Chapter 7

Nursery Practices

Thomas D. Landis

Dr. Landis retired from the USDA Forest Service, State and Private Forestry's Reforestation, Nurseries, and Genetics Research National Team

Contents

Introduction

Plant propagation is both a science and an art. In this chapter, we examine the science of plant propagation, which consists of a knowledge of plant physiology, nursery cultural practices, and the biological characteristics of the particular plant that we want to grow. The art of plant propagation cannot be taught, however, because it consists of certain technical skills that must be acquired through experience and often requires a certain "feel." This special quality is expressed in the saying that people who seem to be able to grow plants have a "green thumb" (Landis and others 1999). But before we get into the specific details of plant propagation, we first need to cover some basic nursery terms.

Terminology

A seedling is a plant grown from a seed, but the term is commonly used generically for many types of nursery stock, including transplants, rooted cuttings, and emblings (plants that are produced through micropropagation). Forest and conservation seedlings are traditionally divided into 2 basic stocktypes, depending on how they were propagated: bareroot seedlings and container seedlings. Bareroot stock is grown in soil in open fields (figure 1A), and the seedlings are removed from the soil during harvesting (figure 1B). Container seedlings are grown in an artificial growing medium in a controlled environment, such as a greenhouse (figure 2A), where most or all of the growth-limiting factors can be manipulated. Because the volume of growing medium in containers is relatively small, roots bind the medium into a cohesive "plug" by the time the seedlings are harvested (figure 2B). Therefore, container-grown stock are sometimes called "plug seedlings."

Another stock type is the transplant, a seedling that has been physically removed from its seedbed or container and then replanted in another location for additional growth. Traditionally, most transplants are bareroot seedlings that were grown for 1 or 2 years and then replanted into a transplant bed and allowed to grow for another year or two. Recently, container transplants are becoming much more popular. This new stock type, also called a plug transplant, is produced by transplanting a small container seedling into the bareroot nursery for an additional year or two of growth.

Bareroot seedlings have been traditionally described with a numerical code. The first number corresponds to the number of years in the seedbed, and the second number refers to the number of years in the transplant bed. Bareroot seedlings are generally produced in 1 to 3 years (1+0 to 3+0), and transplants require 2 to 4 years (for example, 1+1 or 2+2). The sum of the numbers gives the total number of years needed to produce that stock type. For example, a 1+2 transplant takes 3 years to produce.

There is no standard nomenclature for describing container seedlings, and each nursery and region uses its own system. Because most container seedlings are grown in a season or less, they are generally defined by the type and

Figure 1—Chapter 7, Nursery Practices: bareroot seedlings are grown in outdoor beds where they are exposed to local weather (**A**). During harvesting, the soil is removed from the roots and they are shipped to the outplanting site in the bareroot condition (**B**).

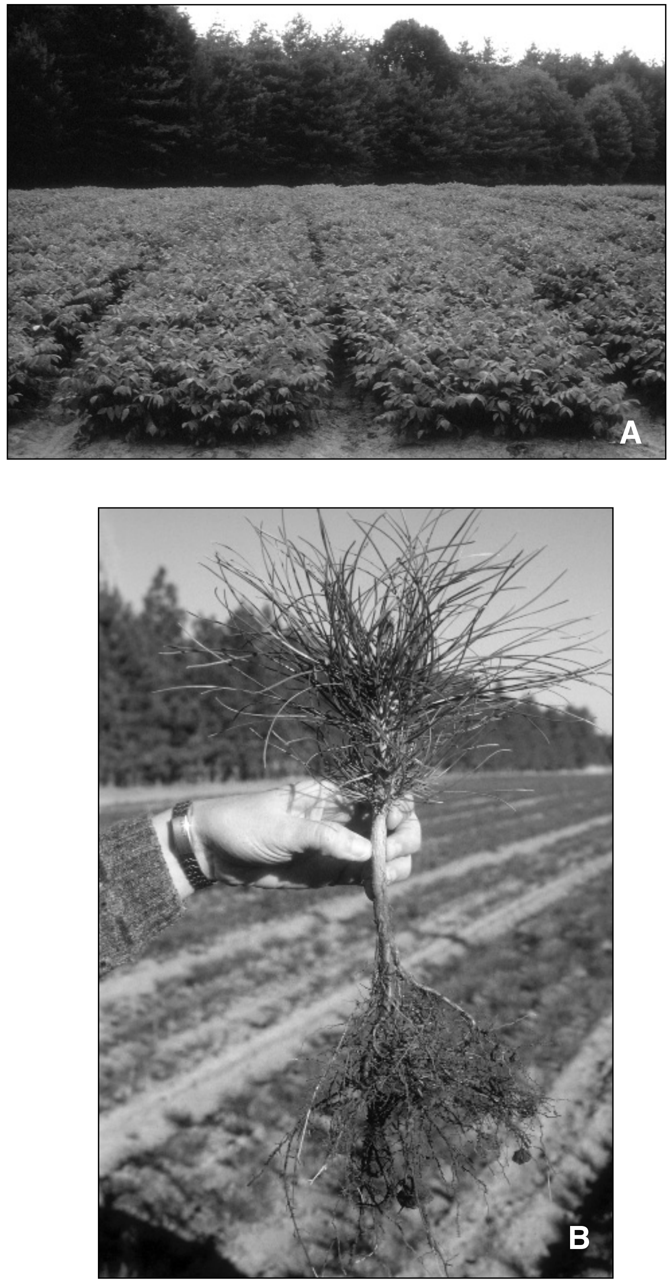
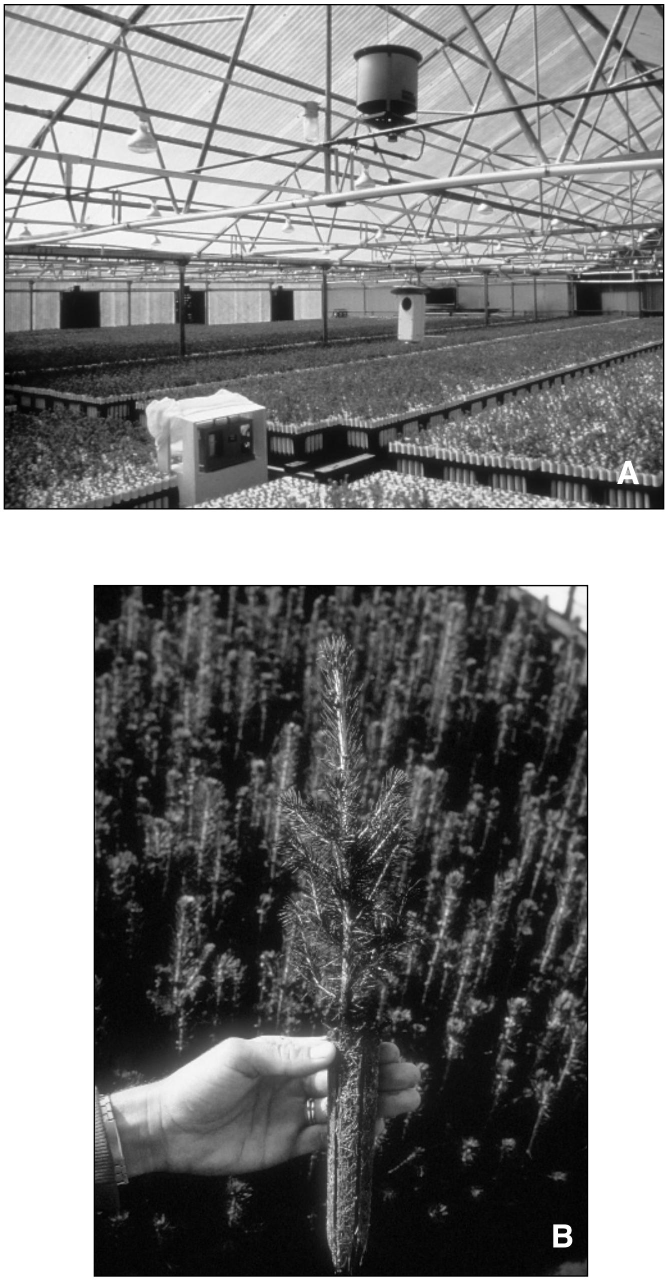


Figure 2—Chapter 7, Nursery Practices: container seedlings are grown in artificial growing media in a controlled environment where seedling growth is accelerated (**A**). By the end of the growing season, the roots have formed a cohesive "plug" (**B**).



volume of the growth container. For example, a "Styro " refers to a seedling that has been produced in a Styrofoam® block container with cells that are approximately 65 cm^3 (4 in^3) in volume. Plug transplants are described by the number of years in the transplant bed, so that a container seedling that is transplanted for an additional year of growth is called a "plug+1."

