PANDA MITI KIBIASHARA

PARTICIPATORY PLANTATION FORESTRY PROGRAMME

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Improved Tree Seed Production Manual

Version November 2020

United Republic of Tanzania
MINISTRY OF NATURAL RESOURCES AND TOURISM
Forestry and Beekeeping Division

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Dar es Salaam

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Report authors:
Christopher Komakech,
Ladislaus Nshubemuki,
Raheli Jonas Swai, and
Anastazia Samwel Kasase.

Other contributors:
Tanzania Tree Growers Association Union (TTGAU), and
Tanzania Forest Service Agency Directorate of Tree Seed Production (TFS-DTSP).

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Private Forestry Programme – Panda Miti Kibiashara
Plot no.21, Block 1, Zone 1A
Gangilonga
P.O. Box 2244, Iringa.

www.privateforestry.or.tz

Cover photo: Improved tree seed orchards in Ibumi village, planted ***Pinus tecunumanii*** and ***Pinus oocarpa***. A person in the photo is Mr. Jafrine Mwinuka caretaker of Ibumi seed orchard.

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ABBREVIATIONS

EUR	Euro
MFA	Ministry for Foreign Affairs of Finland
MNRT	Ministry of Natural Resources and Tourism
MoU	Memorandum of understanding
NGO	Non-governmental organisation
NTFP	non-timber forestry product
PFP	Private Forestry Programme
SME	Small and medium enterprises
TGA	Tree growers' association
TTGAU	Tanzania Tree Growers Association Union
TTSA/DTSP	Tanzania Tree Seed Agency
TZS	Tanzanian shilling

1. INTRODUCTION

Plantation forestry resources are managed for the production of both timber and non-timber forestry products (NTFPs). The quality of these end-products is determined by both the quality of the germplasm used in the initial establishment of the plantations and the management practices applied to the planted trees.

Broadly, two types of planting materials are used to establish plantations: seeds (sexual reproduction) and vegetative material (asexual reproduction). Regardless of which type of germplasm is used, however, various tree breeding operations need to be followed the planted forestry resources are to see sustainable improvements in both growth and wood quality. The development of tree breeding activity guidelines can help stakeholders involved in establishing research infrastructures apply standardised procedures which will guarantee that they meet their research objectives.

Two other ways to ensure success are building technical capacity relevant to local areas of operation through well-tailored practical short courses for the different categories of managers and field staff who will look after trials and seed orchards as well as developing and implementing technical guidelines for the production of improved germplasm.

1.1 Seed orchard management manual

This technical manual will benefit members of tree grower associations (TGAs) through their umbrella body, the Tanzania Tree Growers Association Union (TTGAU), the Directorate of Tree Seed Production (DTSP, which was formerly the Tanzania Tree Seed Agency (TTSA), and the Participatory Plantation Forestry Programme (PFP 2), which was formerly the Private Forestry Programme. Other stakeholders in the industry will also benefit as some private companies are also involved in the in-house generation of improved germplasm from both seeds and vegetative material.

This manual covers the following topics: planning for the establishment of seed orchards, selecting trees for the collection of seeds, the establishment and silvicultural management of seed orchards for maximum seed yield, and the collection and handling of commercial seed. The information in this manual, which was derived from many years of literature from research institutions with well-established tree breeding programmes, is not cast in stone. It should be adapted and updated regularly to include emerging information and to make it more suitable for stakeholders to use in the Tanzanian environment.

1.2 Definitions of terms

A seed orchard is established for the mass production of genetically superior seed of a particular origin in order to “obtain the greatest genetic gain as quickly and as inexpensively as possible" (Zobel *et al.*, 1958). Such an orchard is isolated from other species to reduce cross pollination, rogued of undesirable trees, and managed intensively in order to improve genotype and to produce, as smoothly as possible, frequent, abundant, and easily harvestable seed crops (Schmidt, 1970; Feilberg & Soegaard, 1975).

Seed orchards are established to promote the genetic improvement of specific characteristics, provide significant quantities of genetically improved seed for operational planting, preserve a wide genetic base of multiple traits of economic importance of declining diversity brought about through the selection and breeding processes of commercial tree species, and establish plantations.

There are three main types of seed orchards. A **seedling seed orchard (SSO)** consists of trees raised from seedlings (progenies) produced from selected parents through natural or controlled pollination, while a **clonal seed orchard (CSO)** consists of trees raised from selected clones propagated by the grafting, budding, air-layering or rooting of cuttings (Feilberg &Soegaard, 1975). An **extensive seedling seed orchard (ESSO)**, on the other hand, refers to a stand established with special stock from a balanced mixture of seeds from at least 60 genetically superior parents, preferably of proven superior combining ability tested in progeny trials and gradually culled to remove poor performers. Family identity is not retained in the field and the orchard can technically be managed as a seed stand.

Inbreeding depression. A reduction in vigour often observed in the progeny of mating between close relatives. In seed orchards, it occurs when seed is harvested from only a very few trees flowering in an orchard (isolated pockets of trees).

Plot. In a field study, a group of trees that are all from the same family. In a seedling seed orchard, plots are composed of 4–5 trees perplot.

Rogue. To remove (entire families of) trees that have an undesirable phenotype or that have been shown through progeny tests to have a less desirable genotype from a seed orchard, seed production area, or nursery bed.

Replication. In a genetics test, a replication contains one plot of each entry in the test. In a seed orchard, each replication has one plot of each family included.

Seed. Morphologically, a seed is the structure which develops from the fertilized ovule in a seed plant.

Seed (bulk). Seedlots with seed collected from a group of trees without retaining individual tree identity. No pedigree information is available.

Seed (family). A group of closely related genotypes usually raised from the same tree. They share only their maternal parent (**half-sibs**) or both parents (**full-sibs**). Such seed used in tree breeding work.

Seed collection area. A forest stand that exhibits good growth, form, and vigour and, while not managed for cone production, is nonetheless the source of seed, is a seed collection area. It is an area with defined boundaries and altitude limits in which soil and climate are sufficiently uniform to be able to represent a single **ecotype**.

Seed production area. A forest stand identified as a good source of seed and in which individual trees have been evaluated for desired characteristics and unwanted and competing trees removed to promote cone/capsule production. After being upgraded, the stand is managed for seed production, and seed is collected throughout the life of the stand.

Seed deployment zone. The zone in which seed from a particular seed zone can be used. Seed produced in orchards where the climatic conditions and soils are similar to those of the plantations being established should be used.

Seed source. The locality where a seed lot is collected. If the stand from which seed was collected is exotic, the place where its seed originated is the original seed source.

Seed stand. A stand of trees growing in a seed production area. It is a forest stand established with a good seed source and where trees phenotypically exhibiting poor characteristics are removed through thinning. Idete and MPM *P. tecunumannii* and *P. maximinoi* plantations established from bulk seed sourced internationally qualify to be seed stands.

Seedlot. A quantity of seeds of the same species, origin, date of collection and handling history. Every lot is identified by a single number.

Selected tree seeds (selected seed). Seed collected from plus trees that have been rigidly selected for promising phenotypic characters or properties but have not been progeny-tested. Their source and elevation must be stated.

Selection in a seedling seed orchard. Usually seedling seed orchards are established with multiple-tree plots so that selection can take place first among families and then among individuals within each family plot, reducing each plot to a single tree usually in the second thinning.

1.3 Factors determining the genetic structure of the seeds in a seedlot

Among the several factors that determine the genetic structure of the seeds in a seedlot used to establish an orchard are the following:

- Composition and size of maternal population (number of families and number or trees per family that are planted in a seed orchard)
- Variations in fertility (number of families with good flowering habits and precocity as opposed to the number of families with non-flowering mothers)
- Components of the mating system, including in-breeding and out-breeding, pollen dispersal within an orchard, and pollen contamination from outside sources.
- Viability selection operating on zygotes.

1.4 Seed sources

A seed source can be a tree, a group of trees, a stand, a seed orchard, a population, or any other source which provides seed. Not every seed source is suitable for forestry development. Since a seed source has to meet certain standards to ensure genetic variation and quality, before seeds are collected, a suitable seed source has to be selected. These are mainly in agroforestry systems involving indigenous tree species, but, for commercial forestry, they are an established seed orchard.

Selection of seed sources

If no seed orchard exists, other sources of seeds have to be identified and selected. As there are different provenances and different families within each provenance for both exotic and indigenous tree species, seed sources should be identified in all ecological zones where a species occurs naturally or has proven to perform well. Since tree seed sources are selected assuming that their genetic characteristics will be transmitted to their offspring, seed sources must have outstanding characteristics like fast growth rates and good stem form. Seed sources which are suitable have to be identified accurately. The quality and history of the population selected is an important part of this documentation.

Seed selection for a seed orchard involves the phenotypical selection of “plus trees” for individual family collections or elite trees from seed orchards. Selection is based on the requirements of particular species and traits of economic importance, like timber (long cylindrical straight boles, fine branches, horizontal branching), fodder (high production rate, dense branching), and fuel wood (high production, multi-stem heavy branching, splitting and coppicing potential). Seed sources are also selected according to criteria such as age, health, growth and size. A seed source must be old enough that its performance and health, which is an indication of its adaptability and resistance in a given environment, can be determined. The seed source must also be large enough to produce a large number of different genotypes and thus guarantee genetic variation. To establish seed orchards of pines and eucalyptus, seed sources should have at least 50 families.

Isolated trees are not suitable for seed collection even if they frequently and profusely flower and seed since if they self-pollinate, the plantation will show signs of inbreeding depression: the proportion of hollow seeds (chaff) will be high, the rates of germination low, and offspring will have poor health.

2. SEED GERMINATION

2.1 Factors affecting seed germination

Seed germination is influenced by a number of internal and external factors, including the following:

- The maturity, size, and age of a seed and the nature of its food reserve and enzymes
- Causes of seed dormancy such as rudimentary embryos, impermeable seed coats, and the presence of chemical inhibitors
- The age and vigour of the mother tree
- Geographical origin or provenance
- Germination temperatures, whether they vary or are consistent for a particular species
- External oxygen supply or aeration, except in the case of underwater seeds, where germination depends on oxygen supplied intramolecularly from the chemical transformation of food reserves
- The acidity and alkalinity of the substrate. Tree seeds are more able to withstand extreme acidity than extreme alkalinity. Free ions influence germination by their action on seed enzymes to hydrolyse food reserves.
- Light. Depending on the plant species, light may influence seed germination negatively or positively by raising temperature or by stimulating enzyme action.
- Plant hormones such as auxins, whether natural or artificial. These tend to enhance seed germination.

Figure 2.1 *E. grandis* seed germinating in a petri dish (a) and seedlings pricked out (b).

(a) **(b)**

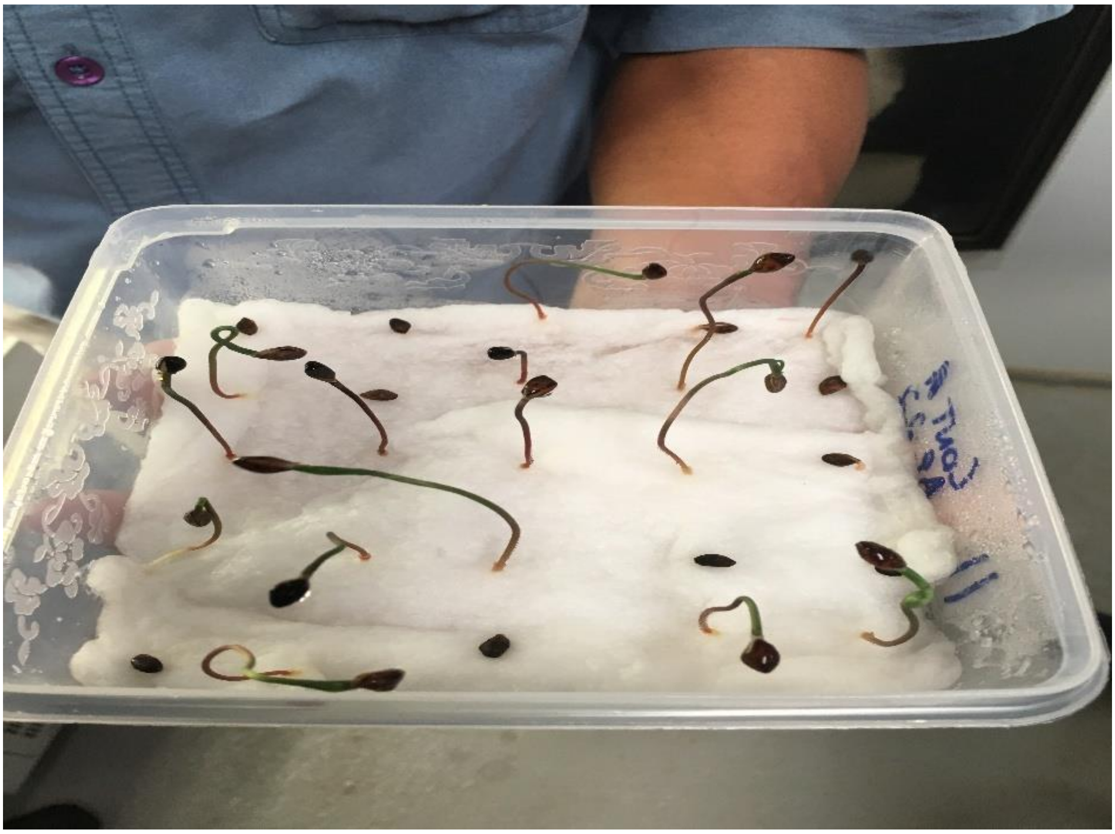
2.2 Seed germination for pine and eucalyptus

Small-seeded *Pinus* and *Eucalyptus* species are tested under these three conditions:

- On a germinating medium (usually blotting or filter paper)
- At 20°C
- In the presence of light.

Germination can be facilitated by placing the seeds in a germinator such as a Jacobsen germinator. Paper is better than cotton wool as a medium because root hairs grow into and become entangled in cotton wool, making transplantation difficult. It is also difficult to count small germinants if they are grown in cotton wool. If fungal contamination is a problem, paper can easily be soaked in a fungicide solution before setting seeds for germination.

