5 x 10<sup>6</sup>

3. AFFORESTATION AND REFORESTATION

- 3.1 Areas
- 3.1.1 Net total area 1/ of plantations at the end of 1978:  
1500 ha
- 3.1.2 Planned annual target/reforestation: 5 000 ha/year
- 3.2 Organization and administration of planting schemes
- 3.2.1 State Forest Services: 100%
- 3.3 Principal product or purpose envisaged (for example, saw-wood, posts and stakes, pulpwood, fuelwood, protection, etc.):

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

3.3.1 Indigenous species:

<u>Product/Purpose</u>	<u>Species</u>	<u>Net Area (ha) <sup>1/</sup></u>	<u>Rotation (years)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Timber for pulping	Pinus caribaea	3 000	25	4
Fuelwood	Leucaena sp.	500	4	30

3.32 Introduced species:

<u>Product/Purpose</u>	<u>Species</u>	<u>Net Area (ha) <sup>1/</sup></u>	<u>Rotation (years)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Protection and fuelwood	Eucalyptus	1 000	-	-
	Camaldulensis	500	4	30

4. SEED AND PLANT SUPPLY

4.1 Service and control of seed supply

4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? NO

4.1.2 Is there a national seed certification system? NO

4.1.3 Are there facilities for storing seed at controlled temperatures? NO

4.1.4 Does the supply of seed cover the demand for the species listed  
in 3.3.1? YES  
in 3.3.2? NO

5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement programme? NO

<sup>1/</sup> The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

Country Statement: PANAMA

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 77 082 km<sup>2</sup>
- 1.2 Location: Longitude: 77°09' - 83°03'; latitude: 7°12' - 9°38' N
- 1.3 Population 1 881 400
- 1.4 Main climatic and vegetative zones:  
Dry tropical forest, humid tropical forest, very humid tropical forest, very humid premontane forest, premontane rainforest, very humid low montane forest.

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 3 225 900 ha
- 2.2 Proportion of land under forest: 50%
- 2.3 Does the country have a written statement of National Forest Policy? YES
- 2.3.1 If a National Policy exists, what are the main objectives stated in it?

To reduce importation by developing local industries, promoting local products, with the intention of remedying shortages in local supplies of the raw material necessary for production of wood and wood products.

- 2.4 Legislation available to implement policy? YES
- 2.5 Ownership of forests: Under state control: 100%
- 2.6 Principal forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):  
Furniture, posts, beams, saw-wood, logs for sleepers, plywood, lumber.

3. AFFORESTATION AND REFORESTATION

- 3.1 Areas
- 3.1.2 Planned annual target area of afforestation/reforestation: 10 000 ha/year
- 3.2 Organization and administration of planting schemes
- 3.2.1 State Forest Services: 100%
- 3.3 Principal product or purpose envisaged (for example, saw-wood, posts and stakes, pulpwood, fuelwood, protection, etc.):
- 3.3.1 Indigenous species:

<u>Product/ Purpose</u>	<u>Species</u>	<u>Net Area (ha) 1/</u>	<u>Rotation (years)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Furniture and beams	Cedrela odorata			
Forest- plots	Bombacopsis quinata			
Fence posts	Cordia alliodora			
Wood	Tabebuia pentaphylla			
Wood	Tabebuia guayacan			

1/ The net area in the gross area of plantations, less the area occupied by roads, paths firebreaks, buildings and other areas not covered by trees.

3.3.2 Introduced species:

<u>Product/ Purpose</u>	<u>Species</u>	<u>Net Area (ha) <sup>1/</sup></u>	<u>Rotation (years)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Posts, wood	Tectona grandis	5.41		
Wood	Gmelina arborea	7.7		
Reforestation	Pinus caribaea	2 400		
Wood	Anthocephalus cadamba	1.5		
Wood	Hibiscus elatus	0.95		

4. SEED AND PLANT SUPPLY

4.1 Service and control of seed supply

4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? YES

4.1.2 Is there a national seed certification system? YES

4.1.3 Are there facilities for storing seed at controlled temperatures? YES

4.1.4 Does the supply of seed cover the demand for the species listed in 3.3.1? 65%  
in 3.3.2? 50%

5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement programme? NO

<sup>1/</sup> The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

Country Statement: PARAGUAY

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 406 752 km<sup>2</sup>  
1.2 Location: Longitude: 54° - 63°W; latitude: 19° - 28°S  
1.3 Population: 3 500 000  
1.4 Main climatic and vegetative zones:  
Sub-tropical temperate climate  
Vegetation: thorny steppe and dry forest (western region) - HOLDRIDGE  
Humid forest (eastern region) - HOLDRIDGE

