

Section 1: Seedling quality

This chapter describes what we mean by ‘quality’ seedlings. Here, we discuss targeting seedlings to the conditions you expect at the site where you will plant them. We give ways to monitor plant development and describe simple routines that help to handle planting stock or to reduce variation amongst seedlings. Feedback provided by experimenters and farmers is important in improving a nursery’s standards.

Targeting seedlings and seedling quality

The clients and the conditions at the site where the seedlings will be planted (the ‘outplanting’ site) determine what kind of seedling is needed. A researcher will require planting stock raised under uniform conditions to ensure that research results are not confounded by the status of the seedlings. Small-scale farmers, on the other hand, who often cannot provide the care to a tree that might be desirable, need seedlings that can survive under hard, often dry and nutrient-deficient conditions. The best looking seedling at the nursery is worthless if it does not survive and grow after planting out. ‘Targeting’ seedling production to the anticipated field site is an important step in producing strong healthy seedlings. It is wrong to think that seedlings destined for harsh environments, for example arid sites, should be raised under harsh conditions in the nursery. However, they do need to be hardened-off— gradually prepared for ‘real-life’ conditions, for example by withholding water from time to time — **after** they have developed a strong and healthy root system. Insufficient care in the nursery leads to weak and retarded plants with small root systems that will not survive in a harsh environment.

‘Targeting’ seedling production to the anticipated field site is an important step in producing strong healthy seedlings.

Quality seedlings targeted for different sites may look different from each other but they all have one thing in common: a well-developed root system with many root tips from which new roots can quickly develop. In areas with adverse environments, such as dry, flooded, saline or nutrient-deficient sites,

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only well-developed plants have a good chance of survival. For dry areas produce seedlings with a deeper root system. For weedy sites larger plants are better — they can outgrow weeds quickly.

Seedling quality is a concept, widely used in forestry, which has received considerable attention in Europe and the US. It is important because afforestation seedlings cannot receive the same care that may be given to individual ornamental or fruit trees. After they are planted, the seedlings have to survive without irrigation or fertilizer, and this is often the case in tropical small-holder agroforestry sites too. Many studies have shown that field survival and productivity are related to the quality of the seedlings used.

Seedling quality depends on:

- the ability to produce new roots quickly
- the speed with which seedlings get anchored in the ground, and start assimilating and growing after planting out
- a well-developed root system
- sun-adapted foliage
- a large root collar diameter
- a balanced shoot:root ratio
- good carbohydrate reserves
- an optimum mineral nutrition content
- the establishment of adequate mycorrhizal or *Rhizobium* infection

Many seedling quality characteristics, such as the shoot:root ratio, are difficult to observe and/or require destructive sampling. The shoot:root ratio is an important measure for seedling survival. It relates the transpiring area (shoot) to the water absorbing area (roots). It is usually measured by determining root and shoot dry weights. A good ratio — one which indicates a healthy plant — is 1:1 to 1:2 shoot:root mass.

A less rigorous, but non-destructive, index is the 'sturdiness quotient', which compares height (in cm) over root collar diameter (in mm). A small quotient indicates a sturdy plant with a higher expected chance of survival, especially on windy or dry sites. A sturdiness quotient higher than 6 is undesirable.

For each nursery population, measure the root and shoot dry weight of a few plants at random to get an idea of the general population quality. Of course the data you get will be meaningless unless you correlate it with field survival at a later stage to see for each species and site how well these simple measurements relate to the survival and growth of the seedlings.

Although plant quality indices have been developed mostly for species in the northern hemisphere and have not been tested on tropical species, they can still give an indication of the quality of tropical agroforestry species.

Nursery bed density, shading, pricking out techniques, seedling size at planting, watering and fertilizing before and after planting out — all these have significant and long-lasting effects on seedling quality and subsequent tree development, insect and pest resistance, and tolerance to environmental stresses such as drought.