Figure 2.2 ***P. patula*** **seed germinants in cotton wool**



A seed is regarded as viable when a radicle protrudes 1 mm or is equal in length to the diameter of the seed. The International Seed Testing Association prescribes that a seed be judged viable only if it is allowed to develop long enough that it is possible to assess whether or not it will develop into a normal plant.

2.3 Pine seed

Considerable variability exists among *Pinus* species with regard to seed dormancy. The seeds of many species have no dormancy at all and will germinate immediately upon collection, but others remain dormant until subjected to special treatment (Table 2.1).

The germination of seeds with embryo dormancy can be increased by using moist perlite as a medium and by subjecting the seeds to a stratification period (a cold moist period that breaks seed dormancy) of one to three months at 0 °C to 4 °C (32 °F to 40 °F).

Table 2.1 Common pine species with and without and dormancy conditions

Without dormancy (no treatment)	With dormancy (require treatment)
• *P. patula* • *P. caribaea var. hondurensis* • *P. caribaea var. caribaea* • *P. caribaea var. bahamensis* • *P. maximinoi* • *P. tecunumannii* • *P. oocarpa* • *P. kesiya*	• *P. elliottii (Soak in cold water for 48 hours and then sow.)* • *P. taeda (Soak in cold water for 48 hours, store in a refrigerator for 120 days, and then sow)*

Another stratification method is to soak seeds overnight in water, drain off the excess water and place them in a refrigerator at 4 °C (39 °F) for 30 days before setting them for germination immediately thereafter.

If seeds are stored for a long time, they should be subjected to a cold stratification period before they are planted.

Pine seeds can be stored for considerable lengths of time and still be viable if they are stored in sealed containers kept at between –15 °C and 0 °C (5 °F to 32 °F). Seeds should not be allowed to dry out.

2.4 Eucalyptus seed

In general, no pre-treatment such as stratification to break dormancy is necessary for *Eucalyptus* seed though a few species, such as *Eucalyptus dives* and *Eucalyptus pauciflora*, require stratification for about two months at 4 °C (40 °F). Since Eucalyptus seeds are highly susceptible to damping off (the rotting of the stem and root tissues at and below the soil surface), precautions need to be taken when seed is treated for a long period of time.

The treatment requirements of some of the *Eucalyptus* species represented in the seedling seed orchards are shown in Table 2.2.

Table 2.2 Eucalyptus species seed included in the seed orchards

Species	Treatment requirement
E. grandis	None
E. saligna	None
E. urophylla	None
E. cloeziana	None (but damping off is a major problem)

3. TYPES OF SEED ORCHARDS

The numerous kinds of seed orchards can be classified into two broad types:

- Vegetative seed orchards
- Seedling seed orchards

Which type is best to use depends on the situation and the availability of both technical and financial resources.

3.1 Vegetative seed orchards

Vegetative, or clonal, orchards are established by using vegetative propagules such as grafts, cuttings, or tissue culture plantlets. In the past, most vegetative orchards were established using grafts.

One type of vegetative orchard is the meadow seed orchard, a non-isolated seed orchard composed of grafts of the best clones planted in very closely spaced monoclonal blocks. Typically, clones are planted in a 1 m x 1 m or 1 m x 2 m array and 5,000–10,000 grafts are planted per hectare. These blocks have a short life (about 5 to 8 years) and are pollinated manually, as flowers become receptive, with either pollen mixes or single pollen. Such an orchard must be planted on a site in which female flowering starts within a year or two of planting. Flower induction treatments can also be applied.

Vegetative seed orchards have the following advantages:

- Progeny tests reveal the genotypes of seed-producing trees.
- Seed production begins soon after orchard establishment (three years for most *Eucalyptus* and five years for most *Pinus* species).
- A vegetative seed orchard can be established in highly productive locations.
- The possibility of inbreeding among seed orchard trees is minimal.
- Vegetative seed orchards offer more genetic gain per unit of time than do seedling seed orchards.

The main disadvantages of vegetative seed orchards are as follows:

- Clonal propagation is unsuitable for species in which grafting problems and incompatibilities prevail.
- Progeny tests must be carried out in a separate operation.
- Managing a vegetative orchard is very expensive and requires well-trained staff with many years of experience.
- A vegetatively orchard usually contains fewer genotypes than a seed orchard.
- Planning and grafting are time-consuming processes; in fact, it may take two to three years before grafted clones can be planted in a seed orchard.

Grafted vegetative seed orchards are the best type of orchard provided that the technical skills for grafting are available and incompatibility is low.

The most common type of vegetative orchard is one that which uses grafted material from mature selected trees. Ideally, orchards of this type comprise not less than 50 clones. They should be designed to discourage the adjacent planting of ramets (independent units) of the same clone.

The first seed crop can be expected a year after grafting for some *Eucalyptus* species, but, because most eucalypts grow very fast, seed-harvesting becomes difficult after about four years. Thus, *Eucalyptus* orchards should be managed for seed harvesting on a three-year rotation basis. Each year, one-third of the ramets should be pollarded (cut off to encourage growth) above the graft union, leaving a skeleton of branch bases to provide a foundation for coppice growth. Seed is harvested from the felled branches on the ground and the coppice must be thinned out judiciously.

While the failure of grafted ramets due to incompatibility is a disadvantage of vegetative orchards, the possibility of failure can be mitigated by planting more than one ramet in each planting position or by grafting scions onto related rootstocks. To further reduce the risk of incompatibility, seed from the same sources as the material to be grafted should be utilised. If neither time nor human resources are limiting factors, seed from the same families should be utilised. Unfortunately, this approach is not practical.

Vegetative orchards can also be based on rooted cuttings instead of grafts. Superior trees from young progeny or provenance trials can be felled and cuttings raised from the subsequent coppice growth. These cuttings can then be used to establish a vegetative orchard. The main advantage of this strategy is that it avoids failure due to. Flowering, however, may occur two to three years later than it does in a grafted seed orchard. Nonetheless, rooted cuttings from the stumps of selected young trees may provide a satisfactory alternative to grafting for species which coppice and for large orchard programmes.

3.2 Seedling seed orchards

Seedling seed orchards are established with open-pollinated seedlings from seed collected from superior selected trees or derived from controlled pollination. Seedling seed orchards normally contain more entries (families and genotypes) than vegetative seed orchards. They are established in a statistically designed, replicated layout, the most common of which is randomised complete block design. In most *Eucalyptus* plantations, 50% of the trees are removed after three to four years, leaving only the better half in each plot.

After five years, the trees are assessed and based on this assessment, a certain percentage of families (often 50%, but the exact percentage is determined by the need for seed for commercial afforestation) are culled completely. The remaining trees are thinned to leave only the best individual trees in each plot. To benefit from an improved pollen cloud, these trees are left to flower for two to three years before they are harvested. Thinning and rogueing operations can be done by repeated felling, harvesting, and coppice regeneration.

The advantages of a seedling seed orchard are as follows:

- A seedling seed orchard may serve first as a progeny trial for previously untested families and then, after rogueing, as a seed production stand.
- Progeny testing is combined with seed production, making the seedling seed orchard a breeding seed orchard.
- A seedling seed orchard is appropriate for species that flower at a young age as well as those which develop incompatibility in grafting. For example, Eucalyptus grandis is reported to flower 12–14 months after planting and *E. macurthurii* develops incompatibility signs early after grafting, thereby resulting in high mortality rates among the ramets produced.
- Because it is possible to include more initial parents, the genetic base is broader than in a vegetative seed orchard.
- It is easier to establish, simpler to manage, and cheaper than a vegetative orchard since seedlings, not grafts, are used.
- No grafting or other specialised techniques are required.

The main disadvantages are as follows:

- Progeny evaluation and seed production are difficult to carry out simultaneously.
- The genotypes of the trees within a seedling seed orchard are unknown.
- Genetic gain is not as high as it is in vegetative seed orchards because superior selections often have to be excluded as they fail to produce seed.
- There is a danger that inbreeding may occur.

A number of *E. grandis* seedling seed orchards were established in Southern Africa with open-pollinated seed from selections in "wild" stands initially and later with selections in progeny and provenance trials. These trials were standardised so that each included the progeny of 99 selections/families. The plot size was 2 m x 2 m trees (later 1 m x 4 m row plots) replicated nine times. At two years, all plots of four trees were reduced to two trees (thinned by 50%). At three-and-a-half years, a second thinning reduced each plot to one tree. At four-and-a-half years, the trials were assessed and immediately thereafter rogued by removing the worst-performing 30%

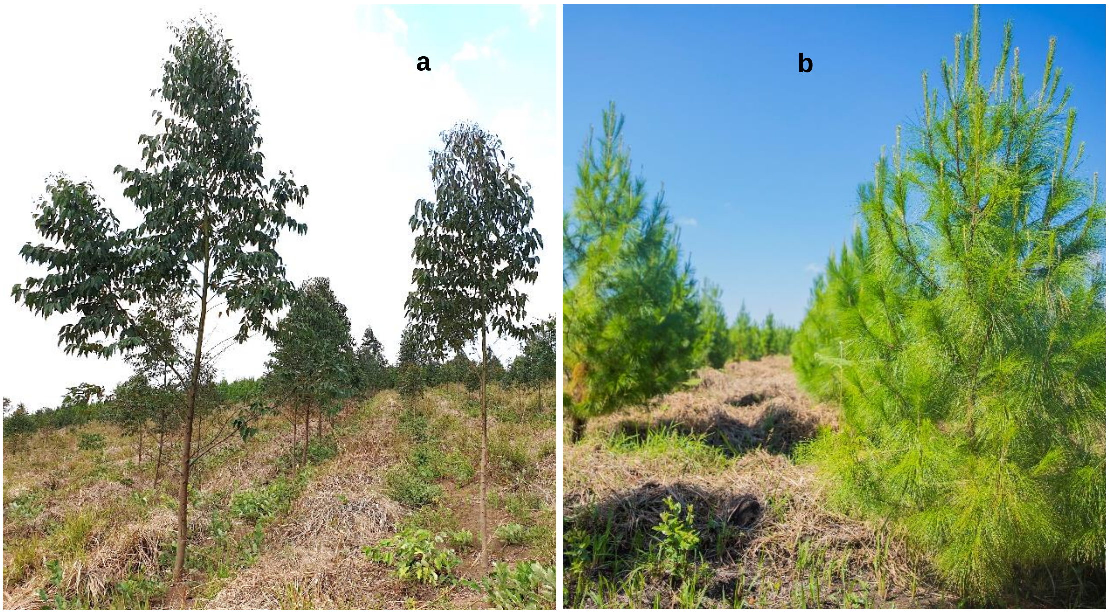
of families. At six years, as soon as the seed crop was mature, the orchard was clear-felled and the seed of each family harvested separately.

A more advanced series of seedling seed orchards was later established using seed from the best individuals of the best-performing families from more than one of the seed orchards established in the first series.

3.3 Seed orchard "generations"

Seed orchards are commonly categorised by generation (first, second, third, and so on), with each named according to how many cycles of improvement (breeding) it has undergone. No matter what kind of orchard is established, pedigree records must be kept to minimise deleterious inbreeding and to help ensure that only the best genetic types are used. A first-generation orchard usually results from selections from natural stands or unimproved plantations, most often by using individual tree selection methods. The pedigrees of the parent trees are not usually known. First-generation orchards are improved by rogueing or removing less desirable genotypes as determined by progeny testing. The removal of trees from an orchard for spacing or health reasons is simply a thinning operation, not a genetic rogueing. Because a first-generation orchard is established with parents whose genetic worth is unknown, the trees are closely spaced to ensure that, even after rogueing, a fully productive seed orchard area remains. Often, 50% or more of the initially established families/clones are removed. If an orchard is not established with optimal spacing and then rogued, there will be large gaps between trees, resulting in inefficient seed production and, because of reduced cross-pollination, poor seed yield and quality.

Figure 3.1 Eucalyptus seedling seed orchard (a) and *P. tecunumannii* seedling seed orchard (b).



4. PRE-PLANTING DECISIONS FOR SEED ORCHARDS

4.1 Rationale for choosing species for seed orchards

The commercial forestry sector in Tanzania is expanding rapidly in all regions with diverse climatic conditions favourable for tree growing, For any investments in plantation forestry to remain competitive and be profitable, it is incumbent upon tree growers of all scales to supply markets with high-quality wood materials which can be processed into various end-products. Species selected for afforestation must have good productivity in multiple sites, be relatively easy to breed for traits of economic value as demanded by particular markets, be relatively easy to manage silviculturally, have high resistance to many diseases, and satisfy market demand by producing the types of wood products required.

To find such species, tree breeders collect seed from many geographic regions, each characterised by different climatic and edaphic factors, thereby enabling them to establish the broad genetic bases they need to make commercial plantations sufficiently adaptable to site conditions and consumer demand and to build resistance against the increase in disease and insect attacks associated with climate change.

Improved seed of the two main commercial species planted extensively in Tanzania, *P. patula* and *E. grandis*, is not readily available to or affordable for growers of all scales. Private and public plantation owners who can afford to occasionally import seed at very high prices, typically USD 800 to USD 1,200 per kg, but these prices are prohibitive for small growers, particularly those in the Southern Highlands. Thus, smallholders plant woodlots and plantations with unimproved material, which, after it is harvested and processed, leads to poor-quality wood-based products. To improve wood quality, smallholders, who annually plant the largest area of forest of any stakeholder in Tanzania, need access to improved seed and technical support in managing woodlots. Thus, an intervention to establish local seed orchards which produce improved seed for sale to all scales of growers at an affordable price makes great sense.

E. grandis and *P. patula* supply the major wood products demanded in local Tanzanian markets, including sawn timber, transmission poles, veneer and plywood, and are the species most preferred for plantation in the Southern Highlands. However, their plantation places the entire industry at risk as both species are currently vulnerable. The pitch canker fungus (*Fusarium circinatum*), which has been a chronic problem in *P. patula* and *P. radiata* nurseries in South Africa for many years, has infected plantation trees in some regions of Tanzania (Coutinho et al. 2007), thereby reducing grafting success, hindering rooted-cutting programmes, and curbing the growth of seedlings of *P. patula*.

Figure 4.1 *P. patula* seedling heavily infested by pitch canker fungus

Similarly, *E. grandis* plantations in warm areas have been devastated by the gall wasp (*Leptocybe invasa*), which forms galls on leaves and twigs, thereby destroying photosynthetic structures and slowing the growth rates of young trees. In severe cases, the wasps kill the trees they infest.