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 6 000 000 ha  
2.2 Proportion of land under forest: 45%  
2.3 Does the country have a written statement of National Forest Policy? YES  
2.3.1 If a National Policy exists, what are the main objectives stated in it?  
a) Management plan; b) Reforestation plan; c) National parks plan; d) Five-year plan for industry.  
2.4 Legislation available to implement policy? YES  
2.5 Ownership of forests:  
Under State control: 10%  
Private ownership: 90%  
2.6 Principal forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):  
Sawn wood; veneer logs, logs for sleepers, posts, poles and stakes, fuelwood and charcoal.  
2.7 Staff
- |  | State | Others |
|--|-------|--------|
| Professional:  | 32    | 10     |
| Subprofessional (with diploma or certificate of training): | 55    | 10     |
- 2.8 Gross annual budget for Forestry:  
US\$ 430 000

3. AFFORESTATION AND REFORESTATION

- 3.1 Areas  
3.1.1 Net total area 1/ of plantation at the end of 1978: 5 000 ha  
3.1.2 Planned annual target area of afforestation/reforestation: 1 500 ha/year  
3.2 Organization and administration of planting schemes  
3.2.1 State Forest Services: - Others (specify): 100% (private)

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

3.3.2 Introduced species:

<u>Product/ Purpose</u>	<u>Species</u>	<u>Net Area (ha) 1/</u>	<u>Rotation (years)</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Pulpwood	Pinus elliottii	4 500	25	21.1
Pulpwood	Pinus taeda	30	25	21.3
Saw-wood	Araucaria angustifolia	3	30	15.8
Pulpwood	Cupressus japonica	2	25	9.2

Note: Results in stands of 13 years, with 20 percent thinning at 9 years.

4. SEED AND PLANT SUPPLY

4.1 Service and control of seed supply

4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? NO

4.1.2 Is there a national seed certification system? NO

4.1.3 Are there facilities for storing seed at controlled temperatures? YES

4.1.4 Does the supply of seed cover the demand for the species listed in 3.3.1? NO in 3.3.2? NO

5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement programme? NO

5.1.2 Most important characters to be improved or bred for:

- a) straight bole
- b) rapid growth
- c) physical-mechanical aptitudes
- d) resistance to pests, diseases and adverse climatic conditions

5.2 Brief outline of improvement methods already applied:

5.2.1 Species/provenance trials (indicate in parentheses the number of provenances being tested). Various exotic species of unknown specific origin have been introduced.

Pinus elliottii (2)	P. caribaea var. caribaea (2)
P. taeda (2)	P. caribaea var. hondurensis (1)
Araucaria angustifolia (1)	P. palustris (1)
Cupressus japonica (1)	Eucalyptus spp. (12 spp.)

5.2.6 Other methods of improvement (specify):

Note: In the second half of 1979, needs of various exotic species (conifers, and hardwoods) were introduced; collection of seeds of native species was also started, all of them tested but without final results.

7. REFERENCES TO TREE IMPROVEMENT

Note: We have no official reports on forest improvement, except for some publications of partial results relating to the introduction of species, adaptability, etc.

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.



Country Statement: PERU

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 1 285 215 km<sup>2</sup>  
1.2 Location: Longitude: 70° - 81°; latitude: 0° - 18°S  
1.3 Population: 20 000 000  
1.4 Main climatic and vegetative zones:  
Coastal region: dd-PT, ds-PT, dp-PT (ppx: 0-200 mm; T.x: 21 C)  
Mountain region: bb-MT, ee-MBT, bmh-MT (ppx: 250-1 400 mm; T.x: 14)  
Forest region: bh-T, bmh-T (ppx: 900-4 000 mm; T.x: 24 C)

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 74 120 000 ha  
2.2 Proportion of land under forest: 60%  
2.3 Does the country have a written statement of National Forest Policy? YES  
2.3.1 If a National Policy exists, what are the main objectives stated in it?  
To meet the national demand for wood and forest products.  
To earmark land suitable for forests through reforestation to promote social and economic development.  
To lay the basis for optimum utilization of forests and wildlife resources.  
2.5 Ownership of forests:  
Under State control: 99.8%  
Private ownership: 0.04%  
Community ownership: 0.16%  
2.6 Principal forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):  
Saw-wood, veneer logs, plywood, parquet, sleepers, posts, timbers for mines, fuel-wood, charcoal.  
2.7 Staff
- |  | State | Others |
|--|-------|--------|
| Professional:  | 240   |        |
| Subprofessional (with diploma or certificate of training): | 130   |        |
- 2.8 Gross annual budget for forestry:  
US\$ 6 000 000 approximately