The Target Seedling

There is no one ideal type of seedling suitable for all purposes, and the ultimate use of the stock will control many aspects of the nursery program. Management objectives determine whether the seedlings will be used for plantation forestry or for ecosystem management purposes. Forest products companies demand plants that are genetically selected for commercial objectives: fast growth and desirable attributes such as fiber length or the ability to "self-prune." On the other hand, seedlings used in ecosystem management must reflect broad genetic diversity because they will be used to restore or maintain natural ecosystems. This distinction is critical because it not only affects target seedling specifications but the entire propagation system.

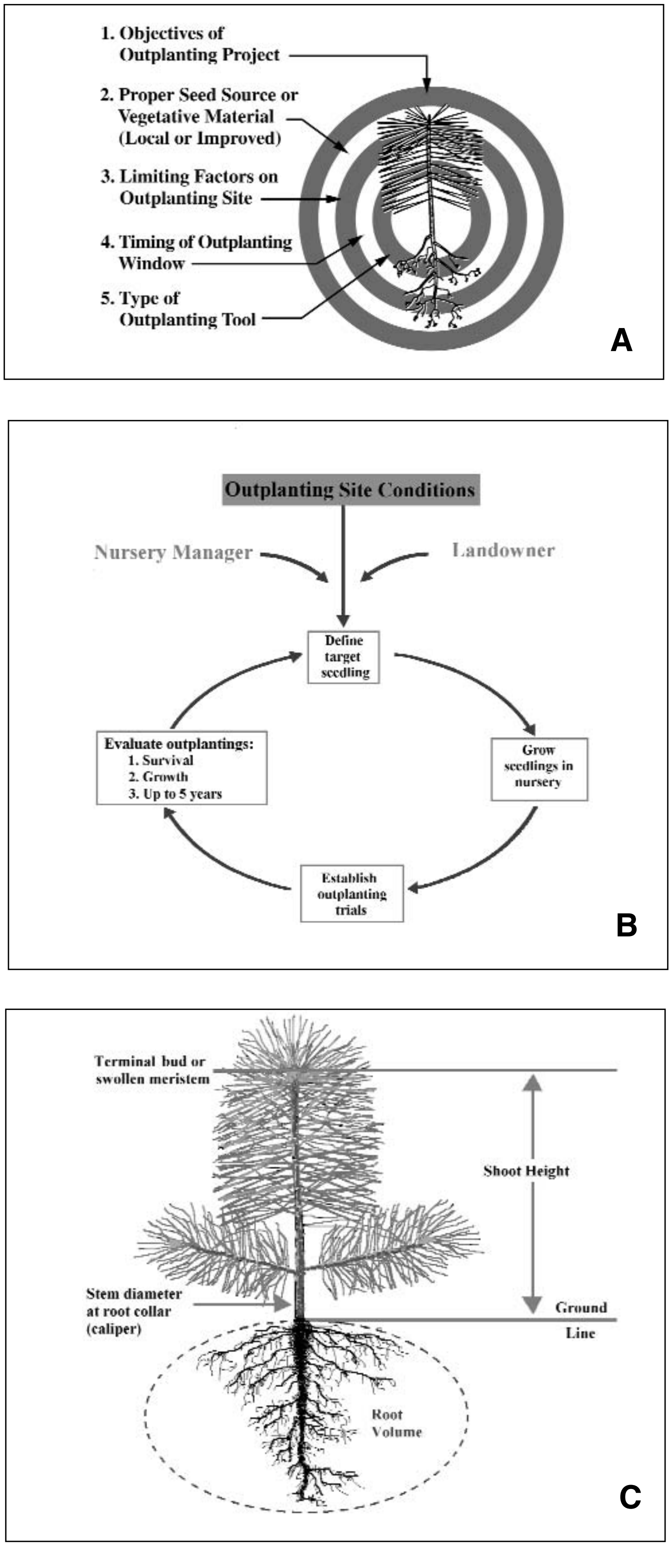
The true measure of seedling quality is performance on the outplanting site—both initial survival and subsequent growth. Because both the seedling user and the nursery manager are jointly responsible for successful plantations, they must work together to define the target seedling for that particular outplanting project (figure 3). Conditions on the outplanting site will determine both what to plant, and when and how to plant it. For example, the seedling user must specify the proper genetic origin for the seedlings (the seed source) and which environmental factors on the outplanting site will be most limiting to survival and growth. A very hot and dry site will require a different target seedling than an outplanting site in a rainy climate. Climate will also determine when to outplant. Planting windows are time periods when stresses are low and the chances for seedling survival and growth are optimal (figure 4).

Target seedlings can be described in terms of (1) morphological factors, such as height and stem diameter, (2) physiological factors, such as root growth capacity and cold hardiness, and (3) genetic factors, such as seed source.

Morphological Specifications

Forest and conservation seedlings are described by traditional morphological dimensions, which are used by both nursery personnel and seedling users. The most common dimensions are shoot height and stem diameter. Shoot height is the vertical distance from the ground line to the tip of the terminal meristem or bud. Stem diameter, often called "caliper" or "root collar diameter," is the diameter of the main stem at the base of the shoot (figure 3C). Other seedling morphological specifications include root volume or length, ovendry (OD) weight, and shoot-to-root ratio (S:R). Though they require destructive sampling, seedling dry weights are useful indices of crop development. The S:R is a relative comparison of the size or weight of the shoot to

Figure 3—Chapter 7, Nursery Practices: the best species and stock type of seedling depends on customer objectives and especially conditions on the outplanting site (**A**). This ideal plant is known as the "target seedling" and has traditionally been described by morphological characteristics (**B**). This prototype seedling must be tested with outplanting trials and these survival and growth results are then used to fine-tune target seedling characteristics (**C**).



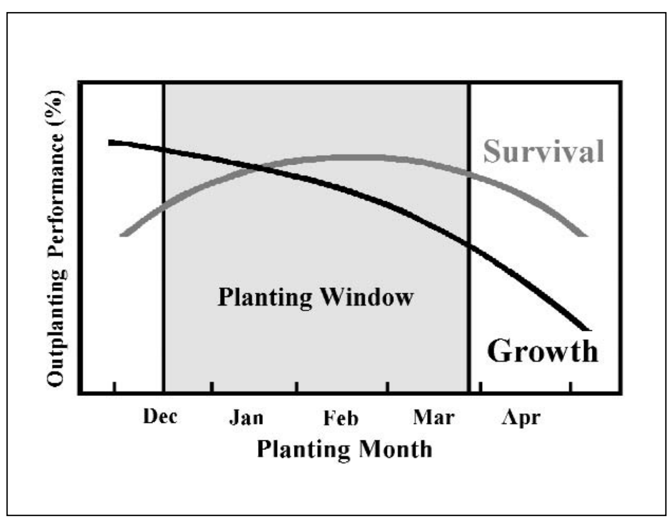
the root system and is sometimes specified by seedling users to match the stock type to conditions on the outplanting site.

Physiological Qualities

The most common measures of the physiological condition of forest and conservation seedlings are dormancy and hardiness. Dormancy refers to the state of relative metabolic activity, and seedlings reach maximum dormancy during the early winter. Hardiness is a general term for resistance to stress. Although cold hardiness is the most common type, hardiness can also refer to resistance to all types of stress, including high temperatures, dehydration, and physical handling.

Recently, nursery managers and foresters have been using 2 criteria to measure seedling quality. Root growth potential (RGP) measures a seedling's ability to produce new roots when growing in an ideal environment, such as a greenhouse. RGP tests are used operationally to establish lifting windows in the nursery and to help predict outplanting performance. The other common measure of physiological quality is the cold hardiness test, which measures the minimum temperature to which a seedling can be exposed without suffering observable cold injury. Because of their strong correlation with general stress resistance, cold hardiness tests have been used to establish nursery lifting windows and predict seedling tolerance to operational stresses such as dehydration and mishandling.

Figure 4—Chapter 7, Nursery Practices: seedling survival and growth is greatest during the "planting window," which is determined by conditions on the outplanting site, especially moisture and temperature (modified from South and Mexal 1984).



