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Mass production of improved material (2) Seed Orchards

Concepts, Design and Role in Tree Improvement

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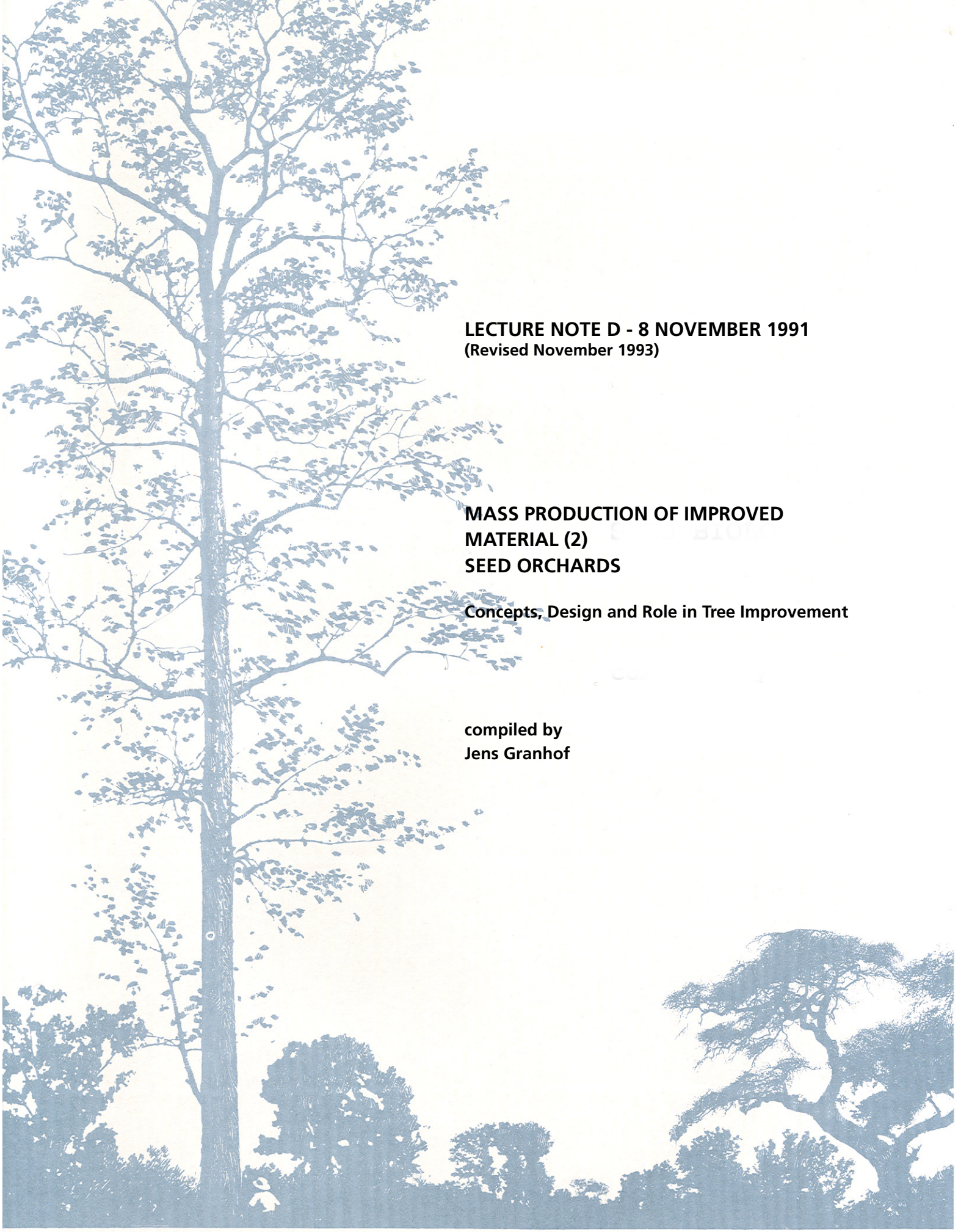

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MASS PRODUCTION OF IMPROVED MATERIAL (2)
SEED ORCHARDS

Concepts, Design and Role in Tree Improvement

compiled by
Jens Granhof

DANIDA FOREST SEED CENTRE

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1. INTRODUCTION

Insufficient seed supply of suitable species is often seen as a major bottleneck for development of planting programmes. This is clearly illustrated by the growing number of »Seed Centre Projects« established or in preparation in recent years.

Seed costs take up only a minor proportion of overall costs of plantation establishment and management. On the other hand seed quality, in particular in genetic aspects, has a major impact on the benefits obtainable from plantation forestry.

There is thus every reason to ensure the production of good quality seed in quantities sufficient to guarantee a stable supply of well adapted and genetically desirable planting stock.

Use of seed orchards is one means to achieve mass production of improved material. Use of vegetatively propagated material (graftings, cuttings or tissue-culture) is another way which is emerging with increasing potential (Lecture Note D-7). In most cases however seed will still be the primary resource for planting material.

The seed orchard is the major vehicle to realize the genetic gains achieved, inasmuch as the output - the seed - carries the combined effort of breeding and selection.

To date, most seed orchard experience relates to conifers, especially pines. Among the tropical hardwoods improvement programmes for notably Teak (India, Thailand, Papua New Guinea, Nigeria), and Gmelina (Malaysia, Nigeria, Columbia) include seed orchards. With the rapidly growing interest in Eucalypts in many tropical and some sub-tropical countries, experience is growing with advancing improvement programmes, e.g. with *Eucalyptus grandis, E. regnans, E. tereticornis*, and *E. camaldulensis*.

With the growing concern in many tropical countries for their dwindling resources of valuable hardwood timbers, for example *Pterocarpus, Dalbergia*, and *Afzelia*, the coming decade shall undoubtedly see a greater emphasis on these species including the establishment of seed orchards.

2. DEFINITION

Early thinking (before 1956) linked the concept of seed orchards to seed production in ordinary plantations. First attempts to establish some kind of differentiation, related the term orchard to plantings established by material from controlled pollination and/or selection, for the creation of genetic improvement.

Zobel *et al.* (1956) conceived a definition which has since been widely used: »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 grafts or cuttings) or seedling progeny of trees selected for desired characteristics«. The importance of the genetic improvement as well as the documented origin of the seed is

stressed.

Less stringent is the classification by OECD: »A seed orchard is a plantation of selected clones or progenies which are isolated or managed in order to avoid or to reduce pollination from outside sources, and managed to produce frequent, abundant and easily harvested seed crops«. This definition provides the possibility to maintain the seed orchard status where the mere production of seed in large quantities is needed, even without involving any higher degree of superiority of the trees involved.