Quality seed

Seedling quality also depends on the seed used. The quality of seed planted in the nursery is of crucial importance, since seeds are the most basic input into any planting programme. It is therefore necessary to pay proper attention to quality issues when procuring and subsequently storing tree seed until planting.

Getting your seed

Seed for a planting programme may be obtained in different ways. You can collect it directly from local stands of a species (such sources include native or naturalized stands and stands established specifically for seed production). Alternatively, you can order it from a commercial or non-commercial seed supplier. Most nursery managers get their seed from seed suppliers. When ordering seed from a supplier, always pay attention to the genetic quality of seed. Genetic quality relates to the origin (provenance) of seed and its genetic diversity.

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Wherever you can, get the best provenance for your particular planting purpose.

- **Origin** is important because most trees exhibit considerable intraspecific genetic variation, so the performance of different provenances (origins) of the same species may vary widely. It is important, wherever you can, to get the best provenance for your particular planting purpose.
- **Genetic base** (the diversity of genes) is especially important when seed is collected, for two reasons. First, a wide genetic base (such as a large number of varieties) gives flexibility to changing user requirements and environmental conditions. Second, since most trees are predominantly outbreeding (they produce seed by cross-fertilization, rather than self-pollination), a wide base provides protection against a future loss in performance through inbreeding depression (a decrease in vigour common to outbreeding species when their genetic base is too narrow).

If seed is collected directly from a local stand, the same issues of quality should be considered. To ensure a wide genetic base, **never** collect seed from a single tree, always collect your seed from a number of trees (normally at least 30). Note the species, origin, collector and date of collection (as a minimum), for future reference. Give this information to any other person you are giving the seed to. It is important to collect mature seed, because immature seed has low viability and storage life. With many species, seed is mature

When ordering seed from a supplier

- Choose a supplier who provides good documentation on his or her seed (this can be judged by asking suppliers for their seed catalogues). The more information a supplier can provide about the seed, including provenance, source (natural, naturalized or planted stand), collection method and collector, the better your selection of material will be and the higher your chances of getting quality planting material.
- Specify the environment in which, and purpose for which, seed will be planted, and ask the supplier to provide the best possible material.
- Remember, it is important for the supplier to specify the origin of seed, so that you can get more seed of the same provenance in the future (from the same or other suppliers), if it performs well.

when it can no longer be crushed between your thumb and forefinger, when the fruits begin to split open (for example, legumes) or when the colour of seed changes. Seed can be cut to check the presence of a mature embryo and endosperm. After collection, follow proper procedures for processing the seed.

After collection

- For most species, **extract** seed from fruit as soon as possible. The method used will depend on the species. For many legumes, pods can be dried in the sun for two days and then rubbed across a coarse wire mesh through which seed falls. The extraction method used should not damage seed so that a significant loss in viability occurs. During extraction, remove impurities (for example, diseased or partly eaten seed, contaminating seed, soil, chaff and insects) by winnowing or hand-sorting.
- After extraction, most seed should be **dried** further before storage. Generally, the lower the moisture of seed, the longer it can be stored. Normally, seed with a moisture content of 10% or less will maintain high viability for several years, if stored correctly. Sun drying seed for two to three days generally reduces moisture to an acceptable level, although more time is needed for large seed. Spread seed on raised beds to help air circulate, and shade the beds from strong sunlight (move seed into the shade for around two hours at midday).
- During processing, the viability and purity of seed is normally **tested**. *Viability* is the percentage of germinating seed in a seedlot and is measured by germinating seed under conditions (including any pre-treatments such as nicking or soaking in hot-water) that would normally be applied during germination. This provides a reference level of germination for users. *Purity* is the percentage by weight of pure seed in a sample and is estimated by weighing a sample of seed before and after the removal of impurities. Record particular impurities, such as contaminating seed. The International Seed Testing Association (ISTA) has published guidelines for seed testing that qualified seed suppliers should adhere to.
- **Label** seed properly during processing and storage. An unidentified seedlot is almost worthless. As a minimum, seed should be labelled with the species name, original collection source, production location, collection date, producer and viability.