Genetic Considerations

Most seedlings grown for forest and conservation purposes are ordered by species, stock type, and seed zone or seed source. A seed zone is a geographic area that is relatively similar in climate and soil and often is described by a numerical code. Seed zones in mountainous terrain are also stratified by elevation (figure 5A). For example, the geographically diverse state of California has more than 80 different seed zones, with numerous elevation bands within each zone. All seeds and cuttings collected in a particular zone are labeled with that source code so that all seedlings produced from them will be planted back into the zone of origin. When a seedling order is sown in the nursery, information on species, seed zone, and elevation is included into a seedlot identification number. The seedlot number remains with this group of seedlings throughout their entire nursery tenure and is marked on the storage container when the seedlings are harvested for outplanting (figure 5B).

Types of Nurseries

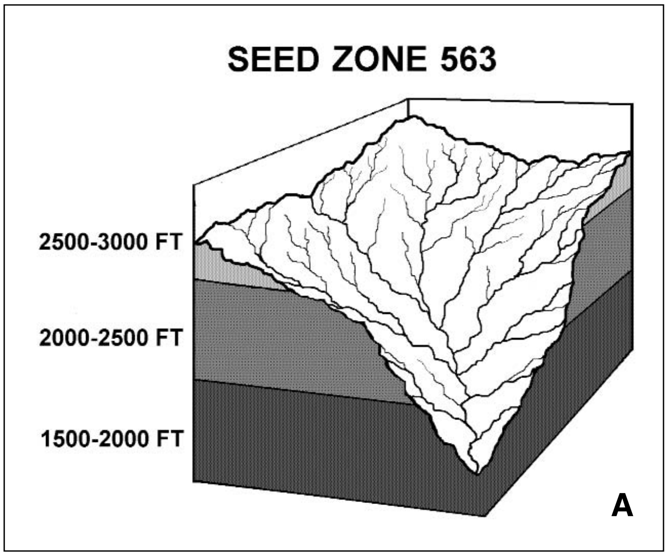
Once the target seedling has been defined, the next step is to decide how best to grow it. Forest and conservation stock is propagated in either bareroot or container nurseries, and the choice is determined by several factors:

1. **Cost.** Container seedlings traditionally have been more expensive than bareroot stock, although, in recent years, the costs are becoming more comparable. Container nurseries also are more cost-effective at low seedling production levels.
2. **Species characteristics.** Most forest and conservation species can be grown as bareroot seedlings, although some do better in containers.
3. **Production time**. Because container seedlings can be produced more quickly than bareroot seedlings, they are often used to reforest burns and other sites that need to be planted quickly.
4. **Outplanting site condition.** Bareroot seedlings are used on typical reforestation sites, but container seedlings often are preferred for the more severe, hard-to-plant sites. Container stock has a wider outplanting window than bareroot stock.
5. **Personal preference.** Some customers tend to prefer one stock type over the other.

Because bareroot seedlings are grown in open fields, the soil, water supply, and climate of the nursery site must be suitable for propagation. The growth rate of bareroot seedlings and the length of the growing season are largely controlled by the climate at the nursery site. Quality nursery soils are difficult to find in convenient locations, and good agricultural land is often expensive. Compared to container nurseries, bareroot nurseries usually require considerable capital to develop but have lower operating costs. A comprehensive discussion of site selection factors that should be evaluated when locating a bareroot nursery is presented in Duryea and Landis (1984) and Lantz (1985).

Container nurseries can be constructed on land with low agricultural value that would be unsuitable for bareroot seedling production. The amount of capital investment and

Figure 5—Chapter 7, Nursery Practices: because plants are genetically adapted to local environmental conditions, forest and conservation nurseries use "seed zones" to ensure that seedlings will be ecologically adapted to the outplanting site (**A**). The seed zone and elevation are included in the seed source code, which will remain with the seedling throughout the nursery cycle (**B**).



operating costs vary with the type of nursery. For example, fully controlled greenhouses require expensive structures and environmental controls, whereas open growing compounds are much less costly. Because container seedlings are grown at high densities, less land is required than for a bareroot nursery.

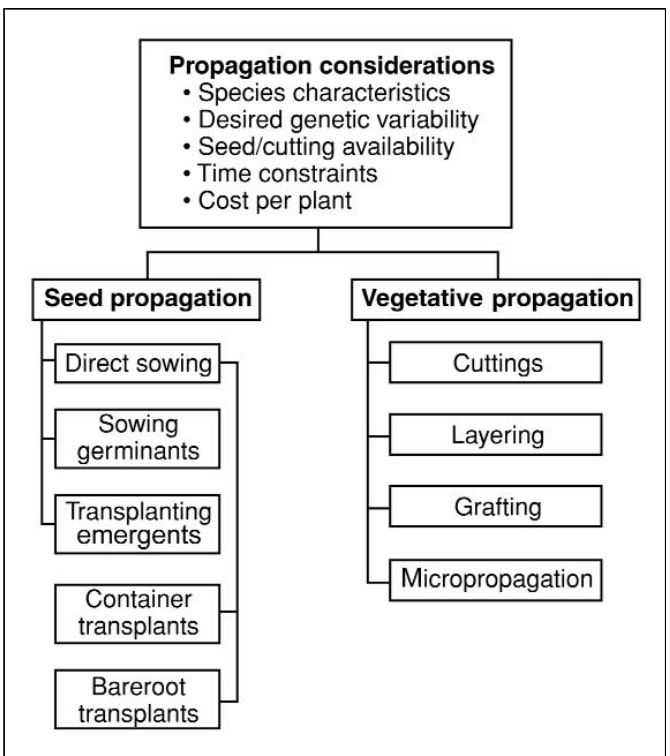
The decision whether to start a bareroot or container nursery must be carefully thought out because there are many considerations. It is helpful to list the various factors side-by-side for ease of comparison. A decision-making process is presented in the first chapter of volume one of the Container Tree Nursery Manual (Landis and others 1994).

Propagation Options

To determine which type of propagation method will be most effective and economical, both the biology of the plant and the objectives of the outplanting project must be considered (figure 6). As mentioned in the target seedling section, management objectives have a critical influence on the selection of propagation system. Most of the commercially important tree species used in plantation forestry can be grown from seeds, but a few are vegetatively propagated on a large scale to multiply selected clones. For example, on commercial forest land in the southeastern United States, southern pines are grown from genetically improved seeds. In the Pacific Northwest, forest product companies are vegetatively propagating fast-growing species such as redwood (*Sequoia sempervirens* (Lamb. ex D. Don) Endl.) and poplars (*Populus* spp.). Because biodiversity is a primary objective in ecosystem management and restoration, seed propagation is usually used, because it better captures and preserves natural genetic variation (table 1).

The availability of propagation material can also have an influence. Some species, such as western larch (*Larix occidentalis* Nutt.), produce seedcrops very irregularly; other species, such as Alaska-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach), produce seeds of poor quality. Availability is critical for emergency planting projects, such as fire restoration, when the crops must be grown in a very short time. As for economics, seed propagation is almost always much less expensive than vegetative propagation. All vegetative propagation techniques involve more hand labor than does seed propagation and also require special equipment and structures (table 1).

Figure 6—Chapter 7, Nursery Practices: nursery managers must consider many biological, operational, and economic factors before deciding on the best propagation system for a given plant species. The first and most important decision is whether to use seed or vegetative propagation.



Seed Propagation

Seed propagation is the most common means of producing forest and conservation seedlings in North America because of its many advantages (table 1):

1. **Cost.** Plants grown from seed are inexpensive.
2. **Ease of propagation.** Seed propagation is simpler and easier than vegetative propagation.
3. **Seedling vigor.** Plants grown from seeds often grow faster than those produced from cuttings.
4. **Phytosanitary restrictions.** It is easier to import and export seeds than vegetative material or whole plants.

There are 4 major ways to produce plants from seeds (table 2). Only direct seeding and transplanting are used in bareroot nurseries, but container seedlings have been produced by all 4 methods.