The fundamental difference between the two definitions of a seed orchard lies thus in the degree of testing required to qualify for orchard:

The OECD concept: Orchard composed of selected but not necessarily tested trees.

The ZOBEL concept:Orchard composed of selected and tested trees, found to be superior.

3. TYPES OF ORCHARD

3.1 According to the TYPE OF PLANT MATERIAL used for the establishment, seed orchards can be divided into two major groups:

a) The clonal seed orchards (CSO) (Appendix 1), where vegetative material (grafts, cuttings or plantlets derived from tissue culture) of selected phenotypes (plus trees) are planted in areas with good isolation, under conditions favouring flowering and fertilization and managed for production of maximum amount of seed. The identity of each ramet (member of a clone) is carefully maintained by tags and maps.

It is a characteristic of the clonal orchard that main emphasis is given to crown development for maximum seed production by use of wide spacing. Therefore silvicultural characteristics such as fine stemform, clean bole and fine branches, which are important in production forests or plantations and are valid criteria for selecting clones for inclusion in the seed orchard, are not valid criteria for seed orchard management.

The establishment of a clonal seed orchard should be preceded, or at least closely followed, by progeny tests.

CSOs established by grafting are most commonly used. The greatest disadvantage of grafted clonal orchards is the laborious work involved with scion collection and grafting, maintaining healthy ramets in nursery before planting and last but not least, incompatibility[1] between stock and scion, which may occur even several years after establishment. Cuttings have also been used in some cases and tissue culture is emerging.

In connection with use of material developed by tissue culture, root deformation, imbalance and flowering problems may however develop with time (Zobel & Talbert, 1984).

1 incompatibility: tissue of rootstock rejects tissue of scion which was grafted onto it.

The right timing and sequence of establishment of clones is crucial for success (see further under »establishment«). Large variation in size between ramets of the individual clones is undesirable but cannot always be avoided.

b) **The seedling seed orchards (SSO)** (Appendix 2), where progenies from open or controlled pollination of selected phenotypes are planted at normal plantation spacings. Isolation and other conditions should be as for clonal orchards. The identity of families is maintained in order to allow for thinning among families and individuals within families based on their phenotypic performance (the socalled roguing). This thinning must be done before abundant seed production starts. The design of the orchard is of great importance for the later thinnings, see chapter 8.

Inasmuch as seedling seed orchards permit selection and roguing within as well as between families, the genetic value of the seeds they produce is very closely linked to the zone (site) where the they are growing.

One disadvantage of SSOs is that their formation and future quality is based on early selection, at a time when the juvenile/mature correlation may still be low (Toda 1964). SSOs also generally take longer to start flowering and to reach seed productivity.

In general it is agreed that only in special circumstances are SSOs preferable to CSOs (Barrett, 1980), for example:

1) where severe problems exist with the health of the ramets, e.g. due to incompatibility or root deformation of cuttings,
2) where large numbers of phenotypes (selected trees) are involved, e.g. more than 100,
3) in species with early flowering, such as many eucalypts, acacias and tropical pines.

SSOs with family identity maintained are somewhat difficult to manage, because a balance is required between: a) the need to grow trees closely together as in plantations for several years, for evaluation of family and individual performance, and b) the need to thin early and heavily enough to maintain a deep live crown for good seed production (Eldridge, 1986).

It is a special feature of the seedling seed orchard that the result of selections in the orchards can be referred to the specific environment only in which the trees are grown, unless the SSOs are supplemented by progeny trials at other sites to provide additional information on the family performance.

Extensive Seedling Seed Orchards (ESSOs) are defined by Nikles *et al.* (1984) as:- Stands established with special stock from a balanced mixture of seeds from at least 60 good parents (preferably of proven superior combining ability) and gradually culled. Tubed planting stock may be used to ensure highest field survival.

For the establishment of an ESSO, the family identity is maintained all through seed collection and nursery to allow for the formation of balanced seedling lots with equal representation from all families. In the field however, the identity is given up and subsequent thinning is then purely silvicultural. ESSOs are being used more and more where large numbers of families are involved. The loss of family identity distinguishes the ESSO from the normal SSO and may be a serious disadvantage. ESSOs are not

well suited as breeding orchards, since it is impossible to recognise, and so avoid, the over-representation of certain families in the new breeding population. They can perform a useful role as production orchards of limited duration.

3.2 Orchards may also be described according to the OBJECTIVE of seed production.

A good example could be an agroforestry species or provenance with potential for either fodder or fuelwood production. Populations could be developed within the provenance with adaptability to the same sites, but with different end use objectives: (a) Maximise fodder production (probably at the expense of fuelwood production); (b) Maximise fuelwood production (probably at the expense of fodder production); (c) Maximise value of combined fodder and fuelwood production (while accepting some reduction in each of the characteristics assessed singly). Another example could be the development from the same original species or provenance of populations adapted to differing elevations or soil types.

More specialized objectives identified by Barner (1975) are:

1. **Provenance-hybrid orchards**. Trees are selected in 2 provenances of widely different origin, which are known to produce a special hybrid effect when crossed (e.g. *Pinus merkusii* continental x insular).
2. **Species-hybrid orchards**. Trees are selected in 2 species which are known to produce a special hybrid effect such as hybrid vigour when crossed. Hybridization is confined to mean crosses between species or provenances of widely different origin.
3. **Advanced orchards**. This category is reserved for the mass production of material which has been subject to more advanced or specific breeding, such as outcrossing after inbreeding, and breeding for special traits like resistance to pests and diseases.

The above examples give an indication of the range of objectives in seed orchards, but do not cover all cases and a certain »overlapping« between kinds of orchards may occur. It may not be possible to establish a classification of orchards which is feasible and covers all cases.

3.3 Seed orchards may also be categorized according to their MAIN FUNCTION in the improvement programme:

a) **Production seed orchards**; functioning as a »seed machine«. Their size is directly related to the quantity of seed required and they can be expanded accordingly. Their »life span« or active period is merely related to the ageing of the plants and their productivity and/or the accessibility of the crowns. In dynamic tree improvement programmes their active period is however more often limited by the turn-over of generations and formation of a new and genetically better production seed orchard.