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Seed storage

After you obtain your seed, you need to store it in the correct conditions in the interval before planting, to maintain its physiological quality. This will ensure that maximum viability is maintained. The supplier should specify the proper conditions for storage of seed. Normally, orthodox seed, which can be stored without losing viability for a long time, should be kept cool, dry and dark in airtight containers (such as plastic or glass bottles with screw-tight lids, or hermetically-sealed foil sachets). If possible, orthodox seed should be stored in a refrigerator. For recalcitrant seed, storage is more problematic. Seed is viable for only a short time and, whenever possible, should be planted out immediately. If this is not possible, storage at 10 to 15°C in humid conditions, for example in moist sawdust, may extend longevity.

Seedling development

There are three phases in seedling development:

- establishment
- production
- hardening

The establishment phase includes seed germination and first root growth. The production phase is manifested by rapid shoot growth. During the hardening phase, seedlings are gradually accustomed to field conditions.

Establishment

Various pre-treatments can be used to accelerate the start of germination and/or to shorten the germination period for all seeds so that germination is uniform rather than scattered over a long period of time. Which method to use depends on the species and the seed: large, hard seeds might require mechanical nicking and soaking, small seeds might only need to be soaked. If information is not available, carry out a few simple tests.

Most common seed pre-treatment methods

- soaking in cold water for 12, 24 or 48 hours
- immersion in hot (70°C) water, letting cool and soaking for 12, 24 or 48 hours
- nicking/partial or complete removal of seed coat

Whenever possible, sow seeds directly into containers or a bare-root nursery bed. Germinating seeds in germination trays or beds and pricking them out later can lead to severe root deformities unless it is done carefully (see box on page 14). If the use of germination trays is absolutely necessary, for example because seeds are extremely small or sensitive, always sow in several trays. This will minimize the risk of losing all seeds due to unforeseen problems, such as disease, flooding or drying out of the tray. If you do need to prick out, do it as early as possible after germination for most species. Only very tender seedlings, such as *Eucalyptus*, need to have the first true leaf pair developed before pricking out. Avoid letting the roots grow too long and developing side roots, or they will be damaged when transplanting. Especially with bigger seeds, transplanting can be done as soon as the root begins to emerge.

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If pricking out is done for an experiment, ensure that seedlings are pricked out block by block, and that each person pricking out does a complete block. This will ensure that experimental treatment effects are not confounded by nursery practices.

Inoculation with mycorrhizal fungi or *Rhizobium* bacteria is necessary for good plant development of most agroforestry tree species. It can increase plant disease resistance and help alleviate plant stress by enhancing the plant's water and nutrient uptake. Early infection with mycorrhiza can also increase the propagation success of cuttings and seedlings. It is especially important that mycorrhizal and *Rhizobium* associations are well-established when you are producing seedlings for acid or degraded soils.

Ideally, get the inoculum from a reputable supplier. If this is not possible you can take advantage of the fact that spores and mycelia of mycorrhizal fungi are abundant in the soil around established trees. Inoculation is easy when some of this soil can be mixed into the propagation substrate. Usually, a small amount (5–10% of the total mixture) of topsoil is sufficient. However, as we discuss in section 5, topsoil can introduce soil-borne pathogens into the nursery. Carry out a preliminary experiment to see whether that will be the case with the topsoil of your choice. If the soil is contaminated with pathogens, you will need to acquire sterile inoculum from a commercial supplier (see Annex 1).