3. AFFORESTATION AND REFORESTATION

- 3.1 Areas  
3.1.1 Net total area 1/ of plantations at the end of 1978: 120 000 ha  
3.1.2 Planned annual target/reforestation: 15 000 ha/year  
3.2 Organization and administration of planting schemes  
3.2.1 State forest Services: 98%  
Others (specify): Private ownership: 2%

1/ The net area in the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

3.3 Principal product or purpose envisaged (for example, saw-wood, posts and stakes, pulpwood, fuelwood, protection, etc.)

3.3.1 Indigenous species:

<u>Product/ Purpose</u>	<u>Species</u>	<u>Net Area (ha) 1/</u>
Saw-wood and Plywood	Cedrela sp. )	1 800
	Swietenia )	
	Cedrelinga )	
Charcoal, fuelwood, fruit, parquet	Prosopis sp. )	4 000
	Tecoma sp. )	
	Lexopterygium )	

3.3.2 Introduced species:

<u>Product/ Purpose</u>	<u>Species</u>	<u>Net Area (ha) 1/</u>	<u>Rotation (ha) 1/</u>	<u>Mean annual increment (without bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Saw-wood posts, sleepers. fuelwood, protection	Eucalyptus globulus	108 000	20	18-20
Sawn wood	Pinus radiata	3 000	20	14-18
Sawn wood	Cupressus sp )	200	20	12-14
	Pinus caribaea )			
	Eucalyptus grandis )			
	E. saligna )			

#### 4. SEED AND PLANT SUPPLY

4.1 Service and control of seed supply

4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? YES

4.1.2 Is there a national seed certification system? YES

4.1.3 Are there facilities for storing seed at controlled temperatures? YES

4.1.4 Does the supply of seed cover the demand for the species listed in 3.3.1? YES in 3.3.2? NO

#### 5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement progr ? YES

5.1.1 If yes, list species involved:

Pinus radiata	P. elliottii
P. greggii	Eucalyptus globulus
P. patula	E. grandis

5.1.2 Most important characters to be improved or bred for:

Rapid growth  
Straight trunk  
Resistance

5.2 Brief outline of improvement methods already applied:

5.2.2 Area of seed stand in each of the main species: Pinus radiata (20 ha)

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

Country Statement: URUGUAY

1. GENERAL GEOGRAPHICAL INFORMATION

1.1 Area of country: 187 000 km<sup>2</sup>

1.2 Location: longitude: 54-58°W; latitude: 30-35°S

1.3 Population: 3 000 000

1.4 Main climatic and vegetative zones:

Due to its small size, the country does not have marked climatic or vegetative variations; the climate is mild temperate and the vegetation mainly grasslands.

2. FORESTS AND NATIONAL FOREST POLICY

2.1 Area of forests: 746 000 ha

2.2 Proportion of land under forest: 3.9%

2.3 Does the country have a written statement of National Forest Policy? YES

2.3.1 If a National Policy exists, what are the main objectives stated in it?

Meeting the internal demand for forest products (sawn wood, pulp and paper, fuel-wood, lumber, etc.)

Export of production surpluses

Concentration of forest stands

2.4 Legislation available to implement policy? YES

2.5 Ownership of forests:

Under State control: 3%

Private ownership: 97%

2.6 Principal forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):

Fuelwood	:	1 200 000 m <sup>3</sup>
Saw and board wood	:	150 000 m <sup>3</sup>
Pulpwood	:	115 000 m <sup>3</sup>
Veneer wood	:	12 000 m <sup>3</sup>

2.7 Staff	State	Others
Professional:	32	60
Subprofessional (with diploma or certificate of training):	8	20

3. AFFORESTATION AND REFORESTATION

3.1 Areas

3.1.1 Net total area 1/ of plantations at the end of 1978: 157 500 ha

3.1.2 Planned annual target area of afforestation/reforestation: 5 000 ha/year

3.2 Organization and administration of planting schemes

3.2.1 State Forest Services: 25%

Others (specify): Private ownership: 75%

3.3 Principal product or purpose envisaged (for example, saw-wood, posts and stakes, pulpwood, fuelwood, protection, etc.):