   Such orchards may be either clonal or seedling seed orchards.

b) **Breeding seed orchards**; a long term breeding programme should always have a number of breeding populations from where to obtain further genetic variation. One form of such a population may be established in connection with progeny trials as plantations with the same number of families as a progeny trial, with family control, but with large plots. The plantation is located away and in isolation from other occurrences of the same species, and on sites optimal for flowering and seed production. A larger number of trees, hence more genetic variation, can be maintained here than in the progeny trials.

4. SEED ORCHARD GENERATIONS

Seed orchards are usually identified by generation, i.e. 1st, 2nd, or advanced generation orchards, depending on how many cycles of improvement they represent.

First generation orchards usually derive from plus trees selected in natural stands or in unimproved plantations. Roguing (genetic thinning) is usually based on complementary progeny testing, and normally 50-75% of the original number of clones or families are removed after successive evaluations. This requires the initial establishment of a high number of clones or families at close spacing.

Occasionally the term »1.5 generation orchard« is used. Zobel & Talbert (1984) conceived this term to cover an improved 1st generation orchard established by combining the very best genotypes selected in one or more orchards covering the same region (seed zone) in a new 1st generation orchard of greatly improved genetic quality. No generation turn-over is involved. A 1.5 generation seed orchard is therefore still a 1st generation orchard, but of an improved genetical composition.

5. APPROVAL AND TESTING OF ORCHARDS

Seed orchards are often established with clones or progenies from selected, but untested plus trees. The fact that fewer mother trees are represented than in selected stands involves an extra risk. Some trees in the orchards produce more flowers or pollen than others. The matching in time of flowering is often poor with the result that some trees rarely ever mate because they are out of synchronization. In addition the ratio of male and female flowering will vary over the years. It is therefore somewhat f a gamble to establish seed orchards. Still, to save time orchards are often established at an early stage but designed in a way that allows the removal of components which do not perform satisfactorily.

As it appears from the above, orchards are often established with a number of assumptions which have to be verified. To avoid too serious risks, the Organisation for Economic Co-operation and Development (OECD), under the scheme for the control of forest reproductive material moving in international trade (OECD 10974), has set out the following minimum requirements for the approval of seed orchards:

1. The objective, design, components, isolation and location must be approved and registered with the Designated Authority[2]. Any subsequent significant changes must also be approved and registered with the Designated Authority.

2. The component clones or progenies shall be planted according to a plan which has been approved by the Designated Authority and established in such a way that each component can be identified.

3. Thinnings carried out in progeny seed orchards will be described together with the selection criteria used for such thinnings.

4. The seed orchards shall be managed and seed harvested in such a way that the objectives of the orchards are attained.

Item 4 may require some comments. The point is that seed should not be harvested for commercial use until a reasonable balance in flowering has been ascertained in the seed orchards. It is a fact that in young orchards the majority of seed is produced by a few of the represented mother trees, resulting in a biased representation of the orchard. Even in orchards which have uniform flowering, differences have been found between offspring from different years of collection. Seed should preferably only be used when harvested in good crop years.

Reproductive material derived from seed orchards established to produce species hybrids or provenance hybrids can only be approved when early tests show that the objectives of the orchard are attained.

Testing of orchards involves either testing of the seed orchard as such or testing the individual components (clones or families) of the orchard, using open or controlled pollinated progeny testing.

The only true test of the gains from orchards over commercial stock collected in plantations is to collect seed directly from the orchard after it has reached full productivity and to compare the improved stock with the unimproved in paired plantings. These should be designed so as to minimise environmental effects but still allow handling in an operational manner (Zobel and Talbot, 1984). If possible seeds from different crop years should be stored and tested simultaneously.

It is important that seed for testing is harvested in years of good flowering and fruit setting, unless artificial pollination is used. The seed should be harvested by methods that ensure that the samples obtained are representative.

[2] An authority designated by and responsible to the Government of a country participating in the O.E.C.D. Scheme for Forest Reproductive Material for the purpose of implementing these rules on its behalf. The authority would often be an office within the national forest service or national forest experiment service.

6. PLANNING

The seed orchard is the major vehicle to realize the genetic gains achieved in tree improvement programmes, inasmuch as the output - the seed - carries the combined effort of breeding and selection. The improvement strategy is therefore to a large extent also the planning of a seed orchard strategy.

Planning is done both at national, regional, and local (seed zone) level. The smallest unit to plan for is the seed collection unit, or a single seed orchard, capable of serving a specific zone within which seed can be freely transferred, and still remain adaptable to local variations of soil and climate (Zobel & Talbert, 1984).

Important factors to consider when planning an orchard programme are aspects of (Van Buitenen, 1984):

a) the biology of the species,
b) the choice of breeding method,
c) the use of combined or separate breeding/seed production populations,
d) the combination of progeny testing and seed production.

a) Biology of species

Some of the major aspects in this respect are illustrated in Table 1 (for some species groups common in plantation programmes in Thailand).

Biological differences of importance for seed orchard establishment may occur at species, provenance as well as individual level.

b) Choice of breeding method

The choice of breeding method has a clear impact on the role of seed orchards in any tree improvement programme. In most programmes based on selection and breeding, orchards function both as »seed machines« for mass production of seed, and for maintenance of genetic variation. In hybridization programmes, seed orchards play a vital role in creating new gene combinations, and altering the gene frequencies. One of the most successful programmes involving both hybridization and selection is the United Industrial Afforestation Company programme in Point Noire, Congo. The improvement is achieved through hybridization for F1 between a range of Eucalyptus species, whereas clonal propagation is used as the mass production method for commercial plantations.

It is necessary to consider the benefit derived as compared to the extra cost involved.

c) Combined or separate breeding/seed production populations

Basically, the question is how to balance the conflict between the possibility of increased genetic gain through increased selection intensity (reducing the number of families or clones in the orchard population), and the maintenance of an adequate genetic base for future breeding. By separating the two populations it is possible to maintain a broad base in the breeding population, and yet achieve a greater gain by only using the very top families for commercial production of improved seed or clonal material. Without a broadly based breeding population, a severe loss of germplasm can be expected. Taking into consideration the risk of inbreeding within a few generations, it is an advantage to separate the breeding and the production populations (Van Buijtenen, 1975). Breeding populations must have a broad base, whereas production populations (»seed machines«) may be more strongly selected.

d) Combination of progeny testing and seed production

Under certain conditions, progeny tests may be converted to seedling seed orchards. This is an advantage favouring the use of seedling seed orchards.

It is important, however, to realize that progeny trials must be planted on sites representing future plantation areas to be reforested with the specific sub-population under test. These are, however, not necessarily the best for good seed production or for efficient orchard management (Zobel & Talbert, 1984).