Steps in pricking out— these apply for both container and bare-root beds

1. Fill the containers well in advance with a good potting substrate and water the day before pricking out.
2. Water the germination tray well the day before pricking out.
3. Lift the seedlings carefully, holding them by the cotyledons, after loosening the substrate, so that the soft stem does not get damaged.
4. Prepare only as many seedlings as you can pot within 30 minutes; put the seedlings into a container with water or cover them with wet paper or cloth and keep them in the shade until needed.
5. Make a hole in the substrate using a small stick. Ensure that the hole is in the centre of the container — or that holes are equally spaced in the case of bare-root beds — and that it is longer than the roots of the seedling to be potted. This can be done in advance of pricking out to speed up the operation.
6. If the roots have already grown longer than the container's depth, cut tap root using a sharp and clean knife.
7. Put the seedling into the hole, ensuring the roots are not curled; insert the seedling a bit deeper than necessary, then lift it up again to straighten the roots.
8. Press substrate firmly around the seedling and water thoroughly to avoid air pockets in the substrate.
9. Keep filled containers under shade for at least two weeks.

Production

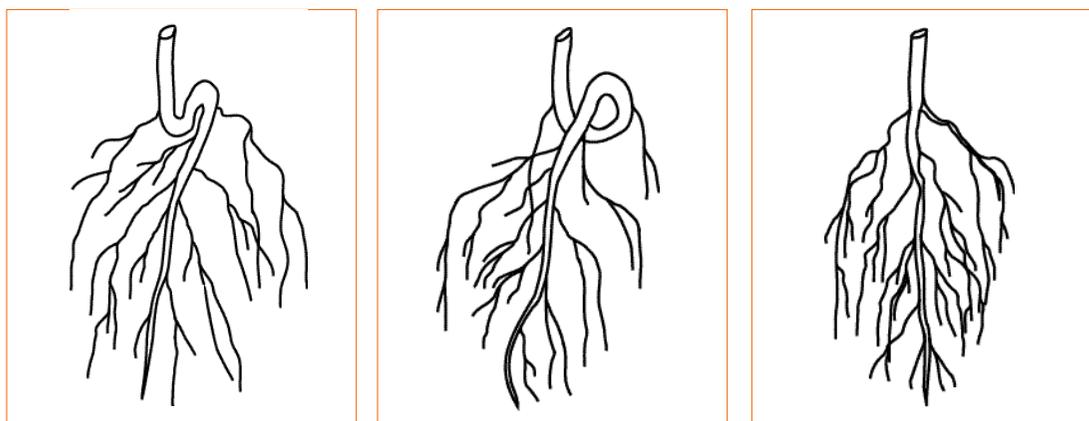
As soon as a seedling is established, either a few days after germination or after pricking out, both roots and shoots begin growing rapidly. This phase is as important as the establishment phase. Root development is important for good inoculation with symbionts, for efficient nutrient uptake and for outplanting success. The number of fine roots with growing points largely determines the ability of the seedling to recover and start growing after planting out. If the root system is small and/or distorted, the tree cannot anchor itself sufficiently in the ground and is prone to wind-throw or lodging when waterlogged.

The appearance of a healthy root system is of course different for species with a strong tap root, than it is for those with a mass of shallow roots. However, most tree seedlings have a straight, slightly tapering main root and a large

Labelling nursery stock

From the moment seeds are sown, they should be carefully labelled. Each seed lot needs to be identified clearly, with species name and code, date of sowing and later treatments on the label. Put two labels on each batch, one at the beginning of the row and one at the end. If smaller numbers of seedlings are produced, label each plant individually with a paper, plastic or metal tag. **Careful labelling is never a waste of time!**

mass of fibrous roots. Healthy roots are not bent, crossing or injured. Knotted and bent roots are common in plants that have been left in the nursery too long or have been pricked out without the necessary care. These plants cannot survive in the field because the crossing roots may eventually strangle the tree or they may die back and become vulnerable to disease and termite attacks. It is worth sacrificing a few plants every now and then to have a look at what usually remains unseen: the roots of the seedlings (see figure below). Compare with the healthy root system of the seedling on the right. You can carry this through to field plantings — dig up and inspect trees after months or years to see how the root system has developed. This is especially important when a planting has failed. When the plants are uprooted, take the time to examine the root systems. You might be surprised how often unsuccessful tree development can be attributed to root deformities.



Examples of bent and looped seedling root systems.

Compare with the healthy root system of the seedling on the right.