Figure 4.2 ***E. saligna seedling heavily infested with gall wasp at Ifinga seed orchard***

Since the 1980s, many tropical countries have tested other Pinus and Eucalyptus tree species for breeding and conservation programmes. Through that effort, new productive pine species, such as *P. tecunumannii* and *P. maximinoi*, have been identified. Both have acceptable growth rates and are resistant to the pitch canker fungus. In the Southern Highlands, both these pine species have shown the potential to out-perform *P. patula*, particularly on some mid-altitude sites between 1,500 masl and 2,000 masl.

Breeding plants for resistance to pests and diseases is time-consuming and expensive. Hybrid programmes, in contrast, offers a quick response to the emergence of new diseases such as pitch canker. Alternative species such as *P. oocarpa* and *P. tecunumannii*, with their resistance to Fusarium, offer much needed relief when they are hybridised with the fast-growing P. patula (Camcore 2010, Kanzler *et al*. 2012).

E. grandis is under threat from the gall wasp (*Lyptocybe invasa*), but if it is crossed with *E. urophylla*, a tropical species from Indonesia with strong resistance to that disease, the hybrid is extremely productive in good soils at high elevations and in dry soils at low elevations. *E. camaldulensis* is another possibility for crossbreeding with *E. urophylla*. In fact, the disease-resistant properties of E. urophylla help justify planting it in seedling seed orchards for use in hybrid combinations as well as plantation in low-lying areas where moisture levels suffice.

In East Africa, *P. patula* is recommended for planting at altitudes above 1,500 m and *P. caribaea*, *P. oocarpa* and *P. kesiya* at at altitudes below 1,500 m (Dvorak, 2005), but some suggest they are improperly sited (Camcore, 2010). Instead, *P. patula* is recommended for plantation at altitudes above 2000 masl, at lower altitudes, it develops large branches and has only average growth.

Table 4.1 Camcore's recommended altitudinal limits for the optimum growth and seed production of *Pinus* species in East Africa.

Species	Altitude (m)	Seed Production (m)
P. caribaea	1,000–1,200	1,500
P. kesiya	1,000–1,200	1,500
P. oocarpa	1,000–1,400	1,500
P. tecunumannii (HE)	1,100–1,800	1,800–2,300
P. maximinoi	1,700–2,100	1,800–2,000
P. patula	Above 2,000	2,400

4.2 Seed orchard size

The area an orchard covers is determined by the amount of seed needed annually for regeneration purposes. To be certain that enough seed will be available, a plantation usually develops a production capacity in excess of the anticipated need. The area needed will vary by species, location, the availability of seed from other sources, seed needs and costs. The most difficult stage in planning a seed orchard is making a good estimate of the quantity of seed (kg) and the number of seedlings that can be produced in a mature seed orchard of a given size. For species with unknown flowering habits, the orchard planner must make an intelligent guess. Neither the number of cones or fruits or even the number of seeds produced are good guides (Bramlett, 1974). The only real criterion is the number of plantable seedlings obtained per unit area of seed orchard.

Bramlett (1974) devised a system to determine seed potential and seed efficiency, that is, a way to determine how many useful seeds will be obtained relative to the potential per cone. When seed efficiency and the number of cones are known, seed yield can be estimated quite accurately.

The factors which determine the area of a seed orchard are discussed in more detail below.

Species. The amount of seed produced varies with species. Eucalypts, for example, produce more seeds per parent than do pines, meaning they require less area to produce the same number of total seeds. In many countries, *P .taeda* produces many seeds, while *P. caribaea* var. *hondurensis* produces few. Since *E. saligna* does not produce a consistent amount of seed year after year once trees have reached reproductive maturity, sizable orchards are needed to compensate.

Provenance and family differences. Some families/clones produce little or no seed while others produce great quantities. When seed production is low, a special effort has to be made to select highly productive individuals visually from all the seed orchards available and re-establish them in a separate orchard. *P. caribaea* var. *hondurensis* is a good example of a species in which provenance and family/clonal differences have a significant impact on seed production.

Periodicity in seed production. Seed orchards must be planned to produce a desired amount of seed over a given time period, including years of crop failure. Although occurring less often in warm-temperate and sub-tropical climates than in cold-temperate and Arctic climates, periodic seed crop failures do occur. A 20% insurance factor is considered acceptable.

Location. If a seed orchard is located within an environment favourable location for seed production, less area is needed to supply a given amount of seed than if it lies outside such a location. Choosing a good site can be facilitated by having responsible departments promptly supply detailed and timely in-country climatic and weather patterns and updates to users in both the agriculture and forestry sectors. Through the careful selection of orchard sites, gains can be obtained and seed supplied without much investment in seed production areas (Nikles 1984).

Intensity of management planned. The more intensive the establishment and management practices (e.g. fertilisation) to be applied in a seed orchard, the smaller the area required. The seed orchards smallholders establish will have to be relatively large as their management will not be very intensive and risks like fire need to be taken into account.

Use of seed. If a seed orchard is to provide seed for direct sowing, it must produce 10 times the amount of seed needed for planting. When seed is sown directly in planting sites, a lot of seedlings will later be thinned out, leaving only the best. For this reason, seed requirements are very high and cheaper seed than is used in clonal seed orchards is sourced.

Rotation of commercial forests. Short rotations need to produce greater amounts of seed annually than do long rotations. *E. grandis* plantations established for pulpwood production, for example, require more seed than do orchards of the same species established for veneer and sawn wood production because the rotation for the former is 7-8 years and that for the latter, 18-20 years.

4.3 Geographic location

Seed orchards should never be established in environments where plant vigour and seed productivity are jeopardised or where environmental conditions are very different from the area from which the trees were selected. It is advisable to place most seed orchards within the geographic range of the species, but, for some species, seed production is higher and the contaminating effects of foreign pollen fewer when an orchard is located outside that range. That said, locating seed orchards outside their range should not be done without considerable reason.

Even within a species range, seed production and tree precocity vary remarkably. In some parts of Southern Africa, for example, *P. elliottii* and *P. taeda* produce three to four times as much seed per clone per hectare in low-lying warm areas than they do in high-altitude cold areas.

4.4 Specific location

If properly isolated, several different orchards can be concentrated in one location and managed as a unit. Managing such an arrangement is more efficient than managing seed orchards in different locations, but the risk of loss due to natural catastrophes is greater. If centralised seed orchards are established, parent trees must be preserved in clonal archives ("tree banks") in a separate location as insurance against a mishap such as a severe drought or fire.

In locating a seed orchard, the following considerations must be kept in mind:

- Avoid areas subject to frequent natural catastrophes, including fire.
- Avoid areas where communities are in conflict as the future of the investment will not be guaranteed.
- Avoid steep terrain, where fires are difficult to control and where it is hard to introduce the sort of mechanisation of maintenance and harvesting that reduces the risks of injury to field crews and of damage to equipment.
- Avoid areas where destructive diseases or pests are prevalent. For example, in some parts of Zimbabwe and South Africa, large baboon populations have damaged P. taeda plantations.
- Avoid frost pockets and depressions without good air drainage as well as slopes on the edge of plateaux and establish protective barriers to reduce the chance of mechanical damage due to the constant downward movement of cold air.
- Avoid sites near residential areas in order to minimise the risks of trespassing, theft, and damage caused by domestic animals.
- Avoid sites near areas where future developmental activities like housing, roads, and power lines may take place or areas where significant mineral deposits make mining a possibility.
- Avoid sites near plantations, adjacent seed orchards and wild stands and consider the direction of the prevailing winds to ensure appropriate isolation.
- Seek sites with a reliable supply of water for use in fire protection and irrigation if necessary.
- For management purposes, seek sites within easy reach and accessible by roads operational throughout the year.
- Seek sites located near a nursery to ensure good use of manpower and machinery but take care that nursery activities are not prioritised over orchard activities.

- Seek sites with good communications with neighbouring villages and farms to help reduce the risk of fire and disease and to be able to handle such hazards if they do occur.

4.5 Soil condition

Perhaps the most important consideration in the selection of a prospective seed orchard site is soil condition. The appropriate soil type for a seed orchard site varies with the species to be planted. Below are the main characteristics to consider.

Gradient.

Flat terrain that is not subject to flooding is preferable. If an area is hilly, gently sloping land is recommended because steep sites impede seed harvesting and other operations.

Physical condition

Texture and structure: Soil texture and structure directly influence tree development and seed production and must be considered because they cannot be changed. The ideal soil type for most species is one with a deep layer of sandy loam overlaying a friable subsoil such as sandy clay soil as this structure presents the fewest management problems and ensures the best production. These factors directly influence tree development and cone production. The influence of soil texture on seed production is shown in Table 4.2.

As Table 4.2 shows, two seed orchards with essentially the same clonal make-up but grown in different soil types show markedly different results. Despite the three-year age difference, the orchard planted in sandy soil has not achieved even a modest level of seed production.

Table 4.2 A comparison of seed orchard yields for two seed orchard sites with different soil types. *P.taeda* in North America. (After Jett and Hatcher (1969)

Soil type	Age (yrs.) as of 1978	Acres	1974	1975	1976	1977	1978
Fine loamy sand:	12	21	0.0	0.0	6.8	-	2.6
Loamy clay:	12	21	10.0	118.8	42.8	-	50.2

Because soil plays a key role in productivity, it is very important to have soil sample records for all seed orchards. Soil type might well be the key to explaining yield differences in seed orchards of the same species planted in different localities.

The most desirable soil type is one with 30-46 cm of sandy loam overlaying a friable subsoil such as sandy soil. Experience has shown that this type of soil profile results in the fewest management problems and best production.

Soil moisture and drainage: Soil moisture and drainage must be considered because poor internal water drainage reduces growth, delays cone production and results in the premature death of trees. Good surface drainage is also required for the easy movement of both personnel and equipment. The advice of a soil expert should be sought to ensure that there are no problems, or, during the land preparation phase, several soil samples should be taken at a reasonable distance from each other to determine effective rooting depth, pH, organic carbon composition, and other variables.

Chemical condition

Fertility: Soil fertility is not a major factor when locating a seed orchard as fertilisers can be added to obtain the desired levels of nutrients. However, extremely poor sites and low-lying areas (pans) should be avoided because soil moisture is frequently a limiting factor. Extremely fertile sites are also undesirable as they tend to cause an increase in vegetative growth at the expense of seed production.

PH: The optimum pH varies with species, but levels between 5.5 and 6 are usually acceptable and appropriate. Within a certain range, soil pH can be modified.

4.6 Isolation

Seed orchards must be isolated from foreign pollen that has potential to produce viable seed with the seed orchard species. Different methods for achieving isolation, or, if that is not possible, pollen dilution are described below.

Geographical method

A seed orchard can be established within a geographical region where flower receptivity is phenologically out of phase with neighbouring pollen sources. Geographic isolation is possible when pollen distribution is quite limited, as in some insect-pollinated species, or where an exotic species has been introduced on a controlled and limited basis. This method usually accomplishes dilution rather than isolation.

Physical methods

These involve the use of physical barriers of various types to either prevent or retard the introduction of pollen of unknown or undesirable quality into an orchard. Such methods may be applied to individual flowers (bagging), individual trees, or a whole seed orchard. The physical design of a seed orchard and the areas surrounding it is one of the most important methods of pollen dilution available. Where possible, seed orchards should be planted in an area where there is no likelihood of orchard trees crossing with neighbouring trees which may not be genetically improved. It is also possible to use another species which doesn't cross with the seed orchard species as a buffer. For example, monocalyptus species like *E. fraxinoides* and *E. elata* can be used as a buffer around E. grandis seedling seed orchards.

Physiological methods

Physiological methods include the manipulation of a tree to cause the abortion or destruction of its pollen-producing structures. Regulator substances, too, can be used to manipulate the time of pollen anthesis or cause the destruction of pollen-bearing structures.

Even when complete isolation is achieved, material originating from a seed orchard will not necessarily be of superior quality due to the random distribution and recombination of genes. Nevertheless, the more complete isolation is, the larger the proportion of good-qulaity seed can be expected. Records show that total isolation is nearly impossible as pine pollen can be carried up to several thousand kilometres from the nearest stand. Efforts should therefore be directed towards improving the degree of isolation rather than completing avoiding contamination. If the amount of foreign pollen can be reduced to a fraction of the total pollen available for pollination within an orchard, the probability that most pollination will be affected by orchard-produced pollen is enhanced.

Dilution zones are especially critical when establishing advanced generation seed orchards, as pollen from inferior trees can, and will, drastically reduce genetic gain. For this reason, dilution zones must be established between early and advanced generations of seed orchards.

A seed orchard should be established as far as possible from other sources of pollen. Depending upon the species and its distribution within a region, the width of an isolation barrier will range from 150 m to many kilometres for pine and other wind-pollinated species. Particularly within young orchards where pollen is limited, some contamination is expected across narrow isolating barriers, but the mass effect of pollen produced within old orchards will minimise the impact of foreign pollen. That said, some contamination takes place even if an isolation barrier is many kilometres wide. The actual size of the barrier should be determined by practical considerations.

An isolation zone should have either no crops or only low-growing crops. When non-hybridising tree species are planted in an isolation zone, the width of the zone should be 300 m or more to reduce the amount of outside pollen to an acceptable minimum. Having stands of trees in an isolation zone is considered a risk since the turbulence generated above a stand can lift pollen from outside that stand above the isolation zone and propel it into the orchard.

When several orchards of various ecotypes of a single species are located in the same place, an isolation distance of 75 m between them is sufficient. Even when inter-orchard pollination cannot be eliminated, the detrimental effects of contamination will not be serious as all the trees in the orchards are from selected material.

The isolation distance of a seed orchard of an insect-pollinated species depends upon the foraging behaviour of the insect pollinators. Most *Eucalyptus* species are pollinated by bees, so the isolation distance of a *Eucalyptus* plantation should be determined by the management of bee colonies. *E. tereticornis*, in contrast, is partly wind-pollinated and is known to hybridise with other species; thus, its isolation distance should be 2 km if a true-to-type seed orchard offspring is desired.