The proper approach would be to establish progeny tests on plantation sites, and seed production units under conditions optimal for seed production.

TABLE 1: MAJOR ASPECTS OF SPECIES BIOLOGY IN SPECIES COMMONLY USED IN AFFORESTATION PROGRAMMES IN THAILAND

BIOLOGY ASPECTS	PINUS KESIYA	TECTONA GRANDIS	GMELINA ARBOREA	EUCAL. CAMAL.	ACACIA MANG.	PTEROC. MACROC.
Sexual behaviour (perfect/imperfect) (bi- or uni-sexual)	BI/IM	PE	PE	PE	PE	PE
Mating system (outcross./mixed)	OU	MI	MI	MI	MI	MI
Degree of selfing	low	low	interm.	interm.	interm.	?
Pollination agent (wind/insect)	WI	IN	IN	IN	IN	IN
Isolation required	> 300 m	> 100 m	> 100 m	> 100 m	> 100 m	> 100 m
Ease of controlled pollination	easy	diffic.	diffic.	diffic.	diffic.	diffic.
Response to stimulation						
a) hormones	+	complex	complex	complex	complex	complex
b) fertilizers	+	complex	complex	+	complex	complex
Flowering habit						
a) periodicity	1 Y	1 Y	1 Y	2-3 Y	?	?
b) time from pollination to maturity	24 M	9 M	5 M	14 M	?	?
c) synchronization	+	+	+	+	?	?
d) initiation	5-7 Y	7-10 Y	3-7 Y	3-7 Y	?	?
Flowering and environment (environmental impact) e.g. altitude, rainfall	important	important	important	?	?	?
Ease of vegetative prop.						
a) grafting	+	+	+	+	+	+
b) cutting	(+)	(+)	+	+	+	+
c) tissue culture	-	+	+	+	?	?
Graft incompatibility	+	+	?	+	?	?

7. LOCATION (SITING)

Of major importance is the selection of a region and sites which promote good flowering and seed development, and provide isolation from contaminating sources. A wrong decision could mean failure.

Size, layout and isolation should aim at maximum cross pollination and at minimum risk of inbreeding and contamination by outside pollen.

The following conditions should be considered for establishment of seed orchards:

(i) Location on sites exceptionally favourable for early, abundant and regular production of good quality seed.

(ii) A location outside the natural range of a species may be justified if the species has shown very good performance in comparative trials and shows irregular and modest seed production in the natural range.

(iii) Access to the proposed site should be adequate for establishment, protection, management and for collection and transport of seed.

(iv) Legal rights to use the site for the purpose should be clearly stated and rest with the managing authority. For this reason government forest reserves may be preferred.

(v) To safeguard against future contamination from foreign pollen, the present and planned use of other tree species in the area should be investigated before a site is approved for seed orchard establishment. This is particularly relevant for wind pollinated species, for which the recommended minimum distance for isolation is 300-500 m. See below under isolation.

(vi) To secure an established seed orchard from obliteration (fire, windfall, pests etc.) it is advisable to replicate the seed orchard on two or more sites.

More specifically the following factors should be considered:

The macro and micro climate

Temperature regimes, extremes as well as temperature sums during the time of bud differentiation, are extremely important (Ilstedt 1982). Dry summers with high temperatures are known to affect bud formation so that more reproductive buds are formed (Sweet 1975). Length of photo period is also recorded as important for the formation of flowers (Werner 1975). In Thailand, occurrence of low temperatures at the time of bud formation in November greatly influences development of male flowers in *Pinus caribaea* and *P. kesiya* (PIC 1980).

During the time of flowering, high air humidity has a negative effect on pollination as observed in *Pinus caribaea var. hondurensis* in western Malaysia under moist tropical conditions resulting in lack of seed formation.

Topography

Changes in topography may have a pronounced influence on the microclimate of a site, e.g. in temperate climates by the effect of cold airflows or »pockets« resulting in frost damage and thus poorer seed formation. The difference between a location on a north or south slope may be considerable because of different incoming sun radiation.

Exposure

Climatic effects may be increased by exposure. Low temperatures during winter times may become critical if accompanied by strong winds, as well as droughts during summer on light sandy soils. Severe drought during seed formation is known to reduce seed yields. Windy conditions are required to obtain effective pollination in wind pollinated species, but a constant wind direction during pollen dispersal appears to be able to cause adverse effects.

Isolation

Good isolation from contaminating pollen sources is a necessity. Complete isolation in wind pollinated species is however very difficult to obtain, unless orchards are established outside the region in which they are found in plantations or natural stands. Pollen of wind pollinated species is known to be able to travel long distances at high altitudes. Local pollen however generally makes up the majority of the pollen cloud (Werner 1975).

Minimum acceptable distances for isolation vary with species, topography and winds. FAO/UNEP recommend a minimum of 300 m for gene conservation stands of tropical pines, this may however be too close for safe conservation of wind pollinated species, depending on stand size.

For insect pollinated species, safety distances are smaller. Pollination success here depends on a range of insects (bees, flies, ants etc.) with different flying ranges and visiting patterns. Genotype (clonal) preference has been discovered for instance in the case of the *Prosopis spp*. The larger the crown or the wider the spacing between orchard trees, the smaller may also be the chances for cross pollination between clones.

For eucalypts a distance of 200 m is considered sufficient for isolation, most efficiently if the spacing between is taken up by a non-hybridizing or wind pollinated species.

The size of orchard has an effect also on the pollination efficiency; a large orchard is less influenced by the effect of outside pollen contamination. A large local pollen cloud (from inside the orchard) is therefore considered the best protection. Edge effects on pollination should be minimised; orchard orientation should therefore be with the axis in the direction of the prevailing wind at the time of pollen dispersal if a rectangular configuration is used (Zobel & Talbert 1984). An orchard size of 5 ha is usually taken as minimum for effective operations. Size is also determined by some management aspects such as mechanisation of operations (establishment, maintenance, protection, harvest).