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Hardening and planting out

Seedlings need to get accustomed to the conditions at a planting site. Therefore, about 4–6 weeks before planting out, start hardening them by reducing watering gradually to once a week and by gradually removing the shading.

Plant seedlings out as soon as they have reached their optimum size. This varies with the species and the site, but it will usually be a height of 15–30 cm. It can be much larger for some slow-growing species, or when there is strong weed competition at the planting site. Do not leave seedlings in the nursery into the next season. Often, late rains, high workloads and other obstacles delay plantings. If this is anticipated you can try to slow down plant

Overgrown plants will have a very slow start in the field. They are prone to insect attack, drought and wind-throw because they have a poor root system. They will never catch up.

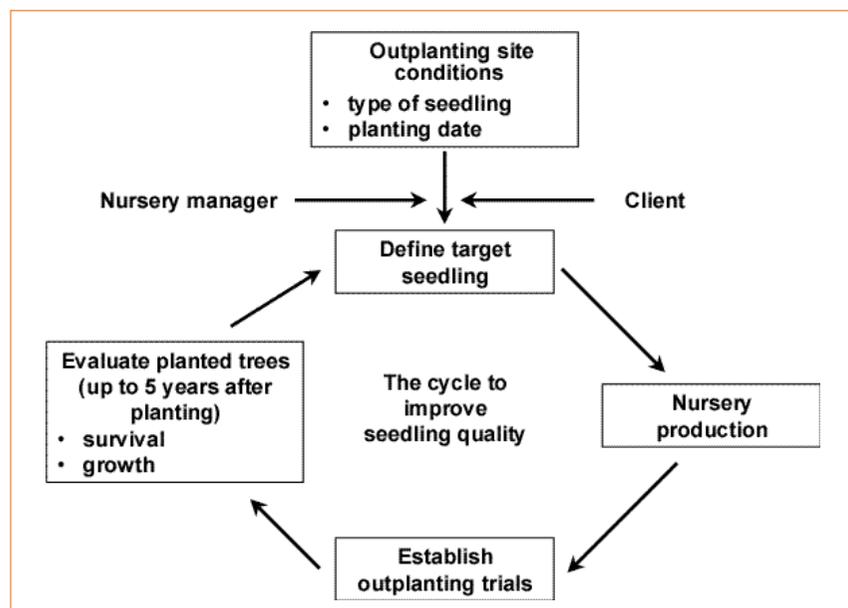
Signs of overgrown plants are

- lack of leaves, as old leaves fall and young ones are not produced
- a root system that lacks young, fibrous roots
- the tap root is often grown into the ground
- root deformities, for example roots coiling at the bottom of the bag
- lignification of the whole stem
- very short tip internodes but in general a tall, thin stem.

development. For example, when producing plants in containers, delay potting-on into bigger containers, or stop fertilizing. These are only temporary solutions, because the quality of the planting stock will deteriorate considerably if it is left too long in the nursery. If you know that planting will be delayed for a whole season, consider re-sowing.

A very important point which is unfortunately often overlooked is that **feedback** from scientists carrying out long-term research and from farmers should be sought and used for further improvement of plant quality. Client feedback is important for the fine-tuning of nursery operations. Try to visit field sites and experiments in the years after planting out, in order to see the effects of particular nursery practices. In addition, collect data on a regular basis to allow evaluations and possibly amendments of current nursery practices.

When you are in the field make the following observations for each tree: is the tree healthy, dead, unhealthy or missing? If so, what are the reasons: drought, cattle, rodents, insects, loosely planted (soil not compacted), shallow planted (holes not deep enough), spiral roots, planted too deep, 'J' root (bent root), small seedling, fire, vandalism? Observe the site conditions, too: is there shallow soil, is it rocky, nutrient deficient or acid?



Handling seedling variability

Every plant population has some degree of variation. This can be greatest for populations which have not undergone any domestication. Since few agroforestry tree species have undergone any significant domestication there will be wide variation in the size and quality of seedlings. This variation is still visible in the field many years after planting.