4.7 Production of grafted plants

During grafting season, rootstocks are grafted using an appropriate technique. Enough surplus grafts for blanking purposes should be prepared.

4.8 Reproductive bud phenology

Female receptivity and the timing of pollen-shed vary greatly within species and between families. A large variation in the abundance of male and female flowers at any one time will influence the contributions of families to the formation of progeny as no family can cross with another family whose flowering time is completely out of synchronicity with its own. Thus, phenological variation affects the genetic make-up of a seed lot. Figure 4.3 illustrates the phenological development of *E. nitens* from stage 1 to stage 4, when capsules are ready for harvest.

Figure 4.3 ***Development of the reproductive structures of E. nitens in a seed orchard.***

The consistent monitoring of and good recordkeeping on phenological developments is crucial in ensuring that good-quality seed is harvested at timely intervals and that corrections can be made in the design of future seed orchards based on information gathered.

4.9 Seed orchard design and clone arrangement

The design of a seed orchard should promote out-crossing among family lines, thereby minimising inbreeding and maximising rogueing flexibility.

To maximise rogueing flexibility, enough families to allow for the complete removal of the poorest 60% to 70% of families should be included in any given orchard block. The larger the number of families present, the greater the genetic gain will be. Having over 100 families provides enough genetic variation to ensure that a seed orchard can adapt to environmental variations, diseases and changing uses of wood. Rogueing flexibility can be increased by avoiding large gaps and tight spots.

Inbreeding in a seed orchard is extremely serious because crosses between two families identical in genotype constitute “selfing”, a phenomenon that must be avoided. Since studies indicate that the majority of pollen that reaches an individual tree comes from its immediate neighbours, related material should not be planted side by side. Planting related families as far apart as possible reduces the chances of inbreeding and increases the likelihood of avoiding inbreeding depression in later generations.

The flowering periods of different provenances of E. globulus differ considerably, a fact which must be taken into account when planning a seed orchard of this species in order to avoid (or foster) flowering synchronicity. The flowering phonologies of all the families which will be included in an orchard need to be clearly understood.

To encourage cross-mating among families/ramets, a randomised design should be used. Such a design can ensure that families that ought to be separated are and that no one family will always occur in combination with the same other family. Such a design is called "repetitive neighbourhoods” (La Bastide, 1967). The number of families used must be sufficient to maintain a minimum distance of about 30 m between the same or related trees. Normally, including about 50 families in any given orchard block suffices. About 50-100 families is commonly regarded as the minimum needed to avoid the bad effects of inbreeding, and many orchards are planted with 60-100 families so that families whose progeny prove to be inferior can be culled.

In his analysis of different seed orchard designs, Giertych (1975) concluded that only random, incomplete block and permutated neighbourhood designs satisfy the two main objectives in a seed orchard: "avoiding selfing and promoting outcrossing”.

Seed orchards designs can be grouped as described below.

4.9.1 Random designs

Random designs are classified as either simple random or completely random (CRD). In a completely random design, all available families are completely randomised among all available planting positions on the site (Figure 4.4). This is the simplest of all designs to plan on paper but it can raise operational difficulties like planting and identifying individual families at a later stage, especially when an orchard is large and contains many families. If systematic thinning is practised by removing certain rows, the design can be further refined by separately randomising those families that are to remain and those that are to be removed.

Quite frequently, however, randomisation is not complete. Instead, it is limited by certain restrictions, like not planting two identical families in adjacent positions horizontally, vertically or diagonally or requiring that at least two different families separate families of the same species. These restrictions are usually imposed by manipulating the positions of the families involved, thus making the design no longer truly random. Such deviations from randomness, however, are seldom relevant.

Figure 4.4 **Example of a completely random design for a seedling seed orchard with 10 families and 4 seedlings per family**

5	3	9	1	10
8	7	5	4	9
6	1	2	6	5
10	3	9	3	2
6	2	7	10	8
4	8	6	7	9
7	2	3	10	1
5	4	1	8	4

Designs can also be categorised as complete and incomplete blocks, as described below.

Randomised complete block (RCBD): In this design, the total area of the seed orchard is first divided into equal blocks, each sufficient in size to contain either all the families of a species being planted or a multiple of that number (in Figure 4.5 there are 10 families randomised in 4 blocks). The family positions within each block are completely randomised and then manipulated to avoid having similar families in adjacent planting positions.

Each block is randomised independently, taking care that any restrictions imposed hold true along the interfaces of the block edges, too. As with the completely random design, this design can be adapted for systematic thinning by applying several randomisations within the same block.

Figure 4.5 **Example of a randomised complete block design for a seedling seed orchard with 10 families, 4 blocks and 4 seedlings per family.**

Bl.1	6	3	1	4	8
	5	10	9	7	2
Bl.2	7	4	8	1	10
	3	6	5	9	2
Bl.3	2	4	8	1	9
	6	7	10	3	5
Bl.4	3	8	9	2	10
	7	5	4	6	1

5. SEED ORCHARD ESTABLISHMENT

5.1 Establishment and management of seed sources

Establishing a seed orchard is a very intensive activity since it influences the success or failure of all future plantations established with seeds from it. Rules and regulations need to be put in place by authorities to minimise the risk of failure.

The basic material for the establishment of a seed orchard must be derived from selected stands, selected single trees (plus trees), progeny trials, or from other seed orchards whose superior quality and genetic variation have been proved by tests like genetic gain trials, in which the quality of improved seed is benchmarked.

The ecological conditions and level of improvement of the provenance material should be known and documented.

Sites should be established where a species best produces seed and there should be seed orchards of a single species distributed across the intended planting range so that the genotype by environment (GxE) interaction can be exploited.

Conditions in a site of plantation establishment should be conducive for the uniform pollination of all the trees planted. Thus, row plantations (hedges) and plantations in areas with extreme climatic influences are not suitable. Seed orchards should have a minimum distance of at least 500 m from trees of the same species and trees of a species with which it can form hybrids.

Seedling seed orchards should be established with at least 1000 genotypes derived from at least 50 different selected mother trees (plus trees/families). At least 100 genotypes should be guaranteed at all stages of a seed orchard.

Clonal seed orchards should have at least 30 clones, each with no less than 20 ramets. The distribution of clones should take into account the future thinning necessary for good crown development as well as the equal participation of all clones in pollination and fertilisation. At least 90% of clones and ramets should be represented at all stages and clearly marked so that they can be identified. to facilitate access and seed collection, the maintenance of seed sources includes weeding and slashing both when a stand is young and may suffer from competition as well as when it is old. Maintenance also includes removing harmful agents and implementing measures to protect against fires, pests, and diseases. A stand must also be managed to ensure free crown development, which increases the number of flowers and consequently seeds by eliminating competing trees and supplying the branches with sufficient light to stimulate flower bud production.

Thinning seed sources other than seed orchards can be done either selectively or systematically. Systematic thinning reduces the number of trees per hectare to stimulate general development and to facilitate future silvicultural measures. Selective thinning reduces the number of undesirable phenotypes and/or promotes good phenotypes by removing competitors. Selective thinning also increases the phenotype quality of the source and promotes the crown development of the remaining trees. Thinning of a seed orchard has to follow a pattern which maintains a high number of clones as well as a high number of ramets per clone so that all are equally represented and removes genetically poor clones determined using progeny trials.

Seed sources are managed to improve the quality of the seed produced. Because tree characteristics are heritable, management involving the elimination of undesirable characteristics improves the genetic qualities of the whole source. Manipulation should not go so far, however, that it risks genetic variation, the most important quality factor within a seed lot.

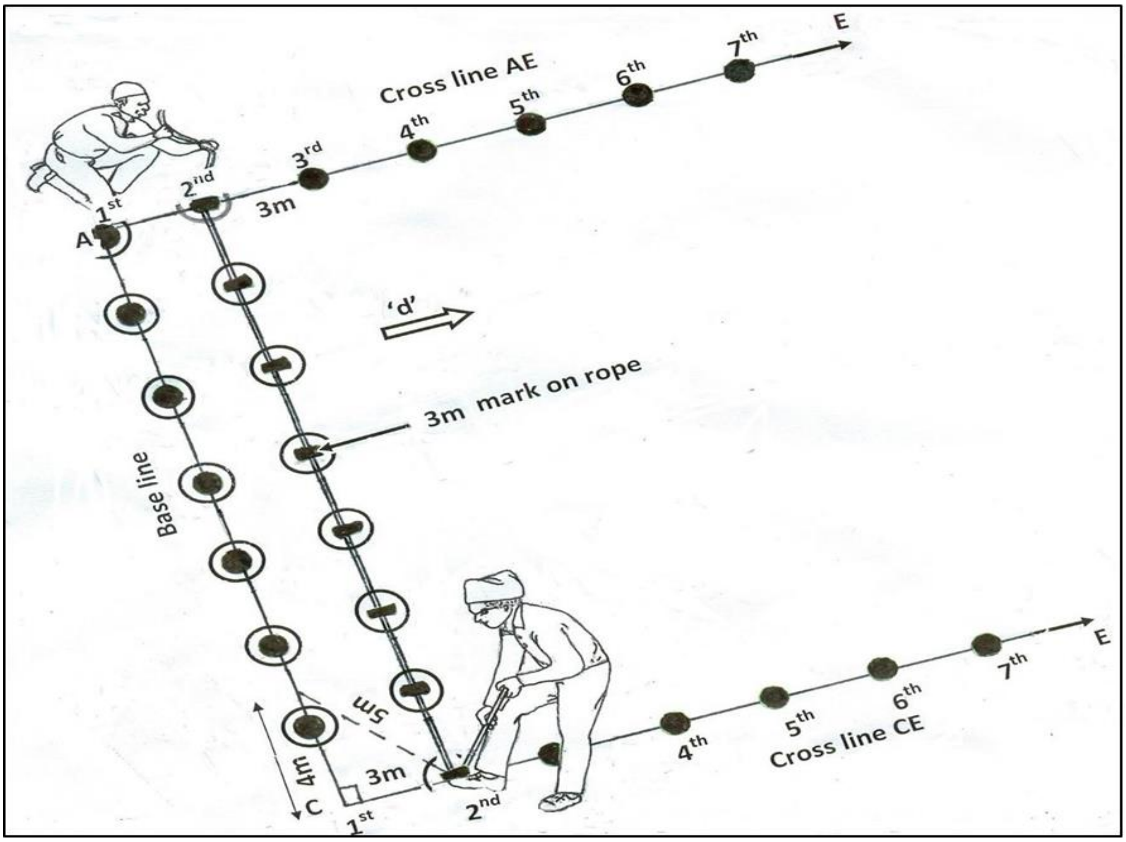
5.2 Site preparation

Since the cost of producing seed orchard planting stock is high, it is essential to prepare sites well and thereby ensure the success of one’s investment. Soil preparation aims to provide optimal conditions for the vigorous root development of seedlings, to improve water penetration and the moisture-holding capacity of the soil, and to reduce competition from weeds and undergrowth. When establishing a seed orchard in highly compacted soil, it is advisable to carrying out ripping (sub-soiling) to a reasonable depth (50 cm) and to harrow before commencing pitting. Ideally, ripping should be carried out just before the beginning of the rainy season (September to October in the Southern Highlands of Tanzania).

Flat areas should be ploughed or, if that is impossible because of steepness or rockiness, the area should be slash and cleared by to prepare large pits and slash and clear the area by hand. This first site preparation will have a beneficial effect on the orchard site for a number of years to follow.

Under strict supervision, pits should be properly dug to a minimum depth of 50 cm and a diameter of 50 cm. Pitting holes need to be accurate to facilitate the numbering of plots so that all the treatment (families) are assigned to individuals plots with equal number of trees per plot according to design with balance number of trees. This operation needs strict supervision from field staff, for any errors in this operation may lead to a delay in or postponement of planting (Figure 5.1).

Figure 5.1 Marking for pitting in a 3 m x 3 m matrix. Adopted from forest plantation and woodlot technical guidelines (MNRT 2017).



It is highly recommended that land designated for seed orchard establishment be ripped and harrowed by tractors before the first onset of rain, preferably in October or November. Later standard silvicultural application should be applied.

Demarcation of the pits must be supervised by a trained research field team, which will have to personally ensure that the pit spacing is consistently correct and that line grids are rectangular or square.

It is the research field team's responsibility to ensure that site preparation is done to the minimum acceptable standards. The team has the authority to insist that site preparation be redone if the first attempt is not to standard. To ensure involvement from the start, field technicians should supervise the laying out of the base line.

Pitting standards to be adhered to:

- Pits should be 50 cm deep
- Pits should be 50 cm in diameter

This operation should be done when the ground is a bit moist, preferably from early rains.

5.3 Planting

Poor survival rates on seed orchards are associated with inadequate adherence to planting standards. A dedicated team needs to be trained for this operation and retained for as long as possible.

The following steps needs to be followed:

- Install temporary plot markers using danger tapes if possible
- Check that all the plots will fit in as stipulated in the design (**NOT** on planting day)
- Transport seedlings, each clearly tagged, to the site
- Place each seedling in the appropriate pit as another assistant ticks it off on a map

Figure 5.2 Eucalyptus seedling just planted and being fertilised using a ring application.

Each seedling should be planted in the centre of the pit allocated to it on the map. It should be placed deep enough that the root collar is just beneath the ground. Row plots with each row having four to eight plants are the most common design. Seedlings should be spaced far enough apart that their crowns can develop fully for long enough to ensure that cone or fruit crops can be obtained for several years before thinning is needed. In the Southern Highlands, seedling seed orchards have been planted at a stocking density of 1,111 stems/hectare, a density assumed to be sparse enough to give trees enough room to develop wide crowns.

Figure 5.3 ***P. caribaea*** **with wide crown flowering at a young age in Uchindile GRL plantation office(a). Note that the spreading of branches for optimum light reception is only possible with widely spaced planting (3 x 3 m). Male caktins full of mature pollen ready for wind dispersion (b).**

The espacement adopted in a seed orchard will vary with the following factors:

Species. Species which flower precociously can be spaced more closely together than those which are slower to start flowering. The crown shape of a species must also be considered. Crowns should always be separate so that trees receive sufficient sunshine and cone and seed harvesting equipment can easily pass between them.

Rogueing. The initial spacing should be close enough that rogueing does not leave large openings. In general, twice the number of trees planned for the production orchard should be planted to prevent the poor utilisation of orchard space following rogueing.