Direct seeding. Direct seeding is the most common and most economical method. After any required pretreatment, seeds can be sown directly into containers or seedbeds. Seeds are always sown by seedlot, and each lot is immediately labeled with some sort of marker that contains all pertinent information. The seedlot location is also permanently recorded in case the markers are lost. Seedlot identity is carefully maintained during the entire nursery operation to ensure that the seedlings are returned to the environment to

Table 1—Chapter 7, Nursery Practices: operational considerations when choosing propagation methods

Considerations	Seeds	Cuttings	Micropropagation
Management objectives			
Fast growth	Most species, using genetically selected seeds from orchards	Good for certain fast growing species	Relatively new but offers enormous potential
Biodiversity	Best	Low, but can be increased with extensive collections	
Availability of propagules	Varies seasonally & yearly; some can be stored for long periods, others not	Collection is seasonal with most species	Collection from stock plants at nursery
Ease of propagation			
Difficulty	Relatively easy	Some species root easily; others not	Currently possible for a few species
Specialized equipment & training	Minimal	Moderate (rooting benches)	Definitely
Timing	BR = seasonal C = year-round	BR = seasonal C= year-round	Year-round
Cost per plant	Low	Moderate	High

Note: BR=Bareroot nursery C=container nursery

which they are adapted. In the Pacific Northwest, some nurseries sow literally hundreds of different seedlots each year, reflecting the many diverse environments in that mountainous terrain. In the South, some nurseries propagate by families and the seedlots from each family are sown and cultured separately.

Many forest and conservation seeds have some type of seed dormancy that keeps them from germinating when placed under unfavorable environmental conditions. Growers need to understand the dormancy characteristics of the seeds that they are trying to germinate, because the type of presowing treatment differs for each. For example, some plants exhibit seedcoat dormancy, which means that the seeds are impermeable to the water and/or oxygen that the embryos need to initiate germination. Culturally, there are a couple of ways to overcome this problem. Scarification—any treatment that breaks down the seedcoats to allow penetration of water and oxygen—can be either mechanical or chemical. Mechanical scarification consists of physically scratching the seedcoat to reduce its thickness, and chemical scarification involves dissolving the seedcoat with caustic chemicals such as acids. Hot water or steam can also be used to soften hard seedcoats.

Another common presowing seed treatment is chilling or stratification, which consists of keeping seeds under a cool, moist environment for a specified period of time. The term stratification comes from the practice of placing layers of seeds between layers of insulating material that keep them moist and cool. A more popular form of stratification is called "naked stratification" because bare seeds are soaked and then placed in a plastic bag without any accompanying material. Bags are kept in a refrigerator for a specified period of time according to the requirements of the individual species. The plastic bag maintains the moisture around the seed but also allows oxygen to enter. Some nurseries place a tube in the mouth of the bag to stimulate better air exchange (see chapter 1 on seed treatments).

Planting germinants. The second method for sowing seeds is to pregerminate the seeds and sow the germinants directly into containers. This technique is particularly helpful with seeds that require long or variable cold, moist stratification treatments; seeds from large-seeded species; and seeds from lots of variable quality (table 2). For seeds that need cold, moist stratification, seeds can be mixed with a moisture-retaining material such as peat moss and placed in a plastic bag in a refrigerator. Another option is to place seeds on moisture-retentive material in a covered tray and keep them refrigerated. Stratifying seeds are checked every few days to see if the seeds have split and germination begun. It is very important to keep seeds moist but not too wet, because mold can develop. Spraying the germination tray with a hand sprayer works well. Germinating seeds are individually picked out of the tray, sown into a container, and then promptly covered with a seed mulch such as white grit to keep them from drying out. Seeds that require warm, moist stratification can be germinated in a greenhouse by

Table 2—Chapter 7, Nursery Practices: characteristics of seed propagation methods for forest and conservation species

Propagation method	Type of nursery	Best use	Advantages	Disadvantage
Direct seeding (seeds are sown with or without pretreatment)	Bareroot or container	Seeds of high quality with viability test information; uniformly shaped seeds with smooth seedcoats	Quick; minimizes seed handling; mechanical seeding possible; most labor efficient; sowing all at once	Requires seed of known high quality; dormant seeds must be pre-treated; Containers require thinning and/or consolidation
Planting germinants or "sowing sprouts" (pregerminated seeds are sown from stratification trays or bags)	Container	Very large or irregularly shaped seeds; seeds of unknown quality or low purity; valuable or scarce seedlots	Good use of growing space; efficient use of seed; can adjust for unknown seed quality	Slower & more labor intensive; sowing can take weeks or months to complete; irregular crop development due to staggered sowings
Transplanting emergents or "pricking out" (seeds are sown into trays & then young emergents are transplanted)	Container	Small or fragile seeds; seeds of unknown quality or low purity; valuable or scarce seedlots	Good use of growing space; efficient use of seeds can adjust for unknown seed quality; more uniform crop development	Slower & more labor intensive; poor technique results in stem deformation; potential disease problems in seed flats
Transplanting seedlings (established seedlings are re-planted into a transplant bed or container)	Bareroot or container	Producing stock with more caliper & larger root systems; hold-over stock	Transplants are more resistant to pests & weeds; increased yields per unit area	Increases cost of stock; requires more bed space than seedlings; "J" or "L" roots result from poor technique

Source: modified from Landis and Simonich (1984).

covering them with a moist layer of burlap. It is important to moisten the seeds frequently during this warm stratification period and then plant them as soon as they crack.

The timing of sowing and seed placement are critical; seeds sown too late or improperly placed may develop weak stems. Germinants must be sown before the radicle becomes too long and begins to curve and must be positioned with the radicle pointing downwards. It is best to dibble a small hole in the growing medium prior to sowing the seed so that the root can be oriented properly.

Transplanting emergents. This method involves growing seedlings to the primary leaf stage and then transplanting them to a container (often called "pricking out"). Transplanting emergents works best for seeds that have complex dormancy, are small in size, or come from lots of variable quality (table 2). In some container nurseries, seeds are sown in special trays and placed in a greenhouse to germinate. Small seeds are covered with a thin layer of sand as a mulch. After the seeds germinate and the young seedlings begin to emerge from the germination medium, they are carefully removed one at a time with a pointed instrument and transplanted into a hole made with a dibble in another container. The growing medium is firmed around the transplant to ensure good root contact, and then the seedlings are allowed to grow into shippable size.

When planting emergents, proper technique is extremely important so that seedlings do not become "J-rooted." One option is to clip off the bottom of the root to make planting easier. Another technique is to use a sharp, forked tool to insert the seedling into the container and then to cut off the root tip after the seedling is placed into the growing medium.

Transplanting seedlings. This propagation technique is used in both bareroot and container nurseries (table 2). Through the 1950s, transplanting was the principal way of producing bareroot seedlings because precision sowing equipment was unavailable. Today, transplanting is again growing in popularity because of the demand for larger seedlings with more-fibrous root systems. Transplants are more expensive to produce than seedlings, but this expense can usually be justified under the new "free-to-grow" reforestation regulations that mandate quick establishment and growth.

Some bareroot nurseries grow seedlings specifically for transplanting, whereas others use smaller-grade stock from harvested seedbeds. Most nurseries transplant bareroot seedlings in the spring, but container seedlings are often transplanted in the summer or early fall. Mechanical transplanters use a vertical "shoe" to open the soil and a wheel with clips to place the transplant into the slit at the proper spacing. Transplant beds have the same physical dimension as seedbeds but seedlings are planted in fewer rows and at much lower densities. Once they become established, transplants are fertilized and irrigated and are given the same root culture treatments as bareroot seedlings.

The first container transplants were made from surplus stock but now seedlings are grown specifically for this purpose. Typically, seedlings are grown in 33- to 66-cm^3 (2- to 4-in^3) containers for 4 to 6 months and are then transplanted to the beds. Miniplugs, the newest type of plug transplant, are grown in very small containers (around 16 cm^3 or 1 in^3) specifically for transplanting. Plug transplants are cultured and harvested in exactly the same manner as are bareroot transplants. Another new larger container stock type is made by transplanting miniplugs into much larger containers—for example, 328 cm^3 (20 in^3).

A complete discussion of seed propagation is provided in Landis and others (1999).