Although much agroforestry research focuses on determining and utilizing the variation within populations, an important prerequisite for some research is **uniformity** of planting stock. For example, an experiment with the aim of comparing management practices will give more precise results if variation in the seedlings used is minimized. How can you ensure that relatively

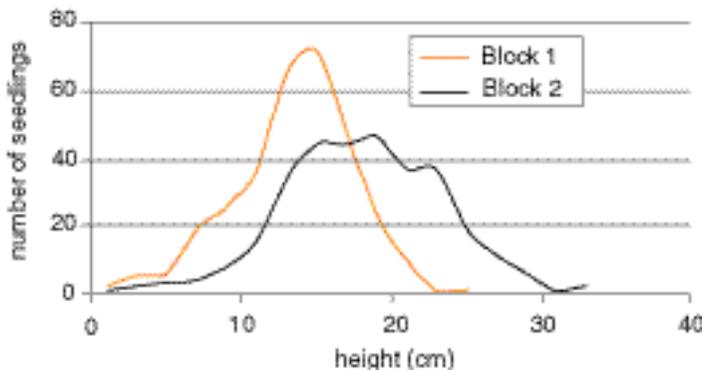
Improved and standardized nursery practices can help deliver more uniform planting material.

Section 1 uniform populations leave the nursery? And how can researchers who are interested in the genetic variability itself handle variable germplasm without losing information?

Uniformity of seedlings from non-domesticated seed sources can be improved by rigorously **culling** the population before the plants leave the nursery. Culling is the removal of weak, diseased, or overgrown plants. It is

Calculating variation

Two blocks of a *Sesbania sesban* experiment show different CVs. In block 1 the CV is 25.9%, in block 2 it is 29.6%. Use various ways of setting culling targets to reduce the variability:



block 1	number of seedlings	average height	SD	CV%
original	315	15.5	3.88	25.0
cull 10% at both ends	251	15.6	2.52	16.1
cull 15% at both ends	221	15.7	2.09	13.3
block 2	number of seedlings	average height	SD	CV%
original	315	18.0	5.25	29.1
cull 10% at both ends	251	18.0	3.48	19.3
cull 15% at both ends	221	18.0	3.02	16.8

essential to set culling targets to reduce the variation in experimental plots in a reproducible way without depending on nursery staff to choose plants to discard (as they are usually very reluctant to discard any plants, especially those that are above average in size), and without significantly increasing costs. Remove unwanted seedlings early on to achieve a relatively homogeneous nursery population. If necessary, cull the plants again before seedlings are planted out.

It is not difficult to check a plant population for traits such as height, collar diameter and growth form, if you know the mean and standard deviation. You can easily get these by using a simple pocket calculator. One way of describing the variability is by using the **coefficient of variation (CV)**. The CV is more useful than the standard deviation, because CV is independent of the measured units (cm, mm, etc.) This allows a better comparison of variability than standard deviation allows. CV is calculated as follows: standard deviation (SD) divided by sample mean = CV. This figure is multiplied by 100 and expressed as a percentage. The smaller the CV, the more uniform the population.

Of course, culling the extremes is not the only answer to improving population homogeneity. Improved and standardized nursery practices can help deliver more uniform planting material.

Recommended nursery practices when assessing variability

Sometimes you might specifically want to assess the variability of the germplasm, for example in provenance trials. In this case, you will not want to rigorously cull. Grow the seedlings in the nursery in several blocks, and keep these together in the field. By doing this, variation that already appears in the nursery, for example slow growth due to shading of a particular nursery bed, is retained in the field and you do not mix these environmental effects with important genetic information.

When culling is necessary in a provenance test, for example to remove severely retarded seedlings, it is especially important that it is done at a low level, separately for each provenance. This will avoid selecting against provenances with a different development pattern than the majority, possibly resulting in the loss of valuable germplasm.

You can distinguish genetic variability from nursery effects by transferring complete nursery blocks into the field.

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