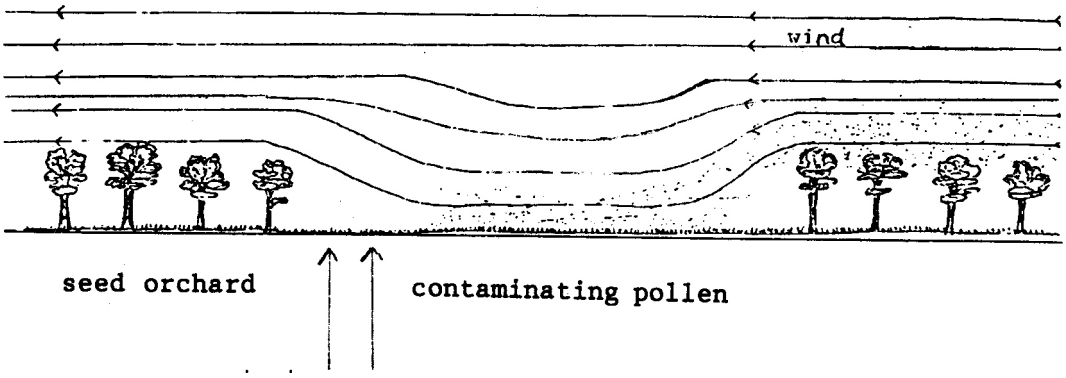

Figure 1: For wind pollinated species low vegetation is preferred so that the wind will descend and deposit pollen before it reaches the seed orchard (Schmidt 1993). A stand of another species between the low vegetation and the seed orchard (arrows) will be an extra barrier against unwanted pollen.

Soil conditions

Soil type, fertility and drainage etc. have a bearing on vegetative growth and flowering, as well as the amount and quality of seed produced. Heavy soils with poor drainage are cold and considered unfavourable for flowering. Conditions promoting good root development, and soils of average or slightly better fertility are recommended, rather than being of a high natural fertility, since it is better to manipulate flowering and growth through fertilizer application at times when specifically needed. In general it is recommended to select an orchard site with the following qualifications:

1) site as level as possible for ease of operation,
2) site slightly sloping to provide good drainage,
3) site with ample light and free from heavy shadow from neighbouring stands,
4) soil should be »warm«, promoting flowering, and of sandy loam to loamy sand texture,
5) soil should be of moderate but balanced fertility.

In summary, one may say that choice of the right environment for seed orchards has a strong bearing on all aspects of flowering and seed development: initiation and ratio of male/female flowers, synchronisation, onset (age at which flowering starts), regularity of flowering and thus seed yield, genetic quality and quantity of seed produced.

Exotics require even more careful attention to the selection of a proper environment than indigenous species. Therefore, in order to avoid great mistakes, orchards should never be established outside the natural range of distribution until the potential of the exotic has been properly tested in the new environment.

Choice of the right region and site should therefore always be given great attention.

8. DESIGN AND COMPOSITION

Many different designs have been invented to accommodate separate requirements, which to a large extent respond to a number of the questions considered under »Biology of species«, see table 1. Other objectives are listed in table 2, which summarizes suitability of the various designs. Several designs are described in detail by Giertych, 1975. The more commonly used designs are:

Pure Rows
Completely Randomized Designs
Randomized Complete Blocks

Pure rows, where individual tree rows contain either ramets of the same clone (CSO), or progenies of the same family (SSO). These were in particular used in some of the early orchards. There are certain disadvantages attached to this design, notably: increased risk of inbreeding within clones and problems with uneven spacing if undesirable clones are discovered and have to be removed.

Completely randomized designs in which all available ramets of all clones are distributed randomly all over the site. The design has some disadvantages in respect of management, viz planting, onsite grafting, relocation of ramets at a later stage, in particular if the orchards are large and contain many clones.

Usually randomization is not complete, since some control is often exercised to avoid planting ramets of the same clone too close to each other. This design has been quite frequently used in Australia, USA, Canada, and Sweden.

Randomized complete blocks, where the area is divided into equal sized blocks, which are sufficiently large to include one ramet of each clone. The ramets are located completely randomized within each block (with occasional manipulation along block borders). This design is commonly used in Europe, USA, Canada and Australia.

Initial spacing should be close enough to allow roguing; 4-6 metres are commonly used all over.

The possibility of roguing (genetic thinning) depends on the availability of progeny trials. As pointed out, these should be established prior to the orchard or at least follow soonest. Often this is not the case, and orchards have to be thinned without the genetic information and knowledge about flowering and seed productivity, in order to maintain crown development. Therefore, too close an initial spacing may result in expensively raised grafts being removed before their value is really known.

Number of clones in clonal seed orchards is an important item:

25 clones or genotypes, at the final stage, are normally considered sufficient to give a genetic base to the seedlings raised from orchard seed which is wide enough to ensure adaptation to normal plantation sites and to avoid serious inbreeding.

But this is only so, if all clones flower simultaneously and with the same intensity, and

ramets are located so as to avoid inbreeding. But frequently flowering is not uniform. Large clonal variation has been reported among clones of many species. Experience with pines showed that 20% of the clones produce 80% of the seed in a young and unthinned orchard. As age increases, differences become somewhat smaller (Lee 1979).

Initially more than 25 clones should therefore be considered. This should also then leave room for the generally unknown rate of stock/scion incompatibility. A greater number also offers possibility for stronger genetic thinning and therefore greater genetic gains.

Of the 3 above mentioned orchard types »completely randomized designs« and »randomized complete blocks« are generally suitable for the following main reasons, whereas »pure rows« do not satisfy the two first items:

1) they avoid selfing
2) they allow mixing of all genotypes
3) they allow expansion
4) they allow any number of clones to fit in the design
5) they are simple and easy to establish
6) they are comparatively cheap

For other more specialised purposes see further details in Giertych, 1975.

Table 2: Comparisons of the suitability of Seed Orchard Designs for various aims

	Design													
	In rows	Chessboard	Completely Random	Random Complete-block	Fixed-block	Rotating-block	Reversed-block	Unbalanced Incomplete-block	Balanced Incomplete-block	Cyclic Balanced Incomplete-block	Directional Cyclic Balanced Incomplete-block	Balanced Lattice	Permutated Neighbourhoods	Systematic
To avoid selfing	−	+	+	+	+	+	−	+	+	+	+	+	+	++
To favour panmixis	−	−	+	+	−	−	−	+	+	++	++	+	++	−
To permit systematic thinning without altering clonal composition	+	−	−	−	+	−	+	−	−	−	−	−	−	++
To permit use of orchard segments as replicates for other experiments	−	+	−	+	+	+	+	−	−	−	−	+	−	+
To permit comparisons of clone performance	−	+	−	+	−	−	+	−	+	+	−	+	+	−
To facilitate the re-location of clones for special cone collections	+	+	−	−	+	−	−	−	−	+	+	−	−	+
To permit expansion	+	+	+	+	+	+	+	+	−	+	+	+	−	+
To fit any orchard shape	+	+	+	−	−	−	−	−	−	−	+	−	−	+
To fit any number of clones and ramets	+	−	+	+	+	+	+	−	−	−	−	−	+	+
To utilise information on compatibilities, flowering times and combining abilities	+	+	−	−	+	−	−	−	−	−	−	−	−	+
Simplicity of design for non-mathematicians	+	+	+	+	+	+	+	−	−	−	−	−	−	+
Low design cost	+	+	+	+	+	+	+	+	+	+	+	+	−	+

Note: ++ = Highly suitable; + = Suitable; − = Unsuitable.