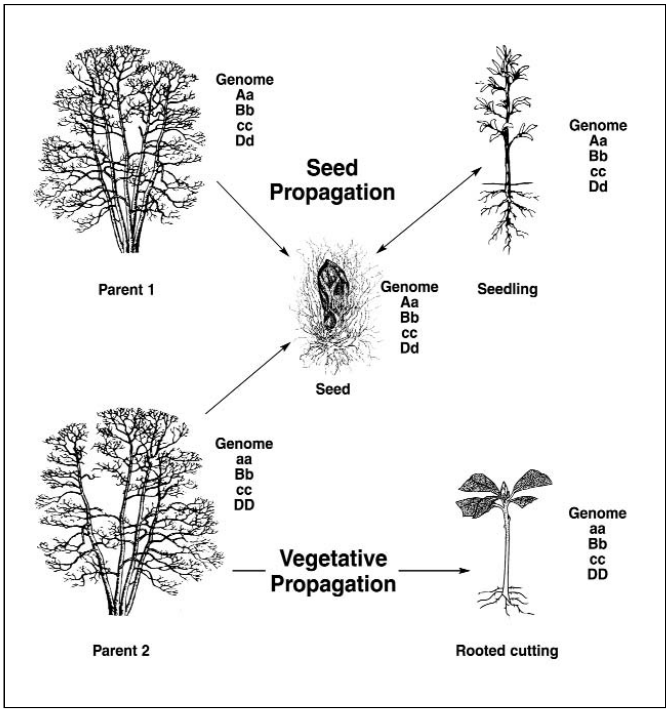
Vegetative Propagation

The second major plant propagation technique is vegetative propagation, which also is called asexual propagation because 2 parents are not required. A clone is defined as a group of genetically uniform individuals that were originally derived from a single parent by asexual propagation. The major benefit of vegetative propagation is that the offspring will very closely resemble the parent because their genetic code is identical (figure 7). Other benefits of vegetative propagation include the following:

1. The ability to obtain a high degree of crop uniformity.
2. The elimination of problems with seed availability, dormancy, and viability.
3. The ability to perpetuate genetically superior plants, such as fast-growing or disease-resistant clones.
4. The ability to "bulk-up" valuable, genetically improved seedlots.

In forest and conservation nurseries, rooted cuttings are the most common type of vegetative propagation, and there are 3 different types that are named for the type of tissue used. Hardwood cuttings (figure 8A) are collected during the dormant period from the last season's growth, stratified in cold storage, and planted ("stuck") in containers or bareroot beds. Semi-hardwood cuttings are collected after the active growth period from hardened woody tissue of the current season's growth. Softwood cuttings are collected from soft succulent new shoots of woody plants that have just begun to harden, normally in spring, but also at any time of

Figure 7—Chapter 7, Nursery Practices: plants propagated from seed appear different from their parents, because they contain a mixture of genetic characteristics **(Top).** Vegetative propagation, on the other hand, produces exact duplicates of the parent plant **(Bottom).**

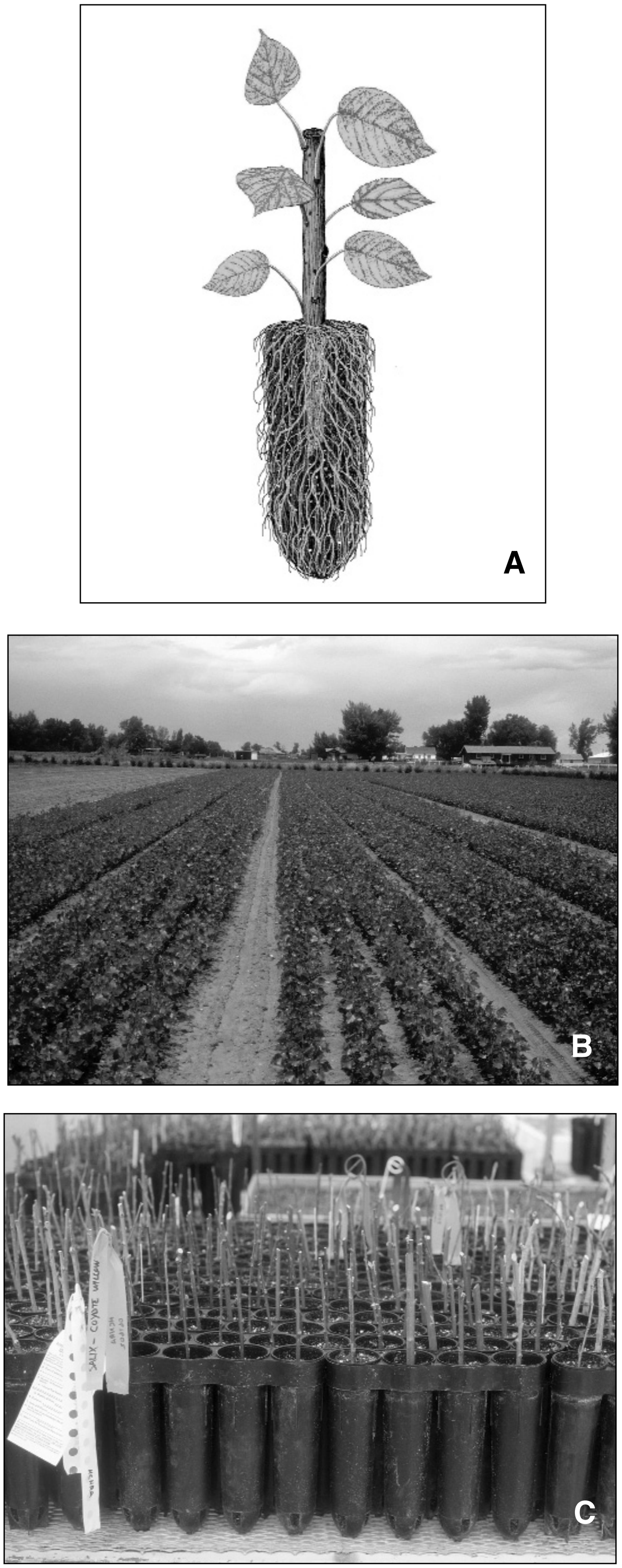


the year in species having multiple flushes. Cuttings can be collected from plants in the wild or from mother plants established in the nursery for that purpose; rows of these mother plants are called stool beds. In bareroot nurseries, cuttings are planted in rows in formed seedbeds and cultured just like seedlings (figure 8B). In container nurseries, cuttings can be rooted in special trays and then transplanted into the growth containers or stuck directly into the containers (figure 8C). Rooting hormones are used to promote new root formation in recalcitrant species. Some nurseries sell unrooted cuttings of such easy-to-root genera as poplar (*Populus*) or willow (*Salix*).

Root cuttings are another type of vegetative propagation source that has been used for some species, such as quaking aspen (*Populus tremuloides* Michx.). Sections of lateral aspen roots, which are actually modified stems, are collected from trees in the wild and placed in growing medium in the greenhouse. After several weeks, shoots form on the roots and can be cut and stuck into growth containers.

Other vegetative propagation methods include air layering, grafting and budding, and micropropagation. Layering is uncommon but can be used for species such as those in the *Rubus* genus that grow as vines. Grafting and budding are normally used for fruit trees; they are too labor intensive

Figure 8—Chapter 7, Nursery Practices: hardwood cuttings are the most common vegetative propagation method used in forest and conservation nurseries (**A**). Hardwood or semi-hardwood cuttings are typically treated with rooting hormones and planted into bareroot beds (**B**) or containers (**C**).

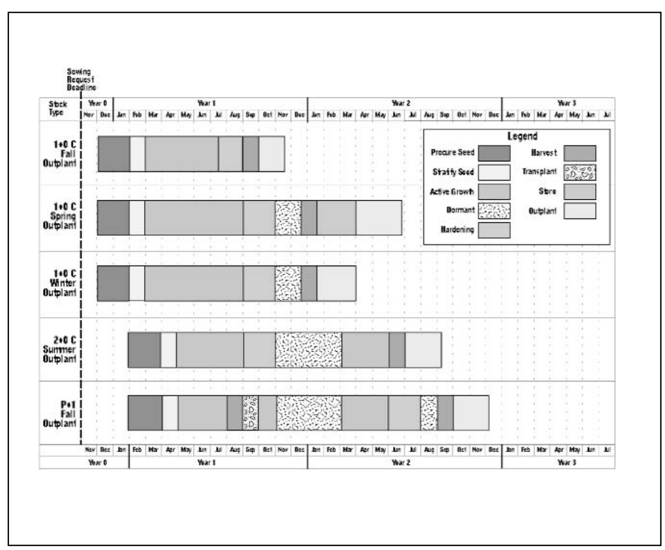


and thus too expensive to use for reforestation stock. Grafting is used in tree improvement programs to develop seed orchards. Micropropagation or tissue culture has been used for some forest species, but it requires specialized equipment and is therefore not currently practical for most species used in reforestation. A complete discussion of vegetative propagation is provided in Landis and others (1999).