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

3.3.2 Introduced species:

Product/ Purpose	Species	Net area (ha) <sup>1/</sup>	Rotation (years)	Mean annual increment (without bark) at the end of the rotation, (m <sup>3</sup> /ha/year)
Saw-wood, pulp and board	P. elliotii, P. taeda, P. pinaster	25 000	20	18
Saw-wood, Fuelwood, pulp board	Eucalyptus umbellata, E. camaldulensis, E. globulus, E. grandis	110 000	20	22
Crates and boxes, saw- wood	Salicaceas	8 000	18	16

4. SEED AND PLANT SUPPLY

4.1 Service and control of seed supply

4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? NO

4.1.2 Is there a national seed certification system?  
Being established.

4.1.3 Are there facilities for storing seed at controlled temperatures? NO

4.1.4 Does the supply of seed cover the demand for the species listed  
in 3.3.1? --  
in 3.3.2? NO

5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement programme? YES

5.1.1 If yes, list species involved:

Pinus elliottee, P. taeda	E. globulus, E. smithii
P. patula, P. pinaster,	E. maidenii, E. resinifera,
P. radiata	E. Bosistoana, E. umbellata
Eucalyptus grandis	Salix sp., Populus sp.
	Platanus occidentalis

5.1.2 Most important characters to be improved or bred for:

Growth	Resistance to climatic factors
Conformation	and disease and pests
Timber quality	

5.2 Brief outline of improvement methods already applied:

5.2.1 Species/provenance trials (indicate in parentheses the number of provenances being tested):

Pinus taeda (11)	Eucalyptus umbellata (15)
Pinus elliotii (5)	Eucalyptus maidenii (3)
Pinus patula (3)	
Eucalyptus grandis (15)	

<sup>1/</sup> The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.



Country Statement: VENEZUELA

1. GENERAL GEOGRAPHICAL INFORMATION

- 1.1 Area of country: 913 050 km<sup>2</sup>
- 1.2 Location: Longitude: 59°48' - 73°11'49"W; latitude: 0°43' - 12°11'46"N
- 1.3 Population: 15 000 000
- 1.4 Main climatic and vegetative zones:  
Dry tropical forest, humid tropical forest, very dry tropical forest, very humid premontane forest.

2. FORESTS AND NATIONAL FOREST POLICY

- 2.1 Area of forests: 47 971 000 ha
- 2.2 Proportion of land under forest: 53%
- 2.3 Does the country have a written statement of National Forest Policy? YES
- 2.3.1 If a National Policy exists, what are the main objectives stated in it?  
The objectives follow the major guidelines for the three classes of forest: protective, productive and the secondary functions such as recreation, research, education, etc.
- 2.4 Legislation available to implement policy? YES
- 2.5 Ownership of forests:  
Under State control: 82%  
Private ownership: 18%
- 2.6 Principal forest products (for example, saw-wood, rubber, beeswax and honey, veneer logs, logs for sleepers, posts, piles and stakes, pulpwood):  
Saw-wood, veneer logs, particle board, sleepers, posts.
- 2.7 Staff
- |  | State | Others |
|--|-------|--------|
| Professional:  | 160   | 294    |
| Subprofessional (with diploma or certificate of training): | -     | -      |
- 2.8 Gross annual budget for forestry:  
US\$ 20 000 000

3. AFFORESTATION AND REFORESTATION

- 3.1 Areas
- 3.1.1 Net total area 1/ of plantations at the end of 1978: 101 850 ha
- 3.1.2 Planned annual target area of afforestation/ reforestation: 32 000 ha/year
- 3.2 Organization and administration of planting schemes
- 3.2.1 State Forest Services: 85%      Others (specify): Combined State and Private ownership: 10%  
Private ownership: 5%
- 3.3 Principal product or purpose envisaged (for example, saw-wood, posts and stakes, pulpwood, fuelwood, protection, etc.):

1/ The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

3.3.1 Indigenous species:

<u>Product/ Purpose</u>	<u>Species</u>	<u>Net Area (ha) <sup>1/</sup></u>	<u>Rotation (years)</u>	<u>Mean annual increment (with- out bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Saw-wood	Anacardium excelsa, Swietenia macro- phylla, Oedrela odorata, Cordia alliodora, Cordia apurensis, Tabebuia rosea	2 800		

3.3.2 Introduced species:

<u>Product/ Purpose</u>	<u>Species</u>	<u>Net Area (ha) <sup>1/</sup></u>	<u>Rotation (years)</u>	<u>Mean annual increment (with- out bark) at the end of the rotation (m<sup>3</sup>/ha/year)</u>
Pulp	Eucalypts	3 000	6	20
Pulp	Caribbean Pine	101 850	12	10
Saw-wood	Teak	620	30	-
Protection	Pine, Eucalypts and others			