9. ESTABLISHMENT

Site preparation

Farmland is often suitable. If the site has been grazed previously for several years, site cultivation should be preceded by a thorough chemical weed control with a systemic leaf herbicide, e.g. Roundup, (Glyphosphate) combined with ploughing, harrowing and a repeated Roundup treatment before planting. A base fertilizer (NPK + micro nutrients) application may be considered to bring fertility up to a suitable level. Sometimes also control of rodents, termites or soil-borne insect larvae is required.

In old forest areas, stump removal may be required or stumps should at least be cut at ground level to facilitate later mechanical operations if available. Chemical treatment of resprouting coppice shoots and weeds may be applied in combination with soil cultivation as above.

Soil cultivation

It is generally agreed that soil cultivation by ploughing and harrowing in the initial phase is essential for a good start. Where a hardpan is present - and no other area is available - deep ripping is required. Soil cultivation increases the effect of fertilizer application and improves the water balance. Experiments in USA showed an increase in seed harvest of *Pinus taeda* by four and a half times after deep ploughing (46 cm), and by one and a half times after ordinary ploughing (15 cm), as compared to the control.

Vegetative propagation for clonal orchards

a) Timing of establishment

Very often there is a variation in the success of preparing the grafts because of variation of skill in grafting, clonal variation, stock/scion incompatibility etc. This may spread the establishment over several years. The result of this is a variation in age and size of the individual orchard trees, causing problems with competition, thinning, flowering etc.

A recommended procedure is to concentrate on a few blocks at a time and make sure that all clones are represented in some blocks, rather than trying to fill as many blocks as possible, resulting in blocks with a large variation in number of clones represented. Uniformity should be **within** blocks, variation **between** blocks.

Selected plus trees should be sexually mature to avoid delayed start of seed production and undesirable juvenile growth of orchard trees.

b) Nursery versus field grafting

A distinction is made between the following two propagation methods:

1) nursery grafting on rooted container-grown stock
2) field grafting on established usually older field stock.

From a physiological point of view, field grafting is preferable because:

1) planting shock is no problem,
2) ramets grow faster,
3) problems with restricted root development in containers are avoided,
4) disease problems (fungi), frequently experienced in greenhouses/grafting sheds are avoided,
5) flowering occurs earlier.

A major problem with field grafting is keeping control of identity of scions. It should be realised that grafting must be done according to a prearranged field plan. Mistakes easily occur. Another problem is that the vegetative material has to be brought into the field, requiring cooling and protection. Protection in the field after grafting is also essential, e.g. against wind, strong sunshine and evaporation during the initial sensitive stage. Protective covers may sometimes be damaged or even stolen.

Spacing

Spacing must be wide enough to ensure that flowering is possible several years before thinning is required.

A closer initial spacing than the final allows for initial losses. Closer spacing may however result in later flowering and carries the need for earlier thinning. The risk of thinning out clones before their full genetic value is known must therefore be considered; in particular if progeny trials are not properly timed.

10. MANAGEMENT

Seed orchards should provide early, abundant and regular production of healthy seed. This requires attention to a number of factors.

Ground cover

Plants should be kept free of weeds the first couple of years, either mechanically or by chemical control. However the latter requires careful attention to dosage and application method. Some of the weed killers with wide application are potentially deadly to the young orchard plants if not carefully applied.

Use of a perennial green legume as cover crop is practised many places. Care should be taken however that cover plants do not climb into the orchard plants.

Fertilizer application

Many reports show that strong, healthy plants flower well. To obtain regular and good seed harvests, regular fertilizer schemes should be planned, in combination with intensive soil cultivation (Lee 1979). Most authors cite N and P as major key elements to flowering but even micro-elements may stimulate flowering (Sweet 1982).

Fertilizers are now applied by routine in several large programmes, e.g. as in the North Carolina State Cooperative (USA) programme with *Pinus taeda* and *Pinus elliotti*.

Watering

The combined positive effect of watering and fertilizers on fruit/seed production is often reported as considerable and better than just one or the other alone. On the other hand, introduction of a »stress« situation before flower initiation by reduction in available water is by itself said to have a strong positive effect on flower development (Sweet 1975).

In pines, fertilizer application seems to increase female flowering, whereas water stress improves male flowering (Ilstedt 1982). It is recommended to select locations with generally dry summers but then use irrigation after flower differentiation.

Treatment with growth hormones

In recent years several reports have been published on the effect of hormone application on flowering, in particular for species of the *Cupressaceae* and *Taxodiaceae* which have flowers at the end of the branches.

There are however also reports on increase in flowering on pines e.g. by application of gibberellic acid 4/7. (Ross *et al.* 1980, Sirikul & Luukkanen, 1987). Lately, success was reported on the use of gibberellic acid 4/7 on *P. caribaea*. Time of application in rela-

tion to stage of bud development is however crucial. It seems to be agreed that treatments with hormones may not be effective where there is an inherited poor flowering, whereas environmentally limited flowering may be promoted.

Treatments with auxins may change the male/female ratio (Sweet 1975).

In general however, it is assumed that costs of hormone treatment are too high for large scale application.

Thinning

Thinning and proper crown development appears clearly to be the best way of stimulating flowering and seed production.

In particular the first thinnings are important as early crown closure has a severe effect on the lower part of the crown. This is particularly important in the case of light demanding species where loss of lower live crown often is permanent.

Shading experiments in pines have shown that flowering decreased progressively from 50% sunlight, disappearing completely by 15% sunlight.

The importance of establishing progeny trials prior to, or at least simultaneously with, the orchards should be realised where genetic thinning is desirable.

Inferior families or clones should be removed as soon as sufficiently reliable information (from progeny or clonal test) becomes available, but in general not before flowering ability can be recognised.

Very early or very late flowering clones and clones with very low seed yield should be removed.

General experience shows that thinning does not influence viability of seed and is of little effect in poor seed years. In good seed years seed production increases considerably in response to previous thinning.