Bareroot Nursery Cultural Practices

Bareroot seedlings take from 1 to as many as 4 years to produce, depending on the species, nursery climate, and stock type (figure 9). Southern pine seedlings are produced in 1 year, whereas some northern spruce transplants require 2 years in the seedbed and 2 more years in the transplant bed. Crop rotation requires at least 1 year longer to allow time for soil management. A typical crop rotation for a 2+0 ponderosa pine crop is 2 years with seedlings growing in the seedbed, followed by a 1-year rest or fallow period for the bed. The most comprehensive references on bareroot nursery management include Duryea and Landis (1984), Lantz (1985) and Williams and Hanks (1976). A complete discussion of the equipment needed to produce bareroot seedlings can be found in the *Bareroot Nursery Equipment Catalog* (Lowman and others 1992).

Figure 9—Chapter 7, Nursery Practices: growing schedule are used in crop planning to illustrate the time required for each phase of the nursery cycle from seed procurement to outplanting.



Soil Management and Seedbed Preparation

The bareroot nursery crop cycle starts with soil preparation. Next to water quality, the most important site quality factor in a bareroot nursery is the soil; maintaining or improving soil quality is an ongoing process. The best soil type for a forest and conservation nursery is sand to sandy loam at least 46 cm (18 in) deep.

A typical nursery crop cycle starts with either a cover crop, a green manure crop, or a year of leaving the soil fallow, depending on the objectives of the nursery manager. If the objective is to protect soil from wind and water erosion and control weeds, then cover crops are sown. Green manure crops are primarily grown to supply organic matter to the soil; they also serve as "catch crops" to capture mineral nutrients such as phosphorus and iron in a readily available form. The cover or green manure crop is plowed down in late summer to allow time for the organic matter to decompose (figure 10). If the objective is to eliminate weed growth and lower soil pathogen levels, then the land is kept fallow by repeated cultivation.

In addition to the organic matter supplied by the cover or green manure crop, many nurseries add organic amendments and fertilizers during the fallow year. Sawdust is a good soil amendment if nitrogen fertilizer is also added to promote decomposition; if no fertilizer is supplied, soil microorganisms will cause a nitrogen deficiency in the subsequent seedling crop. Many growers also add preplant fertilizers such as phosphorus or organic fertilizers during the rest or fallow year. Soil pH can be adjusted to the ideal range of 5.5 to 6.5 by adding dolomite to raise the pH or sulfur to lower it. Because phosphorus is immobile in the soil, phosphorus fertilizers are often incorporated into the soil at this time instead of as a top dressing during the growing season.

Figure 10—Chapter 7, Nursery Practices: the bareroot nursery cycle starts with soil preparation. Many nurseries sow a cover crop or green manure crop during the fallow year to protect the soil and maintain the organic matter level.

Seedbeds are prepared for sowing with a series of sequential cultivations, until the soil is worked into the proper crumb-like structure. Because of the frequent use of heavy equipment under wet conditions, soil compaction is a serious and recurring problem in forest and conservation nurseries. Many nurseries "deep rip" or "subsoil" their fields with long shanks during the rest or fallow year to a depth of 46 to 61 cm (18 to 24 in). Ripping is often done immediately after organic matter is applied so that it can be incorporated throughout the soil profile and prevent formation of hard, impermeable layers ("pans").

Many bareroot nurseries fumigate their seedbeds with soil sterilants such as methyl bromide/chloropicrin or methyl isothiocyanate. Fumigation is expensive, but eliminates all common nursery pests: pathogenic fungi, insects, nematodes, and weed seeds. The fumigants are either injected into or mixed with the soil and then covered with a plastic tarp or sealed with irrigation, allowing the gas to permeate throughout the soil. After several days, the tarp is removed or the soil seal broken to allow the gas to dissipate. Due to environmental concerns that have led to the phasing out of methyl bromide under the Montreal Protocol, nurseries are looking for alternatives to soil fumigation. One of these is encouraging the growth of beneficial microorganisms to make the soil suppressive to pathogens.

Sowing

Fall-sowing has been used to allow seeds to stratify naturally over the winter, but most nurseries sow in the spring as soon as soil temperatures are warm enough. In either case, the seeds are sown into preformed, raised seedbeds that are approximately 10 to 15 cm (4 to 6 in) high and 1.2 m (48 in) wide, a standard dimension that corresponds to all mechanized equipment. Seedbeds are laid out side-by-side between irrigation lines (figure 11).

The amount of seed to sow is calculated with a formula that takes both seed characteristics and "seedling factors" into consideration (figure 12):

Seed sowing rate = (desired seedbed density) ÷ (seed viability x nursery factor x seeds per weight)

Figure 11—Chapter 7, Nursery Practices: bareroot seedlings are grown in raised seedbeds that provide better drainage and warmer soil temperatures. Bed width is standardized to allow cultivation by tractor-drawn equipment (modified from *Bareroot Nursery Equipment Catalog* by Lowman and others 1992).

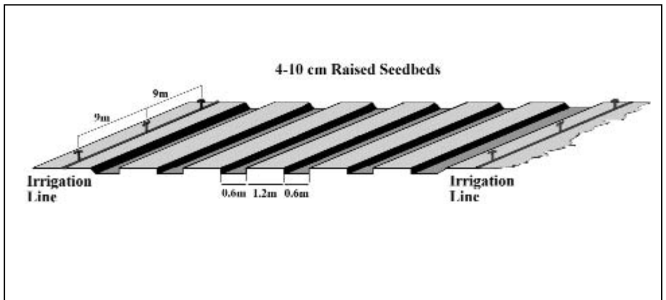
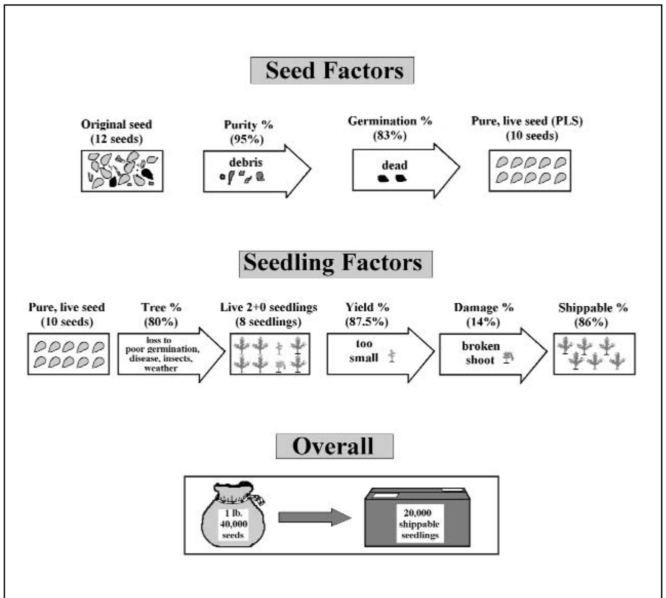


Figure 12—Chapter 7, Nursery Practices: seed use efficiency, the ratio of seeds sown to seedlings harvested, is a function of both seed quality and seedling losses during the growing season (from Thompson 1984).



Sowing seeds at the proper density is one of the most important cultural operations in a bareroot nursery because it controls the quantity and quality of the crop. Seedlings sown at too low a density grow large and out of proper shoot-to-root balance and thus waste valuable growing space. On the other hand, seedlings planted at too high a density often become stunted and spindly and are more susceptible to disease.

Seeds can be broadcast-sown by hand, but this is a critical operation and requires training and practice. Seeds are sown by making quick sideways movements with the hand, pressed into the seedbed with a roller, and then covered with a mulch. Seeds can be mechanically broadcast with a drop spreader, such as a fertilizer spreader, which is calibrated to distribute the proper amount of seeds per area of seedbed. Very small seeds are often mixed with a carrier, such as sand or sawdust, so that they will be distributed more evenly.

Most bareroot nurseries use mechanical seed drills that sow seeds in 6 to 8 rows per seedbed. To control seedling growing density, precision drills are capable of accurately placing seeds at specific distances in the row. Some seed drills automatically cover the seeds with soil, whereas others leave seeds exposed so that they can be covered with mulch, such as sawdust, pine needles, or hydromulch. Mulches serve several functions, including controlling soil erosion, retarding moisture loss, and reducing soil temperature.