Source of pollen during early orchard development. In pines, pollen production develops more slowly than ovulate strobili production; thus, pollen utilisation is least effective when initial tree spacing is wide.

An initial spacing before thinning of about 3 m x 3 m, or a stocky density of 1,111 stems per hectare, is common for all species. Close spacing improves early seed yields by improving pollination as well as by providing more trees per hectare. How closely trees should be spaced also depends on the urgency of seed needs. Wide spacing is required when trees are fully productive in order to increase seed production. In determining optimal spacing, the type of machinery available for both weed control and harvesting must also be considered.

6. SEED ORCHARD MAINTENANCE

Seed orchard maintenance should aim at the early establishment and healthy development of trees and at the promotion of sustained and regular fruiting. Maintenance is easiest to carry out when seed orchards are located close enough to settlements for attendants to visit frequently.

6.1 Blanking after planting

It is advisable to be prepared to blank a seedling seed orchard at least twice after planting. At two weeks, a survival assessment should determine which seedlings to remove in the first blanking. Then, four weeks after planting, another survival assessment should be undertaken and another blanking carried out. In both cases, records of both the survival assessment and the blanking should be filed safely so that the original stock (family) that was removed is the genotype that is replaced.

Table 6.1 Survival assessment form for blanking

REP	PLOT	FAMILY	TREE	STATUS	COM
1	1	72	1	1	
1	1	72	2	1	
1	1	72	3	0	D
1	1	72	4	1	
↓	↓				
4	400	30	1	0	D
4	400	30	2	1	
4	400	30	3	1	
4	400	30	4	1	

Note: REP = replication; COM = comment

As the above table made following a blanking assessment trip shows, family 72 in replication number 1, plot number 1 and tree pit number 3 as well as family 30 in replication number 4, plot number 400, and tree pit number 1 require immediate replacement. Records such as this should be kept in a seed orchard folder for future reference.

6.2 Labelling replications and plots and drawing final maps

Before commencing with a planting programme, replication boundaries should be demarcated with hazard tape and both plots and replications labelled. Later, this labelling should be replaced with permanent markers (treated poles) labelled with aluminium or steel plates engraved with details about the replication as well as the plot and genotype (family identity). For example, a plate reading "**REP 1 PLOT 1 FAM 45"** is used if Family 45 is the first to be planted in replication number1 and plot number 1.

Figure 6.1 A plot marker made of a dropper (a) and a replication marker made of a creosoted pole (b) installed in a seedling seed orchard.

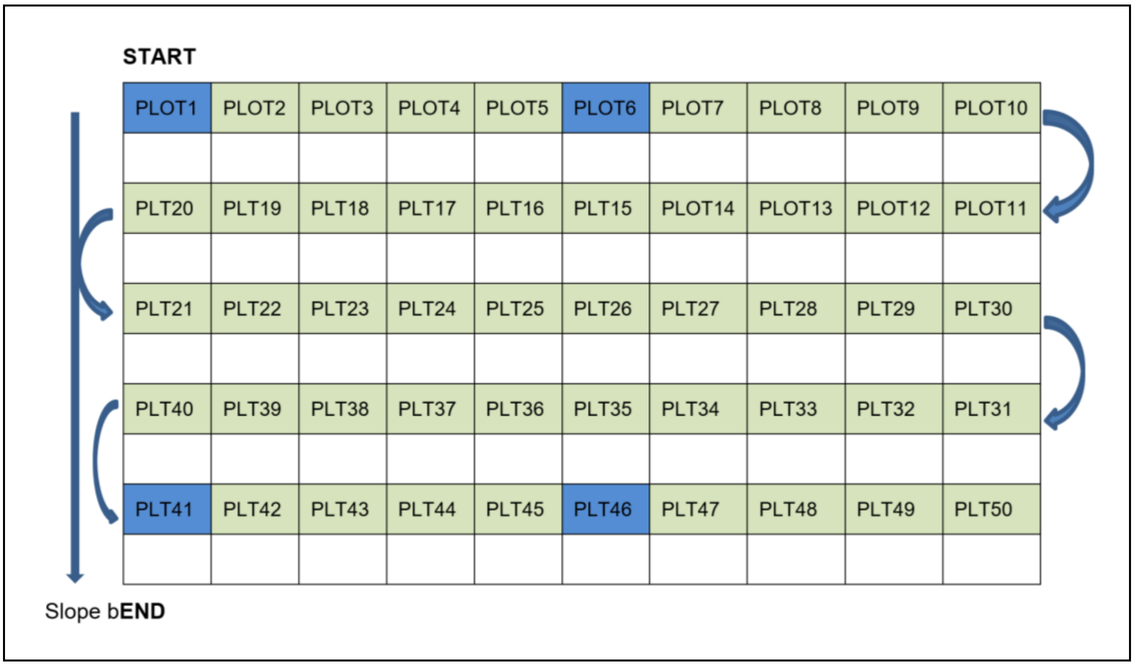
(a) (b)

Replication boundaries should have large treated poles, preferably with a diameter of 12 cm to 15 cm and a length of 1.5 m. Plot markers should be made from droppers with slightly smaller dimensions than those of the replication boundary poles. Maps clearly showing replication layouts, a north arrow, major roads, rivers, and slope directions and aspect should be drawn.

Research technicians must ensure that all seed orchards are properly demarcated so that they won't be felled accidentally and that attendants can orientate themselves within a trial during visits and assessments. Seed orchards planted in TFS plantations should have information readily available at the compartment level and that information should be entered into the TFS management system. Minimum standards for demarcation are:

1. Trial pole and signboard. At plot number 1, tree pit number 1, a large pole (± 10 cm in diameter) must be fixed into the ground with concrete. This pole will serve as a reference point in case plot pegs are stolen. The information to be displayed on this pole using aluminium dymo tape labels is the trial number, material tested, number of treatments and date of establishment.
2. A4-size corner boards must be placed in the corners of a compartment containing a seed orchard to indicate that a seed orchard is present. Also, at the corners of a compartment on village land, a few trees should be marked by spray painting broad bands on them at a height of 1.5 m.
3. Replication boundaries. The demarcation of all replication corners may be done at the discretion of the research technician team by making use of droppers/poles with painted double bands. Once the trees on the replication boundaries are big enough the trees, they must be painted with double bands.
4. Plot pegs. For line plots, a minimum of one peg for every five plots should be used for multiple tree plots, every plot must have a plot peg. Each plot peg must be labelled with an aluminium tag indicating the plot and family numbers as shown in Figure 6.1.

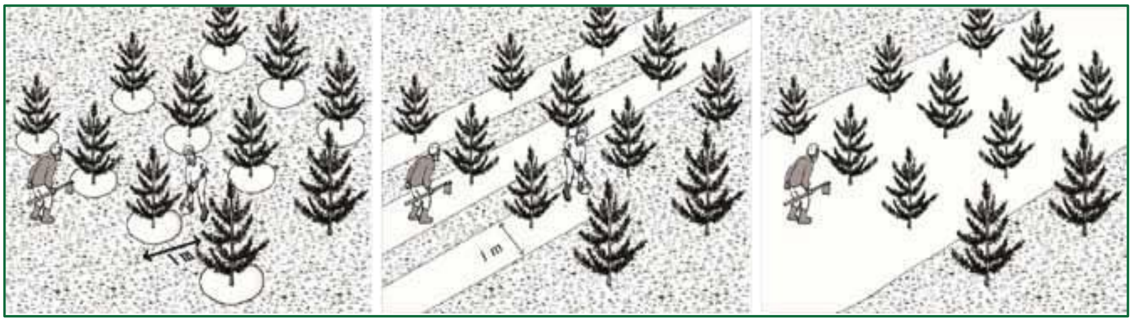
Figure 6.2 Layout of replications and plots used in all seedling seed orchards. Plot markers are in blue and there are four replication poles at the corners.



6.3 Weed control

Ideally, seedling seed orchards should be manually weeded using the complete-weeding technique illustrated in Figure 6.2 below, and manual weeding should be repeated at regular intervals until complete canopy closure is achieved.. *Eucalyptus* species are particularly susceptible to gress competition when young and so need to be clean- weeded for the first 12 months after planting. If there is an overriding need to cut costs strip-weeding followed by the manual slashing of the inter-row band of weeds can also be practiced. Manual slashing usually coincides with the fire season and takes place just before the harvest operation, but even if a seed orchard is not to be harvested, it is important to slash at least once a year. Three weeding practices are illustrated in Figure 6.3.

Figure 6.3 Spot, strip and complete weeding (Adopted from forest plantation and woodlot technical guidelines (MNRT 2017).



Since most orchards are planted within natural areas in order to achieve good isolation, bushes often gradually encroach on their borders and need to be removed. In addition, since the regeneration of orchard trees, especially *P. patula*, occurs both within and outside an orchard, it is advisable to have annual clean-up operations in both places.

6.4 Fertilisation and amendments

Much of the advantage of a tree improvement programme is lost if seed orchards do not produce seed at their potential. Soil-nutrient deficiencies and soil compaction are usually the main causes of reduced yields. Fertilising mature seed orchard trees with nitrogen stimulates and enhances flowering. A thorough investigation should be done to determine the ideal timing of fertilisation for each species. During the planting phase, applying 60 g to 100 g of nitrogen-based fertiliser to each seedling will promote vigorous growth, thereby suppressing undergrowth and greatly reducing the need for weeding.

Fertilisation to increase flowering is a separate treatment from fertilisation to alleviate deficiencies in soil nutrients. Corrective fertilisation is based on annual or biannual soil and foliar chemical analysis and the deficiencies detected.

The use of amendments, such as lime or acid-forming fertilisers, to correct soil pH, is rare. The need for amendment is decided by soil sampling and pH analysis.

6.5 Protection

Seed orchards are essentially monocultures and as such are highly vulnerable to damaging agents; however, they also have characteristics which permit protective measures to be taken easily. The cost of establishing seed orchards is high, as is the value of the crop, so managers usually invest more in their protection than they would under normal plantation forestry for timber production. When orchards are concentrated and intensively managed in one location, constant and close surveillance is possible, and remedial action can be taken quickly. The small area of an orchard, its normally good isolation from the public, and easy access to each tree by motor vehicle all contribute towards safe and effective protection. The availability of trained staff allows for a variety of often sophisticated protective measures to be used.

Insects

Close surveillance for signs of an insect infestation is imperative as a single infestation can destroy over half of all trees and seeds. In particular, insects can cause a lot of problems with the development of seed in *P. patula* and *P. radiata* seed orchards, especially as insect damage exacerbates post-hailstorm-associated dieback in mature trees and increases the likelihood that cones will be damaged by the fungus *Diplodia pinea*. Many methods have been developed to control pests, including manual removal, trapping, and spraying or other application of chemicals. The best method for the control and eradication of any particular pest will depend on both the severity and the extent of the infestation.

Figure 6.4 *Eulachnus rileyi* attack *P. tecunumannii* in the Ukwama village woodlot in Makete (a) and Sao-Hill Div 1 Seed Orchard in Mufindi (b).

(a) (b)

Animals

The consumption of and damage to newly planted seedlings during the first and second years after planting are a problem in areas where wild animals graze and roam. The damage does not affect all species equally. *P. tecunumanii* and *P. oocarpa*, for example, are very susceptible to damage. Bush pigs are known to expose and eat the roots of large *P. oocarpa* and, in sub-tropical zones in Southern Africa, the ring barking of young *P. caribaea* var. *bahamensis* by domesticated goats is a problem. Erecting an appropriate type of fence around a seed orchard for the first three to five years usually provides sufficient protection, as seen in Figure 6.5.

Figure 6.5 Well-fenced *P. tecunumannii* seed orchard at Ifinga plantation at Wino TFS plantation.

Fire

Special attention must be paid to fire protection. Orchard boundaries should be surrounded by 10 m to 15 m fire breaks that are free of flammable vegetation and have short enough grass to ensure mobility in the case of fire. It is also wise to divide very large seed orchards into sections with fire breaks. In hazardous periods, close surveillance is imperative. Equipment, trained personnel and a good communication system are all lessential for fire protection.

In selecting species for plantation, the constraints that smallholder tree growers face, such as fire damage, pest, and diseases, should be considered, and those species which are least vulnerable and which require the least investment should be chosen. *P. elliottii*, *P. tecunumannii*, *P. maximinoi, P. oocarpa*, *P. kesiya*, and *E. cloeziana* are some of the species which, in one way or another, are well placed to address the problems that both small- and large-scale growers in the Southern Highlands currently face. Introducing new species will, with time, address the dominance of *P. patula* and *E. grandis* in the Southern Highland landscape, and make plantations less susceptible to crop losses. Figure 6.6 and Figure 6.7 show seed orchard loss due to fires and fire breaks respectively.

Figure 6.6 **A small section of *P. tecunumannii* seed orchard burnt by fire at Idete/Holo village**

Figure 6.7 ***P. tecunumannii* and *P. maximinoi* seed orchard at Idete/Holo village showing internal and external firebreaks.**

Irrigation

Irrigation is not a general practice in seed orchard management, but, over the years, it has received much attention in the U.S.A. Supporters of seed orchard irrigation argue that the irrigation of young, non-flowering seed orchards enhances tree growth and crown volume and thereby flowering.

However, when trees are well-established, irrigation can be detrimental since excessive watering may lead to an increase in vegetative growth at the expense of seed production. In fact, one flower stimulation treatment consists of exposing trees to a spell of water stress at the time of flower bud development.

Shaping of plants to facilitate fruit harvesting

Some pines do not respond to shaping, whereas others react favourably. Once trees are well established, leaders should be cut back annually to induce branch production. One example is the topping of *P. maximinoi* seedling seed orchards where trees in the Holo and Mugololo village seed orchards planted by the PFP in early 2015 showed signs of forming foxtails.

It is unnecessary to shape eucalypts to facilitate fruit harvesting since trees are cut down every three or four years for capsule harvesting, an approach made possible because of the coppicing ability of the eucalyptus and the persistence of capsules on its branches.

6.6 Growth measurements

This should be a quick operation to test the suitability of the different families planted for their adaptation to the sites. Since it will be done just as the trees begin to achieve canopy closure in the orchard, height growth measured with height rods will suffice. This will only be done once before the first thinning is carried out in seedling seed orchards BUT not in the seed stands at Idete and MPM.