Crown pruning and shaping

Pruning is mostly done to facilitate collection. Reports on its effect on flowering are however divided and depend very much on the species. In conifers there seems to be consensus that when the top of a conifer is removed, many future potential flowering points are lost and the proportion of male to female flowers is increased within a zone of the crown where selfing is likely to occur, with a negative effect on seed yield and quality. The effect of top pruning is generally not long lasting as one of the upper branches will assume dominance after which the situation is restored.

Tying down top and branches of *Eucalyptus* to obtain low growing trees has been tried with some success.

Stem and root treatments

Whereas crown development by thinning is a stimulating treatment that promotes vegetative growth as well as flowering and overall health, artificial treatments of stem and root may have negative side effects. Generally, the objective of these treatments is to create a higher carbohydrate level, believed to promote flowering.

Such treatments may be root pruning (by deep ploughing), stem girdling or banding. Many reports are available, particularly in horticulture. The general consensus indicates that such treatments can be very effective in the short term, in particular when applied at the right time of flower development (Sweet, 1975). However there may be severe long term effects on the general health and conditions of trees, in particular if used over a longer period.

The effect of root/stem treatment relates to a stress situation forced upon the trees, which will respond in a self-preserving manner by increased reproduction to secure »survival of the species«.

Physiological stress situations such as drought (stopping of irrigation), and confinement of roots are known to provide increased flowering. The explanation could be (Lee 1979) that, if the balance between photosynthesis and nutrient uptake is disturbed, then the internal mechanism which regulates sexual reproduction is also disturbed. This causes a change in the bud differentiation, from vegetative to reproductive, as a defence for survival.

Protection

Management plans must include possible protection against mammals, including humans in particular (encroachment on seed orchard areas, man-lit fires). Prevention or treatment of insect attack, diseases (on root, stem, leaves as well as flowers and fruits) or damage by birds is however equally important.

Since the seed from seed orchards is the result of the accumulated effort of the breeding programme, the amount of seed produced can be taken as a measure of the success of the whole improvement programme. Programmes which fail to produce enough seed are of little use, irrespective of how large genetic gains have been achieved by breeding. Thus the major task of any orchard manager is to keep his orchard healthy and free of pests and diseases and in a state of high productivity.

Recording

Good records are an essential tool in orchard management. Records are needed to maintain identity of the genetic material as well as to evaluate the effect of various management practices and the impact of environmental fluctuations.

Basically two types of records are needed:

a) records covering the orchard as a whole, and

b) records related to the individual seedlings or clones/ramets within the orchard.

A comprehensive set of information to be recorded for the two types would contain details:

a) For the orchard as **a unit:**

Location (including isolation from possible contaminating sources)
Site (including soil conditions/cultivation)
Orchard composition, including a detailed map with exact location and identification of clone/ramets or seedlings
Establishment planting/beating-up
Management e.g. fertilizer application and use of chemical pest control (type, rate, date, method); pruning (date, method); roguing or thinning (date, no. of removals, silvicultural and/or genetic)
Environmental and biological events and actions taken e.g. gales, drought, late frost, floods
Standard weather records to identify long term climatic changes, e.g. for precipitation, relative humidity, temperature, wind velocity/direction.

The above information provides the necessary general framework of knowledge to ensure that the management of the orchard is correct, and to obtain maximum return from the improvement programme.

b) For the **individual components** of the orchard:

Vegetative propagation i.e. type, date, occurrence of incompatibility.
Flowering i.e. age at initiation of male/female flowering, regularity, heaviness.
Cone, fruit and seed production i.e. quantity, quality, viability
Variation in susceptibility to insects and diseases on fruits (cones) and seed.

The information available from these records provides a comprehensive background for a thorough understanding of the development of the orchard, as well as for the actions required, e.g. thinning, to obtain maximum output of good seed. Even if resources and time do not permit such thorough recording in all detail, the type of information may be kept in mind as a guide for general observation of development of the orchard.

The above recording is of little use unless the identity of the trees in the field is fully assured. Labelling must be continuous and meticulous, right from the collection of scions or seed from plus trees through the grafting or nursery stage to transport and planting in the field.

For identification, a notoriously critical stage is found during the establishment phase, when the original labels, given during grafting in nursery or at transfer to field, are replaced by more permanent ones. This phase must not be delayed, so that old tags become illegible or even disappear and new tags are attached without the positive identification from a previous label. This final tagging is crucial since activities hereafter (thinning, pollination etc.) are carried out according to tag number.

11. CONCLUSION

In summary of the discussion on the role of seed orchards, it may be concluded as follows:

There are some important limitations to the use of seed orchards, i.e. (a) environmental dependence involving the risk of failure of flowering and seed production because of wrong location, (b) requirements for isolation, (c) large individual variation in reproduction ability between different individuals - and as a result of this - pollen clouds dominated by a few individuals, and (d) incompatibility between scion and stock into an advanced age.

But in spite of these limitations, seed orchards will remain an important link in future tree improvement programmes even when the vegetative propagation systems become economically viable and safe for large scale plant production. Vegetative propagation in itself is a »dead end« in tree improvement, and there must always be close contact with breeding either as breeding seed orchards or controlled crossings.