Many nurseries apply chemical herbicides immediately after sowing. These pre-emergence herbicides selectively kill germinating weed seeds but do not harm the tree seedlings. Newly sown seedbeds are kept moist until germination occurs, which usually takes 3 to 4 weeks.

Irrigation and Fertilization

The ability to supply water and mineral nutrients for accelerated seedling growth is one of the most important cultural activities in forest and conservation nurseries. Nurseries have used both wells and surface impoundments as water sources; both are adequate as long as they are properly designed to deliver the right amount of water at the right pressure at the right time. Total nursery demand must be calculated to include water for other cultural activities such as cooling or frost protection as well as for seedling growth. The quality of irrigation water is critical and should have been checked before the nursery was ever developed. High pH values of water can be controlled with acid injection but high salt levels cannot be corrected economically.

Most bareroot nurseries pump water through semi-permanent sprinkler systems to keep the seedbeds at the proper soil moisture level. The amount of water to apply can be estimated from soil moisture measurements and predictions of evapotranspirational demand, but successful irrigation requires both good judgement and practical experience. Sprinkler irrigation also is used to cool the soil surface while new germinants are still succulent and to provide protection against late spring or early fall frosts.

Bareroot nurseries apply mineral nutrients needed for rapid seedling growth with chemical or organic fertilizers. Maintaining a slightly acid soil pH is important to ensure that all nutrients remain available. A presowing application of sulfur to lower pH or dolomite to raise it were discussed earlier, along with incorporation of phosphorus. Unless soil tests show other nutrient deficiencies, nitrogen and potassium are the only fertilizers that are typically applied during the growing season. These applications are called "top dressings," because they are applied over the top of the crop. Application rates are determined by experience or from chemical tests of the soil and seedling foliage, and the fertilizers applied by drop or rotary spreaders. Some nurseries inject soluble fertilizer solutions into the irrigation system or apply them through a spray boom behind a tractor. Suspected nutrient deficiencies, as indicated by symptoms such as chlorosis ("yellowing"), should always be confirmed by soil or foliage tests because symptoms can be caused by many factors.

Figure 13—Chapter 7, Nursery Practices: root culturing is important to develop a fibrous root system. These pine seedlings are being wrenched with a sharp-angled blade that is being pulled under the seedbed.

Root Culturing and Top-Pruning

Root culturing is critically important. A tree seedling is only as good as its root system, because forest and conservation species need fibrous roots to absorb water quickly after outplanting. Root-pruning consists of undercutting seedbeds with a stationary or oscillating horizontal blade to sever the dominant tap root and promote new, more-fibrous root growth. Wrenching is a special type of undercutting that uses a thicker angled blade to shatter the soil profile and increase soil permeability and aeration (figure 13). During the hardening period, wrenching also is used to induce a temporary seedling moisture stress that retards shoot growth and induces dormancy. Lateral root pruning with a vertical blade or coulter is used to cut the lateral roots between the seedling rows. This piece of equipment is sometimes "belly-mounted" under the tractor, which allows precise placement by the tractor operator.

Some nurseries top-prune their seedlings to control shoot height and increase crop uniformity. The timing of this operation is extremely critical to ensure that the seedlings are not injured or stimulated to produce abnormal shoot growth. The window for top pruning usually lasts only a few weeks and must be scheduled each year based on seedling development.

Harvesting

Harvesting, or lifting, is done during the dormant period when seedlings are in a state of maximum dormancy and hardiness. This time period, known as the "lifting window" occurs during the late fall, winter, or early spring, depending on the climate of the nursery. Nurseries in milder climates can lift all winter, but nurseries located where the ground freezes have only 2 narrow lifting windows: one in the fall and another in the spring. Because the weather is often too wet in the spring, some nurseries must lift a significant portion of their crop in the fall.

The lifting operation consists of drawing an inclined, vibrating blade under the seedlings, usually at a depth of about 25 to 30 cm (10 to 12 in). The inclined blade lifts seedlings out of the seedbed and the vibrating action loosens soil from around their roots (figure 14A). Some nurseries hand-lift their stock after the seedlings are loosened: the seedlings are pulled from the seedbeds, the loosened soil shaken from the roots, and the seedlings placed in a box. The lifting boxes often are lined with wet burlap to keep the roots from drying out. Several different types of mechanical harvesters are also used to lift seedlings. Most use a digger blade to lift the entire seedbed onto a moving, vibrating belt that shakes soil from the roots; others have rubber gripper belts that pull the seedlings from the soil and transfer them to the work platform. Boxes or larger totes of seedlings are quickly transported to a pre-storage cooler to await grading and processing. In the South, some nurseries "field-pack" their seedlings, which involves bagging seedlings immediately after they are lifted and weighing them. The number of seedlings per bag is estimated from a ratio between the weight of seedling samples and the seedling count.

The time period from when seedlings are lifted until they are outplanted is one of the most critical in the entire reforestation sequence. Tiny fibrous roots are especially prone to drying and can be killed by a few minutes of exposure to heat, direct sunlight, or drying wind. The lifting crew includes several people who are assigned to keep the seedling boxes wet until they can be moved to the pre-storage cooler (figure 14B). Progressive nurseries monitor seedling quality during the seedling harvesting/outplanting operation. The pressure chamber directly measures seedling moisture stress and is used to determine when weather conditions are too dry to lift and to identify potential problems.

Grading, Packing, Storing, and Shipping

Boxes of seedlings that are not field-packed are brought into the packing shed where they are graded and counted. Graders visually rate each seedling according to predetermined grading standards (figure 14 C and D). Bundles of "shippable" seedlings are placed on a moving belt and "culls" are discarded onto the floor and destroyed. Seedlings grown especially for transplanting are also graded in this manner, and some nurseries use a multiple grading system: shippable seedlings, transplants, and culls. Grading standards often are specified by the customer, depending on the intended use. Usually, the nursery manager negotiates these standards with the customer when the seedling order is taken. Grading standards usually consist of a range of acceptable shoot heights, a minimum acceptable stem diameter (caliper), and the length and fibrosity of the root system. Each seedlot is processed separately during the grading process and each box is marked with the proper seed source code (figure 5B).

Shippable seedlings are placed in moisture-retaining boxes or bags. The root systems of southern species are dipped in a clay slurry that coats them and prevents desiccation. For northern species, sphagnum moss or cedar shavings ("shingle toe") is sometimes added to the storage container to keep roots moist. These storage containers are transported to a cooler where they are kept at temperatures near freezing to maintain dormancy and cold hardiness. Cold storage facilities keep the ambient temperature near freezing, but it is important to monitor the temperature inside the storage container. The type of storage depends on the cold tolerance of the species and the length of the storage period. Southern pines will not tolerate freezing and can be cold-stored at slightly above freezing for only 1 to 2 weeks. Cold storage is prescribed for northern species when the storage period is 3 months or less. If the storage period exceeds 3 months, seedlings need to be kept in frozen storage with temperatures kept slightly below freezing. Research has shown that frozen storage can maintain high seedling quality for more than 6 months and also retards the development of storage molds. Hardwood seedlings are cold-stored in open bins under very high humidity. Sometimes, when cold storage is not available, hardwoods are "heeled-in" in outside beds until they can be outplanted. Heeling-in is effective because dormant hardwoods have lost their leaves and therefore lose little moisture through transpiration.

The period between leaving the storage area to outplanting of seedlings is one of the most critical in the entire nursery and reforestation process. Seedlings are susceptible to many abuses; desiccation and warm temperatures are the most serious. Cold is the primary environmental factor that maintains seedling dormancy, and even fully dormant seedlings can begin to grow after relatively short exposures to warm temperatures. Ideally, seedlings will always be shipped and stored on the outplanting site in refrigerated vans. If seedlings must be shipped in non-refrigerated trucks, then they should be covered with white or reflective tarps to keep them cool and retard desiccation. An excellent guide to all aspects of seedling handling that pertains to all species—not just southern pines—is provided by Lantz (1989) in *A Guide to the Care and Planting of Southern Pine Seedlings*.