An example of a data sheet from an Ifinga *P. tecunumannii* seed orchard) for carrying out such assessment is presented in Table 6.2.

Table 6.2 Form for growth assessment in seed orchards

Name of the seed orchard: **Ifinga Seed Orchard**

Date of assessment**: 29/10/2020**

Supervisor: **Anna & Team**

REP	PLOT	TREE	FAMILY (Treatment)	HEIGHT (m)	STEM FORM (1-8)	COMMENTS (CODES)
1	1	1	77	9.3	7	FB
1	1	2	77	7.9	7	
1	1	3	77	9.0	8	
1	1	4	77	9.1	7	
5	400	1	100	3.6	3	BT
5	400	2	100	3.2	2	
5	400	3	100	3.4	1	WB
5	400	4	100	3.5	1	

Key for stem form definitions:

Tree status	Code
Forked	FB, FM, FT
Dead	D
Recessive/runt	R
Broken	BT, BM
Multiple stem	MS
Kink	KB, KM, KT

Tree status	Code
Heavy lateral	HLB, HLM, HLT
Wind blow	WB
Butt sweep	BS

B (Base), M (Middle) T (Top)

The ideal time for conducting a growth assessment is during the dry season before the onset of rain.

6.7 Thinning

Operationally, thinning and rogueing are done in seedling seed orchards to improve the quality of the pollen produced by the flowers families. Thinning should ideally be done before the first onset of flowering. Light is fundamental to stimulating flowering and is provided when canopies are opened up through rogueing.

The need to thin a seed orchard is closely linked to the initial planting distance and planting pattern. If an orchard is to be thinned, the espacement of each tree and the distribution of families within an orchard must be planned and designed before planting. When the families established in a seed orchard are progeny-tested, those genotypes that have proven to be genetically inferior must be rogued, and the remaining trees must be thinned systematically to allow for full crop development.

The selection of trees to thin should be based on an analysis of their heights and of independent culling factors based on the physical observations of the team in the field. Diseased trees should be taken out of the seed orchards irrespective of how tall they are.

It is important to keep orchard sites well mapped and marked with treated poles/pegs, so that later thinning or rogueing can occur without wrong identification of treatments/ families.

Seedling seed orchard growth data should ideally become available at 2 to 3 years of age in well managed *Eucalyptus* seed orchards and 3 to 4 years in *Pinus* seed orchards. This information can be used to improve a seed orchard by both thinning and rogueing the poorest quality families based on early growth assessment.

When a completely random design is used to establish first-generation (P_o) orchards of *Pinus* and *Eucalyptus* species, culling should be practiced instead of thinning. The second generations (F_1) of such orchards, however, are specially designed and planted so that when alternate rows are removed, the same number of trees per family are thinned, thereby leaving the family composition of the orchard unaffected.

In deciding whether a tree within a plot should be conserved or marked for thinning (removed), the following points should be considered:

Height

The tree should be having a good/best height relatively to other trees within a plot

Diameter

The diameter of the tree over bark should be the biggest in the plot.

Straightness

The stem should not lean or have any bends. Slight bends may be accepted if the tree is better than its neighbours and destined for seed production. A lean is sometimes caused a tree's attempt to avoid suppression from neighbouring trees and therefore not a huge problem for seed production, a well-trained team can make a collective decision.

Branch frequency

Two or three whorls of branches should develop each year, preferably at even distances apart. Avoid trees which develop only one whorl each year as they will not have enough branches to carry reproductive structures. To find the approximate number of whorls per year, count all the whorls and divide by the age of the tree. This technique is possible with *Pinus* species, especially *P. maximinoi*.

Branch angle

Branches coming out at right angles to the stem are ideal. Avoid trees with very steep branches, particularly those with steep branches competing with the leader. Of course, trees with double leaders and forked trees should not be selected.

Branch length

Avoid trees which have grown very long, closely spaced branches. A tree with short branches growing far apart is particularly attractive.

Cones and capsules

Avoid trees with an extremely large number of cones on the stem at an early age if they have any symptom of environmental stress, like the yellowing of needles and leaves for *Pinus* and *Eucalyptus* species respectively. Excessive cones and capsules can easily be an expression of a dying tree due to some stress due to specific site.

Health

Any sign of a dead top or die back is enough to eliminate a tree within a plot. Avoid a thin crown of light green needles, (fox tailing), a characteristic common in *P. maximinoi* and *P. tecunumannii* at MPM and Idete.

Space

Consider the space the tree has for growth. Are trees missing around it which will show a tree has an unfair advantage over those with all neighbours intact. Buffer trees are not used in thinning operations in well-designed seed orchards but can be used for seed collection once there is excessive demand for seed.

Self-pruning

Choose trees whose branches dehinge clearly and close to the stem rather than those than leave long dead stubs which will later result in large dead knots in boards made from those trees. A "clean" stem with few knobs and branch stubs is usually an indication that the tree is a good "self-pruner," a desirable characteristic.

Internal spirality

Internal spirality is sometimes indicated by the appearance of longitudinal fissures in the bark which also appear to "twist" around the bole. These bark fissures do not run parallel with the main axis of the hole but at an angle to it. Avoid such trees.

6.8 Marking for thinning

Using white paint, paint a band around the stems of trees to be removed at breast height. Mark these trees on the orchard map and file it in the seed orchard folder. Thinning needs to be taken before felling operation otherwise the field team will be under undue pressure and mistakes may creep in.

6.9 Rogueing

Rogueing a seed orchard involves the complete removal of all families proven genetically inferior in a progeny test. A well-chosen seed orchard design will maximise rogueing flexibility. Therefore, the principle of rogueing only applies to seedling seed orchards planted with families (parent) materials being tested in progeny trials. Seed stands established from bulk seedlot can only undergo intensive thinning since parental identity is unknown.

Families susceptible to disease or deformity must be culled or removed. Families that do not produce large numbers of cones or large amounts seed should also be culled. A natural culling process also takes place continuously within most seed orchards as families whose genotypes are not suitable for the site die.

The intensity of rogueing is determined by the genetic gain desired in the seed orchard and the amount of seed expected from it. If a large genetic gain is to be obtained, the intensity of rogueing must be high. However, some genetic gain must be sacrificed for the sake of seed yield, since the elimination of several families or clones will reduce seed production.

6.10 Record keeping requirements for seed certification

Recordkeeping documents an orchard’s performance and thereby gives insight into its productivity and into corrective actions that should be taken if a problem develops. Records of importance include the following:

- Previous crops and types and dates of land preparation.
- Planting dates.
- Survival assessment and blanking dates.
- Weeding and thinning dates.
- Age at first flowering.
- Months of flower production and level of flowering.
- Weather records and historical data (to aid in the management and planning of future orchards).
- Fertiliser rates, formulae, and dates of application.
- Irrigation quantity, frequency and dates (to aid in establishing the relationship between flowering and seed production).
- Insect and disease management records.
- Silvicultural treatment records.
- Records of adverse environmental conditions such as droughts, hail damage, high winds, floods and heavy rains. The effects these events have on both flowering and seed production should also be noted.

7. SUPPLEMENTAL MASS POLLINATION AND POLLINATION MANAGEMENT

Supplemental pollination is a method of pollen application that can be used when pollen of known genetic quality is easily obtained in bulk, which is the case for most pine species. It includes a variety of procedures, all of which involve the application of pollen to trees without the use of physical isolation.

Before these procedures are discussed, it is necessary to consider the characteristics of an ideal seed orchard with regard to pollination management:

- The individual trees of each family are well isolated from unselected trees in the surroundings, especially if those trees are of poor genetic quality.
- Trees within a family are all equally productive of pollen and female flowers.
- Periods of pollen dispersal and female-flower receptivity coincide.
- Crosses among families are equally compatible.
- Natural self-fertilisation occurs at insignificant rates.

Seed orchards do not usually exhibit all the above-mentioned characteristics. In fact, the frequency of self-pollination within the crown of seed orchard trees is often high, a fact that significantly reduces seed yield. Since deviations from an ideal seed orchard frequently result from the lack of pollen production or from uneven pollen distribution, supplemental pollination can increase seed yield considerably. This technique is useful in the following ways:

- In a young seed orchard where female flowers are produced before enough pollen is available, these flowers can be mass pollinated with the pollen of selected trees and improved seed can be obtained when the orchard is still young.
- Mass pollination reduces the chances of fertilisation by pollen with an undesirable background and increases the amount of seed obtained.
- Even if natural pollen production within an orchard is abundant, supplemental pollination can more than double seed yield.
- Supplemental pollination also reduces the incidence of selfing in an orchard, particularly when female-flower receptivity and pollen release are synchronised.

Supplementary mass pollination techniques are simple and straightforward. With a simple pollinator, equal quantities of pollen from selected genotypes are mixed and dusted onto all receptive flowers in an orchard. The success rate of supplemental mass pollination is directly affected by the amount of pollen produced by the seed orchard trees (the competing pollen cloud density), the timing of the application of pollen, and the quality (viability) of the supplementary pollen.

Supplemental mass pollination is not possible in *Eucalyptus* seed orchards except, perhaps, in plantations of the few species, like *E. tereticornis*, that are wind pollinated. *Eucalyptus* has preferential out-crossing mechanisms, so emasculation is not necessary to obtain a majority of cross-fertilised seed.

It is possible to have some indirect control over natural pollination, too. Most pollination within a *Eucalyptus* seed orchard is done by bees, so, in those cases where orchards are not well isolated, a seed orchard can be provided with beehives to prevent bees from carrying in foreign pollen. In addition, families can be planted within a seedling seed orchard to promote cross-pollination. The fact that bees forage within a restricted area and repeatedly visit the same area suggests that trees should be placed close to one another, perhaps in clusters or closely spaced rows.

Information from controlled pollinated progeny tests—if it is available—can be used to determine pollination strategies for outstanding specific combinations. Because through analysis of the data gathered, outcrossing and selfing levels in an orchard can be determined for species involved on specific sites.

Parents with high specific combining abilities can be planted in pairs or even clustered in groups of three or four individual trees. Branches can intermingle, and the pairs or clusters will provide a restricted area that bees will consider as "one tree" and revisit during consecutive trips.

8. SEED HARVESTING FOR PINUS AND EUCALYPTUS SPECIES

8.1 Cone and capsule maturity

Key to ensuring an efficient cone harvest is recognition of cone or capsule maturity. Harvesting mature cones/capsules will do much to promote the proper opening and extraction of high-quality seed. If cones/capsules are harvested while immature, they will fail to open properly, seed yield will be reduced, and seed viability and quality will be diminished.

To check pinecone maturity, field technicians should bend a freshly picked cone in their hands to see if it "cracks". This method has been found to give a good indication of ripeness.

A weekly to daily inspection of seed orchards to test for maturity is necessary, especially if those visits are arranged during the known harvesting period for a particular species.

As seeds of pines mature, the specific gravity of the cones decreases because of water loss. This change provides one of the most reliable tests for determining the ripeness of a cone. A flotation test using SAE 20 motor oil provides a good ripeness test. If the cone sinks or lies suspended near the bottom of the container with one end touching the bottom, it is considered too green to harvest. Experience regarding the month of cone ripeness for different species serves as an aid to judging maturity. The following pine species grown in southern Africa should be used as a guide for scheduling harvesting in Tanzania Table 8.1.

Table 8.1 Seed harvesting schedule for *Pinus* species in Southern Africa

Pinus species	Approximate harvesting months (Zimbabwe Forestry Commission)
Pinus caribaea var. *hondurensis*	Jan – Feb
Pinus oocarpa	May – June
Pinus tecunumanii (LE)	May – June
Pinus patula	Aug – Sept
Pinus kesiya	July – Aug

Eucalyptus species the other hand, can be harvested of mature seed throughout the year. This is because *Eucalyptus* retains its seed for a number of years and will only release that seed once it has been harvested or if the branches still on the tree die, a common problem found in the older *E. grandis* seed orchards. The flowering of *E. grandis* may be affected by differences in climate and height above sea level.

For species like *Eucalyptus*, seed does not need to be collected every year. *Eucalyptus* capsules remain closed on a tree and are not shed until the branch to which they are attached dies. Thus, it is possible to phase harvesting cycles by dividing a seed orchard into three or four blocks, depending on the annual seed requirement and seed production of each block. If, for example, the area of a seed orchard is twelve hectares and enough seed is harvested annually from just four hectares, then the orchard could be divided into three blocks of four hectares each. This division will result in the felling and harvesting of each four-hectare block every third year. This is a very efficient technique as tree climbing is avoided, and the wastage of seed is minimised.

8.2 Cone and capsule collection

Pine cone collection

Using specially designed "forked sticks," climbers perform all of the harvesting operations. Use of mechanical equipment such as tractor-mounted platforms and hoisting equipment will not be successful and is uneconomical compared to climbing and hand-picking using ladders, tree bicycles and tree spikes. Each labourer may be given a specified task, for example, to collect 6–12 hessian bags of cones depending on the height of the trees in the orchard and the availability of the cones that fall down after being knocked off. Not all species have the same ease of cone harvesting.

Cones must be collected and stored in hessian bags. Plastic fertilizer bags and woven plastic bags should be avoided as they do not breathe. The resultant rotting of cones drastically reduces the amount of viable seed. Roughly, a standard hessian bag of cones of any species produces one kilogram of clean viable seed. Thus, if 44 kg of seed is needed, 44 bags of cones needs to be harvested and the field team assigned to seed production must ensure this outcome.

Eucalyptus capsule collection

Capsules can be collected from standing trees by climbing the trees and hand-picking the capsules or by felling trees and collecting capsules on the ground. The advantage of felling trees is that all the seed from a tree can be easily collected with little seed loss. By felling trees, a team can harvest approximately 25 kg of capsules per day.

E. grandis, a dominant species in Southern Highlands fortunately retains its capsules and does not release its seed as long as a branch is living and gets enough light. Thus, seed that developed three or four seasons earlier can simultaneously be harvested with more recently formed seed, depending on the demand. Inner and lower branches that do not receive enough light and die need be cut off and harvested at least twice a year. Experienced supervisors will tell harvesting teams/contractors when to remove some lower branches which receive no adequate light specifically for *E. grandis*.