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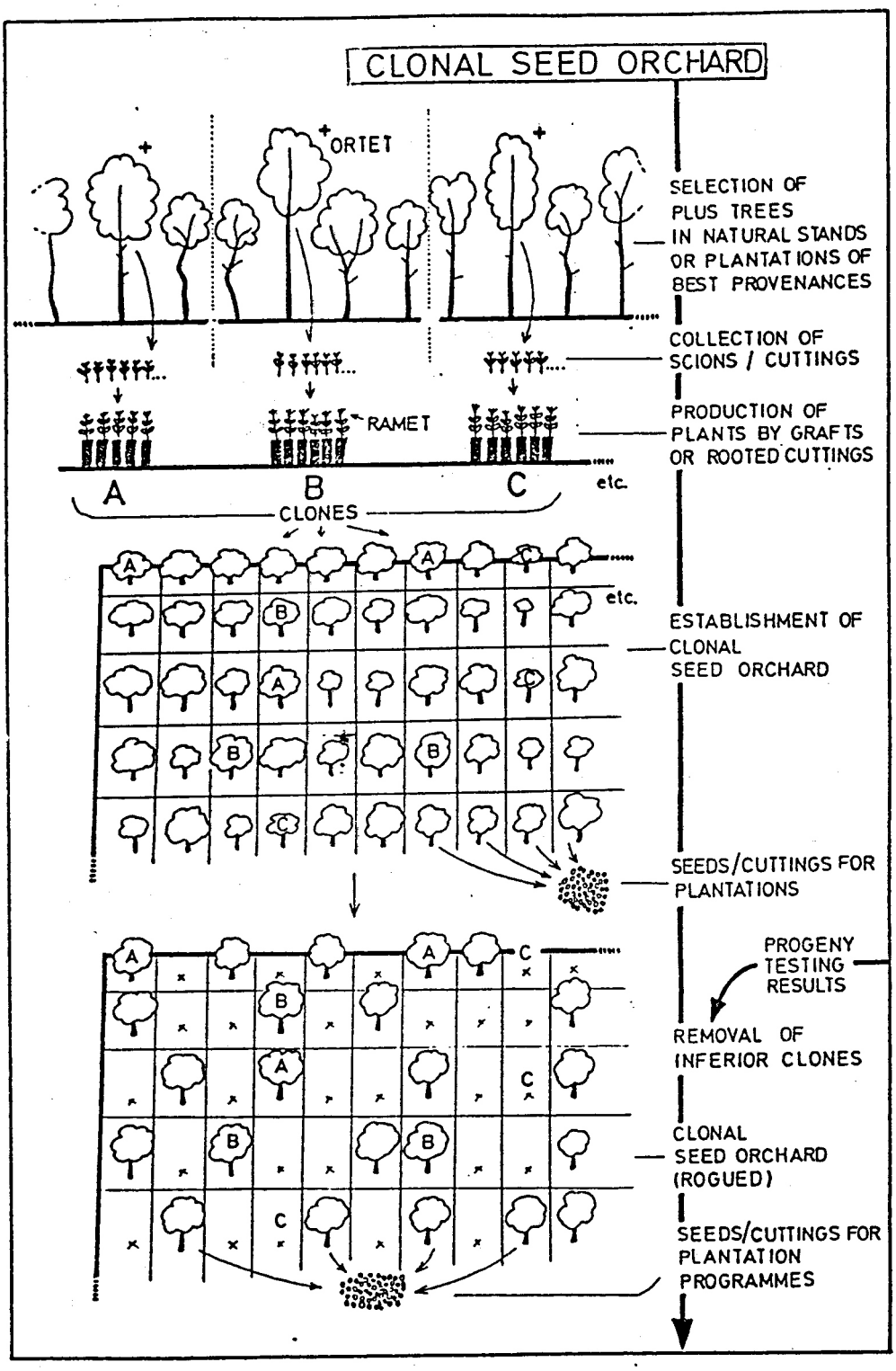
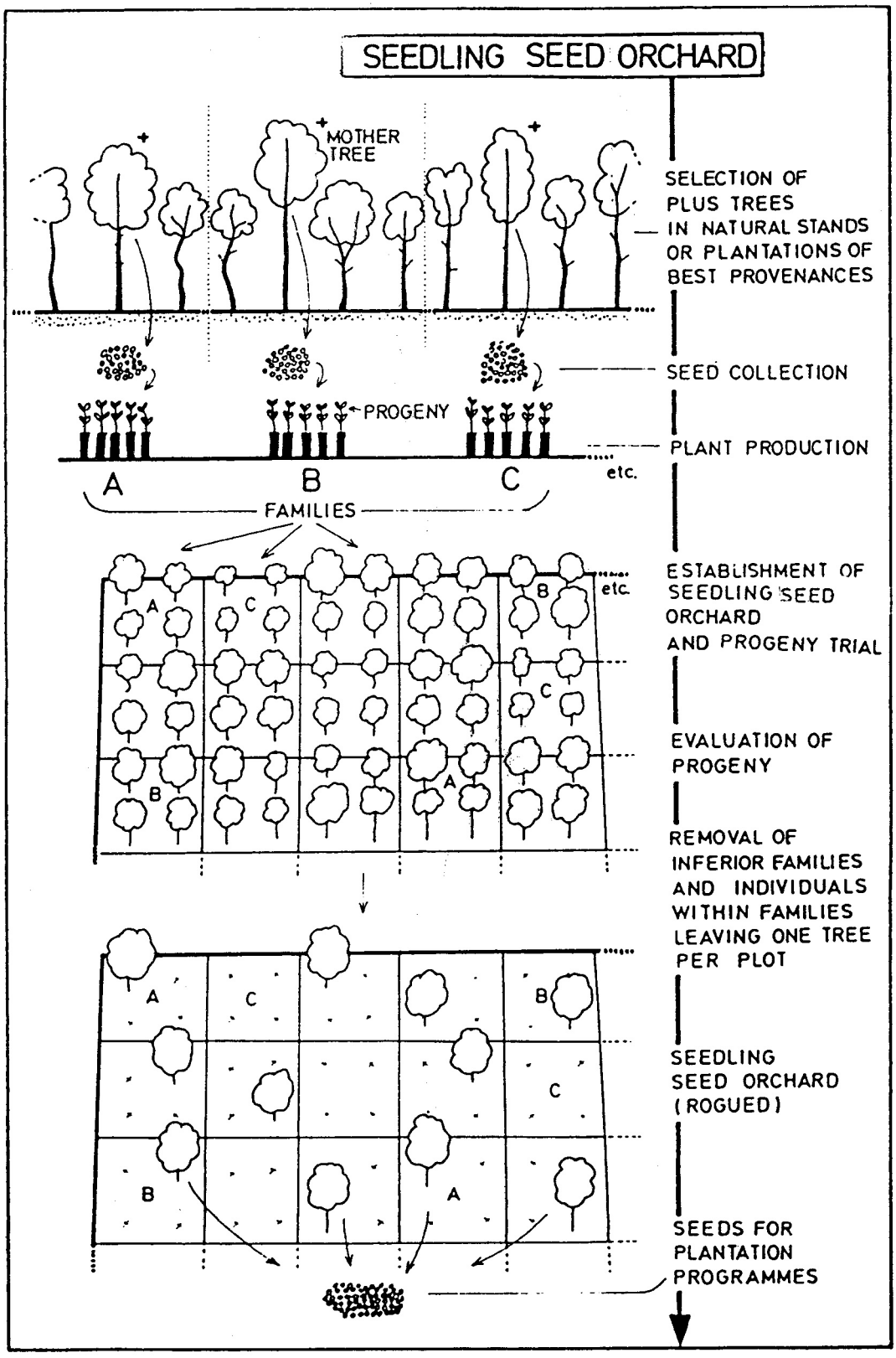
Appendix 1

Development of clonal seed orchards. From Ditlevsen *et al.* 1988.



Appendix 2

Development of seedling seed orchards. From Ditlevsen *et al.* 1988