4. SEED AND PLANT SUPPLY

4.1 Service and control of seed supply

- 4.1.1 Have seed zones been defined for indigenous species (i.e. is it common to restrict the use of seed for afforestation/reforestation to the particular zone in which it was collected)? YES
- 4.1.2 Is there a national seed certification system? YES
- 4.1.3 Are there facilities for storing seed at controlled temperatures? YES
- 4.1.4 Does the supply of seed cover the demand for the species listed in 3.3.1? YES in 3.3.2? NO

5. TREE IMPROVEMENT

5.1 Does the country have an official tree improvement programme?

In-depth tree breeding studies are done only in autonomous research organizations, or institutes: there is no State programme at national level.

5.1.1 If yes, list species involved:

Pinus caribaea var. hondurensis  
Bombacopsis quinata

5.1.2 Most important characters to be improved or bred for:

Straightness of stem, bifurcations, anomalies, height, wood density and volume (caribbean pine). Buttresses, bifurcation in Bombacopsis quinata.

5.2 Brief outline of improvement methods already applied:

5.2.1 Species/provenance trials (indicate in parentheses the number of provenances being tested):

Genero Pinus (32 spp.)  
Indigenous hardwoods (10 spp.)  
Exotic hardwoods (25 spp.)

<sup>1/</sup> The net area is the gross area of plantations, less the area occupied by roads, paths, firebreaks, buildings and other areas not covered by trees.

- 5.2.2 Area of seed stands in each of the main species:  
Pinus caribaea var. hondurensis (520 ha) - in process of establishment (CVG-CONARE)
- 5.2.3 Plus trees of main species (indicate in parentheses the number of trees):  
There are 40 Pinus caribaea trees selected as candidates
- 5.2.4 Seed orchards (species, area and number of clones or mother trees):  
Bombacopsis quinata  
Tabebuia rosea  
Pinus caribaea
- 5.2.5 Progeny testing (species and area):  
Bombacopsis quinata  
Tabebuia rosea
- 5.2.6 Other methods of improvement (specify):  
Controlled and open pollination of Bombacopsis quinata

6. SUCCESSFUL METHODS IN VEGETATIVE PROPAGATION FOR MAIN SPECIES:

<u>Species</u>	<u>Method</u>	<u>% of success</u>
Bombacopsis quinata	Grafting and cutting	90
Cedrela odorata	Grafting	
Tabebuia rosea	Grafting	
Pinus caribaea	Grafting, aerial shoots	30-50

7. REFERENCES TO TREE IMPROVEMENT

Please list the references to tree improvement in the country, in publications, reports, etc.

Quijada and Gutierrez. Estudio sobre la propagación vegetativa de especies forestales venezolanas.

Mendez and Luis. Etapas preliminares para el establecimiento de un rodal semillero en Chaguaras Estado Monagas.

Norman Smith. Selección de árboles en Cachipo para establecer un huerto semillero de Pinus caribaea. (Tree selection in Cachipo for the establishment of a Pinus caribaea seed orchard).



Appendix VII

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1. Publications distributed to all participants

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Burley, J. & Wood, P.J., 1979. (Editors). Manual sobre investigaciones de especies y procedencias con referencia especial a los trópicos. CFI Tropical Forestry Papers no. 10 & 10A (Edición Española). Oxford, Reino Unido.

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Bonner, F.T., 1977. Equipment and Supplies for Collecting, Processing, Storing and Testing Forest Tree Seed. USDA Forest Service, General Technical Report SO-13. Southern Forest Expt. Station, New Orleans, Louisiana.

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FAO 1977. Manual I, sobre elección de rodales para la recolección de semillas forestales. INAFOR-BANSEFOR-FAO. FAO/TCP GUA-6/01-T, Guatemala.

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van Dijk, K., Venegas Tovar, L., & Melchior, G.H., 1978. El suministro de semillas como base de reforestaciones en Colombia. FAO/PNUD COL/74/005, P.I.F. No. 13. INDERENA, Bogotá.

Gordon, A.W., 1979. Uso y abastecimiento de semillas forestales en Chile. FAO/PNUD, DP/CHI.76/003, Documento de Trabajo No. 16. Santiago de Chile.

f. Information on specific species

g. Reforestation, forest plantations

FAO, 1978. Establishment Techniques for Forest Plantations. FAO Forestry Paper No.8. FAO, Rome.

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APPENDIX VIII

CERTIFICATE OF PARTICIPATION PRESENTED TO PARTICIPANTS



**DANIDA**

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*Con la presente se certifica que*

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