8.3 Cone and capsule pre-drying

Cone pre-drying

A covered pre-drying shed is essential for pre-curing cones before extracting their seed. This building is designed to be well ventilated. The bags of cones collected in the field are carried from the lorry that transports them to the shed, where they are are easily stacked in single layers on the shelves and left for three weeks to one month to cure. A cured cone is much lighter than a fresh one due to the loss of moisture and starts to open. Care should be taken each batch of cones on every shelf is documented to avoid confusing them with other batches that are drying simultaneously.

Capsule pre-drying

To pre-dry *Eucalyptus* seed a well-ventilated drying shed with mesh- and solid-bottomed wooden trays is needed. The capsules are evenly spread on trays with mesh bases and then those trays are placed on top of the solid wooden trays and left to dry. Depending on weather conditions, it should take the capsules from three to seven days to dry and release the seed. The two trays on top of each other are shaken so that all the loose seed falls out and through the mesh and is collected in the lower tray.

8.4 Seed extraction

Cone extraction

The drying kilns available control air moisture and temperature, shortening the handling time needed before the release of seed. Once the cones are cured, they are placed into kilns and left overnight at 38 degrees Celcius. The coal-operating kilns can usually process 90 bags of cones per night (90 kg of clean seed). A bag and a half of cones is sufficient for each tray, as if there are too many, when the cones open and expand, the overflow of cones could cause seed loss to occur.

Other options for seed extraction machinery for consideration are the following:

i. Conveyor belt system cone tumbler, which tumbles the cones as the leave the kiln, facilitating the release of all the seed from the cones.

ii. De-winger: A rotating drum where the seed is separated from the attached wing using a strong air current.

iii. Seed separator: The light, empty seed shells are separated from the heavier, viable seed.

These three machines can be locally designed and constructed to suit extraction needs and are very efficient in accomplishing extraction. A four-man team will have to clean a kiln full of cones and re-pack the kiln on a daily basis. The empty cones are then left lying outside to weather and rot for three years before being hammer-milled and used for nursery medium. It is specially good for the grafting of rootstocks. A seed extractor machine is shown in Figure 8.1.

Figure 8.1 Seed extractor from harvested cones.

Capsule extraction

One of the most important precautions to be taken during seed extraction is to keep the dry. If they get wet as a result of rain or dew, they must be allowed to dry out on wire mesh for 3 days day in order to avoid "arrested germination," which reduces viability. Factors that influence the harvesting rate include weather conditions and the availability of drying trays. Harvested *Eucalyptus* capsules are shown in Figure 8.2.

Figure 8.2 Ripe *Eucalyptus* capsules harvested for seed processing

8.5 Storage and transport of seed

The seed is stored in hessian bags before being transported to a seed storage facility. The bags must be kept off the ground and under cover and never over-stuffed as experience has shown that seed coats are inclined to crack during transportation if bags are tightly packed. The optimum weight for pine seed is 50 kg of seed per bag. Full bags of seed must never be left on cement floors as the bags will sweat and the moisture can penetrate the bottom layers of seed and cause fungal growth.

Eucalyptus seed can usually be transported in smaller linen bags, but, like pine seed, it must not be overly compressed.

For safety, each bag of pine seed is sown into a second bag before it is transported. The identification of the seed source and stock number on and inside the bag is very important. Figure 8.3 shows *P. caribaea* cones being processed.

Figure 8.3 *P. caribaea* cones being processed

8.6 Registers

All the seed harvested must be noted and the records kept in a register. Every seed source must be allocated an individual stock number so that allseed orchard trees can be traced back tracked to the original seed orchard, family, replication and plot.

9. TIMING SEED MATURITY AND HANDLING TO AVOID PESTS AND DISEASES

9.1 Seed maturity

As an embryo develops, its seed coat begins to harden and a food reserve starts to accumulate in the endosperm. Seed moisture content drops slowly with the accumulation of dry mass following dehydration. This change is accompanied by colour changes and the development of a sweet scent to attract seed dispersal agents. In recalcitrant seeds, however, ahigh moisture content is maintained even at maturity in order to ensure that desiccation-sensitive embryos and tissues are not exposed to moisture stress.

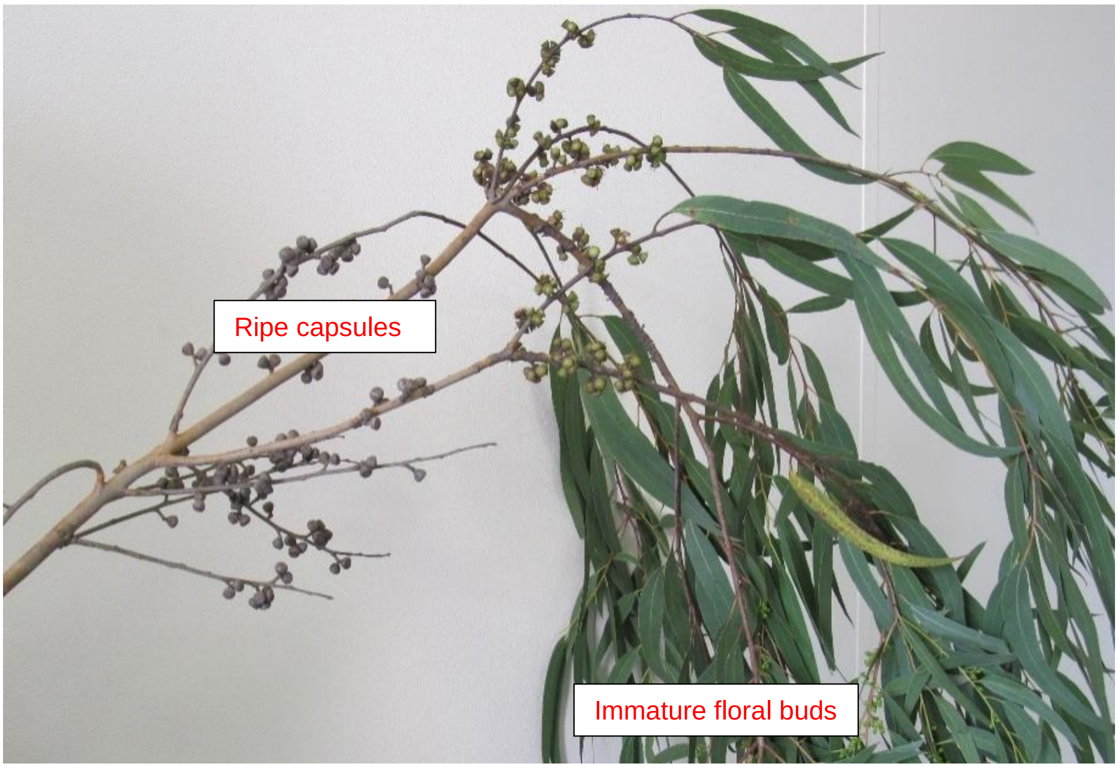
A seed is considered to be mature when it achieves its maximum potential to germinate and produce a normal, vigorous seedling. The exact time when this occurs is difficult to predict but can be estimated by visual and simple tests. The interval between flowering and seed maturation varies greatly within species and depending on growth conditions. A mature angiosperm seed usually consists of a seed coat, endosperm and an embryo. However, there are exemptions. For example, like a gymnosperm, *G. robusta* has no endosperm and stores the bulk of its food reserves in its cotyledons.

9.2 Visual seed maturity indicators

Visual seed maturity indicators include the following:

- Firmness of embryo and endosperm.
- A colour change from green to yellow and/or orange and/or brown/black/purplish fruits.
- Dehiscence of pods or cones.
- The hardening and drying out of seeds.
- Visibility of embryo.
- Abscission (seeds/fruits start falling from the crown).
- Softness of fleshy fruits such as berries.

Figure 9.1 Eucalyptus fruits from three successive years on the same branch. Note the colour change from light green immature floral buds to dark grey mature capsules ready for harvest.



9.3 Physiological maturity

Physiological maturity is accompanied by the following changes:

- Increase in size and weight.
- Accumulation of dry matter.
- Development of essential structures (hypocotyl and epicotyl).
- Reduction in moisture content.
- Increase in seed vigour, viability and storability.
- After maturity, seeds deteriorate due to natural ageing, destruction by pests and diseases and abscission. Their dormancy also increases.

9.4 Timing

Timely detection of cone or capsule maturity is key to ensuring an efficient harvest and a good seed yield. If cones or capsules are harvested when they are immature, seed release will be hampered, and seed viability reduced. On the other hand, if fruit collection is delayed, seeds will be shed, and the yield will be poor. Weekly to daily inspections of seed orchards are necessary to test for maturity.

One method of checking for pine cone maturity is to bend a freshly picked cone in one's hands to observe if it "cracks." If it does, it is ripe and can be harvested immediately. As the seeds of a pine cone mature, the specific gravity of the cone decreases due to moisture loss. This change provides a reliable test for determining the ripeness of a cone. A flotation test using SAE 20 motor oil is another good test. If a cone sinks or lies suspended near the bottom of a container of oil, with one end touching it, it is considered too green to be harvested. If it floats, however, it is considered ripe enough for collection.

Experience is also a good guide to judging maturity. Table 9.1 indicates the months in which the cones of various pine species are normally harvested in different countries.

Table 9.1 Usual harvest times of cones of pine species in different countries (Camcore, 2009).

Pinus patula:

Country (Location)	Latitude	Altitude (m)	Harvest season
Uganda (Mafuga)	01^0 45'N	2160	February
Tanzania (Kihanga)	08^0 25'S	1820	May–August
Tanzania (Matanana)	08^0 25'S	1400	May–June
South Africa (Mondi)	25^0 10'S	1120	July–August
South Africa (PG Bison NE Cape)	31^0 14'S	1400	June–July
South Africa (Sappi Pine Woods)	29^0 39'S	1400	June–July

Pinus tecunumannii (low):

Country (Location)	Latitude	Altitude (m)	Harvest season
South Africa (KLF Sabie)	25^0 10'S	1120	May–June
South Africa (Sappi Mavuya)	28^0 31'S	50	June–July
Zimbabwe (Mukandi)		1600	May–June

Pinus tecunumannii (high):

Country (Location)	Latitude	Altitude (m)	Harvest season
South Africa (KLF Sabie)	25^0 10'S	1120	May–June
South Africa (Sappi Mavuya)	28^0 31'S	50	June–July

Pinus oocarpa:

Country (Location)	Latitude	Altitude (m)	Harvest season
Uganda (Katugo)	00^0 22'N	1120	October–December
Uganda (Lendu)	02^0 30'N	1650	July–October
Swaziland (Sappi)	26^0 52'S	1050	July–August
Zimbabwe		1290	July–August

Pinus caribaea var. hondurensis:

Country (Location)	Latitude	Altitude (m)	Harvest season
Uganda (Nyabyeya)	01^0 45'N	1066	January–February
South Africa (Mondi Sabie)	25^0 10'S	1120	January–February
South Africa (KLF Zululand)	28^0 23'S	72	February–March

Pinus maximinoi:

Country (Location)	Latitude	Altitude (m)	Harvest season
South Africa (Sabie)	25^0 10'S	1120	November–December
SKCC (Cabuyerita)	02^0 31'N	1810	October–November
CAMCORE (S Juan Sac)	14^0 41'N	1600	April–May
Zimbabwe		1260	November–December

Other pine species in Southern Africa:

Pine species	Harvest season
Pinus elliottii	March—April
Pinus taeda	May—June
Pinus kesiya	July—August

With *Eucalyptus* species, in contrast, mature seed can be harvested throughout the year. This is possible because Eucalyptus retains its seed for a number of years and only releases it after harvesting or the branch that it is on dies. Seed may also be shed from branches that receive little light, which is a common problem in older *E. grandis* seed orchards.

9.5 Seed pathology and seed-borne diseases

Although there are abundant fungal and bacterial flora on the seeds of planting stock, the fact that a seed is contaminated does not necessarily mean that the resultant plant will be diseased. For a pathogen to be able to attack, environmental conditions also have to favour it.

Fungi

Fungi constitute the largest and the most important group of plant pathogens. Both saprophytic and pathogenic fungi are associated with seed, but, whereas saprophytic fungi are not specific to any particular host, pathogenic fungi are normally confined to a limited range of hosts. Both types may occur on the surface of a seed or inside its seed coat.

A fungus may occur on seeds as spores or as mycelium that does not endanger the seed coat but merely adheres to it, its future closely staked to that of the seed. Alternatively, a fungus might occur in association with a seed, not carried on it but accompanying it. Such a fungus will infect the seedling when the two are sown together. Finally, a fungus may be dormant mycelium within the internal tissue of a seed.

The control measure to apply will depend on the significance of the fungal pathogen for a seed, which in turn depends on how the fungus presents itself.

Three main types of fungi affect seeds:

Field fungi: These invade seeds either during flowering and seed development or after harvest but before processing. They are carried from the field to the store by the seed. Typical examples are *Alternaria, Cladosporium*, *Epicoccum* and *Fusarium spp*. They discolour and reduce the germination of seeds and, in most cases, cause disease in seedlings. These fungi remain dormant during storage because they require high humidity to develop.

Storage fungi: These develop in storage and do not require free water. They can be carried into the store either as surface contaminants or on seed coats. They develop at high temperatures and humidities. They are saprophytes and include *Penicullum* and *Asperigillus spp*. Most storage fungi cause seeds to deteriorate not only by invading them but also by producing toxins that destroy the seeds they subsist on.

Saprophytic fungi: These exist on all seeds and do not cause plant diseases. These spores occur on seeds, on equipment, and in storage and will germinate and grow profusely any time the storage environment exceeds 75% relative humidity and about 15 °C. Common species in this category are *Mucor* and *Rhizopus.*

Bacteria

Most pathogenic plant bacteria are bacillus, which multiply very rapidly under ideal conditions. The bacteria enter plant tissue passively, i.e. they don’t grow into it. Most kill plant cells and rapidly cause the soft rot of seeds. In growing plants and seedlings, bacteria cause wilting by destroying translocation (xylem and phloem) tissues. Bacterial infection and spread are more prevalent at high temperatures and in wet conditions than at low temperatures and in dry conditions.

Viruses

Viruses require a wounding agency to enter plant tissue and vectors to move from one place to another. They multiply in living cells and interfere with plant metabolism. The effects of viral infections include stunting.

Seeds that carry disease agents are important for the following reasons:

- Infected seeds may fail to or be late in germinating or cause seedlings to die or have reduced vigour
- Infected seeds may be a source of inoculum, which, under suitable conditions, may trigger disease at a later stage of plant growth, resulting into reduced growth rates, low productivity, and poor-quality products
- Infected seeds can introduce pathogens into new areas
- In most cases, the impact of seed-borne transmission pathogens depends on the age of the seeds since pathogens have different longevities and can lose viability before seeds are sown. Some pathogenic fungi, like *Fusarium circinatum*, lower the viability of seeds during both in storage and germination.

10. SEED QUALITY CONTROL AND TESTING

10.1 Quality control

Seed quality control is essential in providing consumer protection regarding purity, germination capacity, genetic integrity and freedom from diseases. It also aims to ensure that users are provided high-quality seeds. Good-quality seed is a product of specialised selection and handling. The excellent physiological status of seed at maturity must therefore be maintained during processing and storage.

Concept of total quality

The ability of a seed lot to be stored and germinated to produce usable seedlings and the degree to which the genes in a seed lot represent the genes in a natural population or selected populations in a seed orchard are the main focuses of seed quality.

The principles of seed orchard and source establishment, development and identification must be observed correctly in the initial stages of seed orchard establishment in order to guarantee the integrity and quality of that orchard. This means that the material used to establish a seed source must be high quality. If the source is a natural one, individuals from which seed is collected must be properly assessed to ensure that they meet acceptable standards in terms of health, form, vigour and other desirable traits of economic importance that are likely to be transmitted by their seeds.

Seed produced from a large number of families or individual trees ensures a wide enough genetic base to provide assurance against natural disasters (pests and diseases, drought, frost damage, and the like). Production from a few or closely related individuals, in contrast, could artificially narrow the genetic base, thereby leading to the loss of advantageous genes, the accumulation of recessive genes, reduced vigour and genetic instability. All these aspects should be borne in mind whenever activities for seed production are carried out. It is ideal to use only live seeds, so factors that could indicate their negative physiological state must be taken into account during the production process. At all levels of handling, seed must be treated in a fashion that ensures that it will retain its viability until the time it is sown. Seed lots with a low germination capacity are useless and unfit for storage.

Seed is usually at its highest potential when it attains physiological maturity, i.e. when it is at its maximum dry weight. At this stage, the seed is at its maximum vigour, the state best suited for sowing. Beyond this stage, ageing and reduction of vigour commence and proceed at a rate determined by environmental conditions. Timely harvests are therefore important to avoid the premature low vigour of seed due to age.

It is important to consider the health of mother plants and the manner of harvest. Most plant diseases are caused by fungi, which prefer warm moist to cold dry conditions for survival and reproduction. Diseased plants should be removed from a seed production unit or orchard as soon as they are identified. Thus, field inspection and continuous surveys are important exercises. Alternatively, to reduce the need for field inspection, harvesting should be carried out during dry seasons or times of the day when the risk of fungal infection is low. When seed processing requires wet methods, seeds should be dried immediately to a desirable level of moisture to avoid invasion by fungi.

10.2 Standard seed testing

Seed testing aims to establish the physiological quality of seeds. Seed testing is the science of evaluating seed quality for sowing purposes. Ideally, no seed should be sown until its quality is known. Quality is itself a composite of many factors, all of which contribute to the desirability and sowing value of any given lot of seed.

The essence of seed testing is to apply reliable methods that ensure uniformity and reproducible results. In addition, the standardisation of procedures is essential both for trade and for quality assurance. Methods developed by the International Seed Testing Association (ISTA) have been adopted by many countries and laboratories.

Sampling

A sample is a small but true representation of an entire seed lot. It is obtained by reducing a large quantity, say a 60 g composite sample obtained from a seed lot to a smaller quantity, say a 15 g working sample. At every stage, homogeneity should be improved through mixing. Sample sizes grouped according to seed size are shown in .

Table 10.1 Sample size of seed testing according to seed size

Approximate no. of seeds/kg	Sample size for the determination of:	
	Purity/weight (g)	Moisture content (g)
>1,000,000	5	15
500,000 -1,000,000	5	15
250,000-500,000	5	15
100,000-250,000	10	15
50,000-100,000	20	15
25,000-50,000	40	15
10,000-25,000	100	15
5,000-10,000	200	15
2,500-5,000	400	15
1,000-2,500	1,000	15
500-1,000	2,000	15 g or 25 seeds
250-500	5,000	25 seeds
<250	10,000	25 seeds

Seed purity

Even though seeds are cleaned during handling, a seed lot often contains impurities. Pure seeds are those of the species under consideration. They include all pieces larger than half the size of an average seed. All seeds of other species; pieces less than half the average seed size; and inert matter, including twigs, wings, leaves, soil, broken fruit pieces, legumes and conifer seeds with no seed coat, have to be moved. Since other seed tests are conducted on pure seeds, the purity of a seed lot must be determined first. Purity analysis gives the percentage by weight of pure seeds in a seed lot.

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

The purity percentage plays an important role in determining the amount of seed required for planting.

10.3 Utilisation of seed testing results

The results of a seed test should help in decision-making. Most results are reported as data, which need to be interpreted to determine whether a seed lot is bad or good in terms of the minimum standards admissible. To decide, standards (where they exist), data from similar organisations, and accumulated experience is helpful.

11. SEED DOCUMENTATION

11.1 Introduction

The major objective of a seed supplier is to supply high-quality seed, and the documentation of a seed lot is important in defining its quality. Even a physiologically high-quality seed lot may not achieve its potential if an error in its documentation means it is used in the wrong environment. The bedrock for proper documentation is laid in the field, where the whole seed production system rather than any one particular seed lot *per se* must be well documented.

11.2 Why document seed production

As the documentation of a seed lot is a mark of seed quality, disclosing the attributes of a seed lot makes its quality evident. Good documentation informs suppliers and users exactly what they are dealing with, from the name of the species to the source of the seed to the results of seed testing.

Seed documentation also gives a seed lot a unique reference number which enables suppliers and users to keep track of its performance. Such monitoring will reduce arbitration and facilitate requests for more seed from the same seed lot.

Documentation also facilitates seed exchange and trade as users and suppliers are able to easily discuss a common subject identifiable by a reference number, thereby enabling a supplier to match requests for seed with particular seed lots.

Furthermore, documentation is an important management tool for facilitating the use of procedures that result in high-quality seed lots, the avoidance of activities that result in bad seeds, and the making of informed decisions. For example, in setting targets for the mass of fruit to collect to get a specific quantity of seeds, records of past fruit weight to seed weight ratios will enable a collector to easily calculate a reasonable estimate. Moreover, documentation eliminates the burden of memorising details and enables activities to be continued even when staff changes.

11.3 What should be documented

The entire seed production system should be documented. Such technical documentation includes the following information.

Seed orchard establishment (identification) and development

- Seed source/origin
- Phenology

Seed collection and handling documents

- Botanical name of species
- Provenance of parent material
- Date of collection
- Name of collectors
- Seed collected
- Seed quality test results

Seed storage

- Seed lot number (a unique identification code that identifies the seed collected, the year it was collected, and the seed orchard from which it was collected)
- Weight stored
- Running balance

- Seed dispatch
- Stand establishment

Seed quality test results

- Seed test and seed lot numbers
- Date of seed testing
- Seed purity percentage
- 1000-seed weight test or number of seeds per kilogram
- Moisture content percentage
- Germination percentage
- Cutting test

Managerial documentation

Managerial documentation should also be done to help manage a seed orchard or production unit. Such documentation includes the following:

- Cost of operations
- Records of harvesting trips
- Research records
- Publications/reports
- List of seed orchards/seed sources
- Ecology of plantation seed source (elevation, temperature, rainfall, soil type)
- Ecology of original seed source in the case of a seed orchard or seed production unit.
- Number of families and trees in the seed orchard
- Age of the seed orchard/seed source (planting dates)
- Percentage of families rogued
- Size of seed orchard

The distinction between managerial and technical documentation is vague and some items considered technical, like storage and dispatch, can easily be viewed as managerial.

12. SEED DISTRIBUTION, MARKETING AND LEGAL REQUIREMENTS

12.1 Introduction

Seed producers are responsible for ensuring that the seed they supply is of good quality, while seed distributers have to maintain this quality and ensure that the right seed reaches the right places at the right times and in sufficient quantities. Seed stock must be managed well, keeping in mind a wide view of future developments in forestry and present demands for seed. Furthermore, distribution should consider which ecological zones favour which tree species and, to be viable, meet seed requirements accordingly. To accomplish all these ends, Tanzania needs a smoothly running system of documentation, which in turn requires adopting realistic but demanding and long-sighted legal regulations for the production, collection and distribution of tree seed.

12.2 Seed distribution

The proper distribution of seeds must include information for seed users on how to handle and treat seed. Legally, each seed lot must include basic information on labels both inside and outside seed packets.

Seed producers are responsible for supplying users with sufficient seeds to meet their requirements for different purposes. Demand for seed has to be realistically assessed and over-supply avoided since seeds are valuable, sometimes even very valuable, depending on the reproductive nature of a particular tree species. There is no need to factor a "safety margin" into a seed order if the user is dealing with a reputable institution which hires qualified staff and has proper facilities, including laboratories and cold stores, to guarantee the quality of its seed. The amount issued should be based on the weight of the seeds (in number of seeds/kg), purity and germination capacity. The amount of seeds required to raise a given number of seedlings is calculated as follows:

$$\text{Quantity of seeds required (kg)} = \frac{\text{No. of seedlings desired}}{\text{\% purity x \% germination x no. seeds/kg}}$$

For example, if 3000 seedlings of P. taeda are needed and the seed lot has the following properties:

Purity = 98.9%

Germination = 92%

No. of seeds/kg = 19,000

Then the quantity Q needed in kg is:

$$Q = \frac{3000}{0.989 \times 0.92 \times 19{,}000}$$

$$= 0.17 \text{ kg}$$

12.3 Seed distribution and marketing

Ideally, distributed seeds should be accompanied by information on how to handle and treat them before sowing. Legally, each seed lot must contain at least the following basic information on its inner and outer labels: species name, germination percentage, pre-treatment method, planting zones, and the last testing date. To improve the quality of seed in circulation, the main seed dealers should be registered and trained in various aspects of seed handling and distribution. Seed should be packed in quantities of 100 g to 200 g, quantities which meet the demands of specific users. Packaging materials popular among smallholder seed users are polyethylene and paper envelops, and, in fact, such packaging has proved appropriate for most seed recipients. Seed dealers handling bulky seeds should have efficient storage facilities in order to reduce the rate at which the quality of stored seeds declines.

Seed marketing involves the continuous and systematic determination of consumer needs, the accumulation of seeds and services to certify those needs, and communication back and forth with potential consumers. The ultimate objective of a marketing programme is to see that seeds are used. The price that tree growers will pay for seed is determined by their perception of its benefits and their ability to pay. Some important points to note during marketing are the following

- Minimise the time between packaging and planting
- Distribute in appropriate, user-friendly packaging material
- Ensure that seeds have labels that document facts
- Determine consumer needs
- Accumulate adequate seed supplies
- Promote market communications
- Establish distribution channels and logistics
- Set suitable prices

12.4 Seed legislation

Seed legislation is an expression of government policy on seeds. Seed laws have two main functions:

- Prevention of fraud
- Protection of producers and consumers

Seed laws are designed to regulate the activities of the seed industry and are applied to the following two principles:

- Minimum standards: These require that all seed for commercial distribution meets minimum physiological standards regarding germination and purity.
- Truth in labelling: This system suggests that seeds of any quality can be sold as long as the consumer knows the quality of the seed they are buying. Truth can be achieved through proper and accurate documentation.

Without a regulatory system, the risks attributed to site mismatch and fraud could be enormous. National and international seed laws provide the means by which good seed can be distinguished from bad. Thus, they protect users from using poor germplasm and guarantee a sustainable seed industry. While a seed act is an essential step in the development of a seed industry, seed laws can achieve their aim only if high-quality seed is available. Legislation alone produces no seed. A seed quality-control system aims at promoting the use of high-quality seed. Controls should involve, among other things, the monitoring of quality throughout the various stages of collection, handling and marketing. Ideally, no seed should be used if its quality is unknown. The only way to guarantee a good control system is to have it backed by legislation.

Controlling imports and exports aims to protect local seed industries. Thus, each country will have its own requirements regarding prohibited pests and diseases, endangered species, and the volume of seed to be traded.

12.5 Seed certification

Certification ensures that seeds conform to the standards set by a regulatory authority. Activities undertaken during a seed certification process include the following:

- Seed source inspection to ensure that standard procedures are being followed and that field standards like isolation distances and species trueness are maintained.

- Monitoring during seed harvesting to ensure that no mixing occurs
- Processing and packaging to ensure the use of appropriate methods
- Testing to ensure adherence to set rules
- Labelling and proper documentation to determine the true identity of the seed and its physical and physiological qualities
- Distribution and marketing that preserves the state and genuineness of the seed being marketed

Setting standards for the seeds of many tree species will require extensive research and the establishment of appropriate quality-control procedures. The scheme of certification of the Organization of Economic Cooperation and Development (OECD) should be adopted as it demands that seeds be comprehensively documented and appropriately labelled.

12.6 Seed and plant variety act

A seed and plant variety act should stipulate that only duly registered merchants and institutions can engage in seed trade at all levels. Plant health inspectorate service providers in member countries are designated as authorities to implement the act. Such an act controls a seed industry by providing the legal framework in which seed production and trade is conducted. Regulations governing the act protect both the producers and the users of tree seeds. Seed certification is based on set standards to ensure that only high-quality seeds are traded and used.

In many countries, forestry seed regulations were developed under the assumption that end-users were not aware of the existing technology or the consequences of using low-quality seeds. Although seeds can easily be obtained to meet targets, the basic principles of collection, handling and distribution need to be adhered to; otherwise, the end results will be expensive and time-wasting as well as, in the long run, frustrating because, unlike in agricultural crops, mistakes caused by using poor tree planting material may take many years to detect.

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