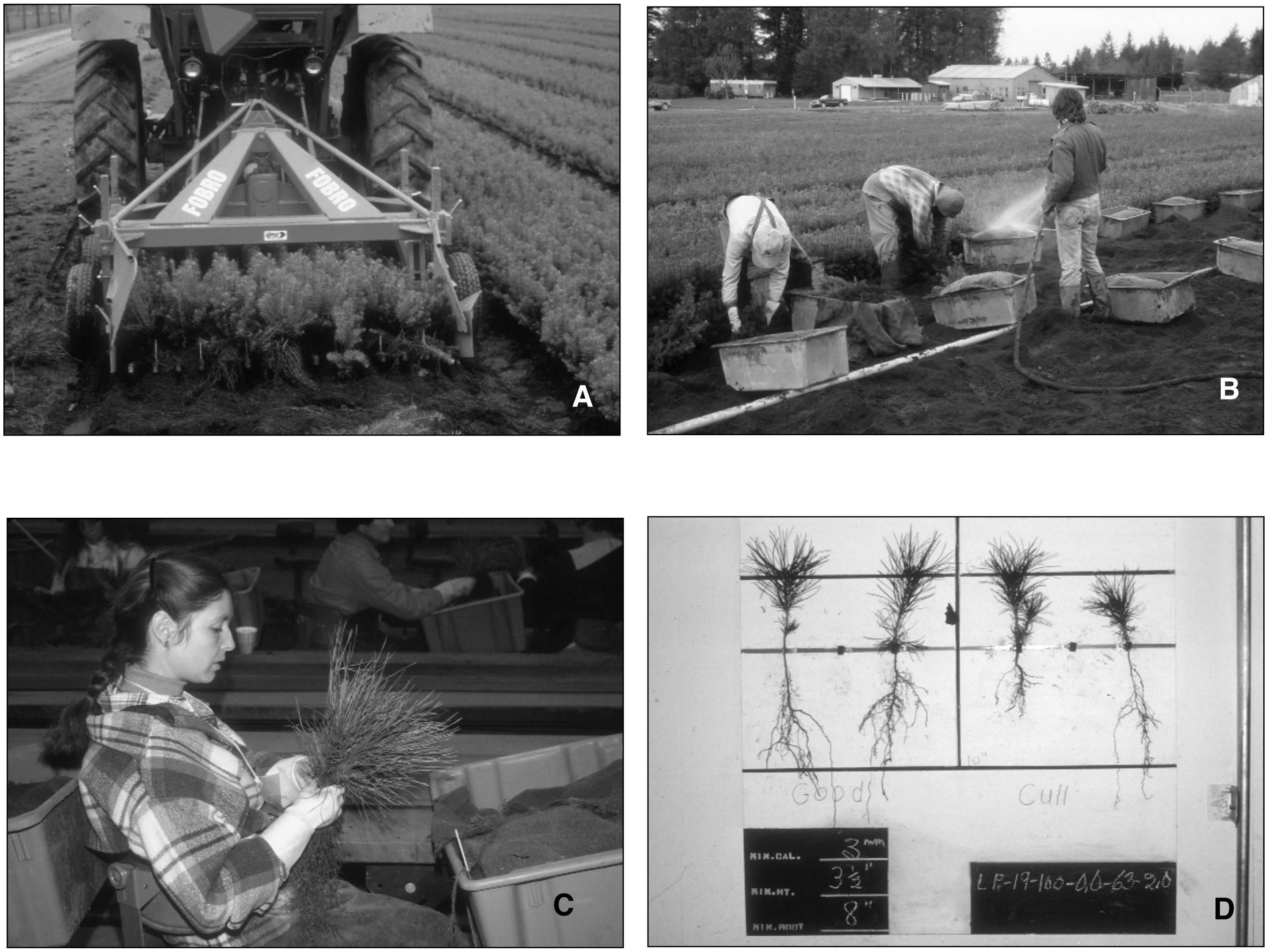
Container Nursery Cultural Practices

Container seedlings are grown in relatively small-capacity containers in special growth-promoting environments that can produce a shippable seedling in as little as 9 to 12 months (figure 2B). In the temperate zone, container crops are scheduled around the summer solstice, when solar energy and temperatures are at levels that promote rapid growth. Although many container nurseries typically grow just 1 crop per season, some can raise 2 or 3 crops by careful scheduling. The first crop is sown in late winter and grown in the greenhouse until outdoor conditions are mild enough to move seedlings outside. The second crop is sown just before the summer solstice so that the seedlings can still benefit from the intense sunlight of early summer and are left in the greenhouse through fall. In semitropical and tropical climates, container seedlings can be grown year-round and the growing schedule is primarily determined by moisture conditions on the outplanting site.

Propagation Environments

Several different types of growing environments are used to produce container seedlings. Fully controlled environments, such as the traditional greenhouse, are popular in colder climates and feature permanent sides and a full range of environmental control equipment. Semi-controlled environments, called shelterhouses, have sides that can be rolled up to promote better cross ventilation (figure 15A).

Figure 14—Chapter 7, Nursery Practices: harvesting equipment lifts bareroot seedlings by undercutting them and loosening soil from around the roots with vibration (**A**). During hand-lifting, workers pull seedlings from the seedbed and place them in tubs, being careful to avoid excessive exposure and desiccation (**B**). Seedlings are then taken to the packing shed where they are counted and graded (**C**) to predetermined morphological specifications that were agreed upon by the nursery manager and the customer: shoot height, stem diameter (caliper), and some measure of root size and fibrosity (**D**). Finally, the "shippable" seedlings are sealed into moisture-retentive bags or boxes for refrigerated storage (**E**).



Shelterhouses produce one crop per season, and the seedlings benefit from exposure to ambient conditions during the hardening phase. In milder climates, container seedlings can be grown in outdoor compounds (figure 15B). The type of growing environment will determine which cultural options are available and the resultant seedling growth rate. To reach the genetic potential of the crop, greenhouses and shelterhouses supply heating, ventilation, photoperiodic lighting, irrigation, fertilization, and even supplemental carbon dioxide. In open compounds, the ground is covered with weed barrier cloth and gravel to control weed growth, and the seedlings are raised on tables. Although temperatures cannot be controlled, the crop has the benefit of irrigation, fertilization, and sometimes even photoperiodic lighting.

Figure 15—Chapter 7, Nursery Practices: container seedlings are grown in a variety of propagation environments ranging from traditional greenhouses, to shelterhouses (**A**), and open growing compounds (**B**).

Types of Containers

There are many different types of containers, with capacities ranging from as small as 16 cm^3 (1 in^3) to more than 492 cm^3 (30 in^3). The most commonly used container types include Styrofoam® blocks, book planters, and several types made of molded hard plastic. Other growing containers, such as peat plugs and plastic bags, are sometimes used, but these lack vertical ribs on their insides for controlling root spiraling. The best type of container depends on available nursery equipment, the species of plant, and conditions at the outplanting site. Hardwood species must be grown in relatively larger containers than conifers because their large leaves intercept irrigation and create more shade competition with their neighbors. Foresters prefer seedlings grown in smaller containers for moist outplanting sites, but demand larger container stock for harsh dry conditions or sites with heavy brush competition. New container types are continually being developed. One of the newest innovations involves lining the container cavity with copper compounds that "chemically prune" the root system. Most containers can be used for more than 1 growing season and thus must be cleaned and sterilized between crops with hot water or chemical disinfectants.

Growing Media

Almost all container nurseries use some type of artificial growing medium instead of native soil. An ideal medium should be sterile, lightweight, porous, and consistent in quality. Several different brands of media are commercially available, and most are composed of sphagnum peat moss, vermiculite, and sometimes perlite, composted bark, or sawdust. Some nurseries mix their own growing media. Larger nurseries have specially designed mixers for blending the components, and some have customized equipment using cement mixers and so forth. Some components of growing media, such as vermiculite and perlite, are inherently sterile; sphagnum moss, however, may contain pathogenic fungi. Chemical fumigants or steam heat are typically used to sterilize media. Fertilizers or other chemical amendments are sometimes added to growing media during the mixing process. Dolomitic limestone is used to supply calcium and magnesium and raise the low pH. Slow-release fertilizers, such as Osmocote®, are composed of resin-coated pellets that release mineral nutrients in response to temperature and moisture.

Containers are filled with growing medium in several different ways. Smaller nurseries fill containers by hand. Automated filling machines that do everything from filling and tamping the medium to sowing and covering the seeds can also be used. A complete discussion of container types and growing media can be found in Landis and others (1990).

Sowing and Thinning

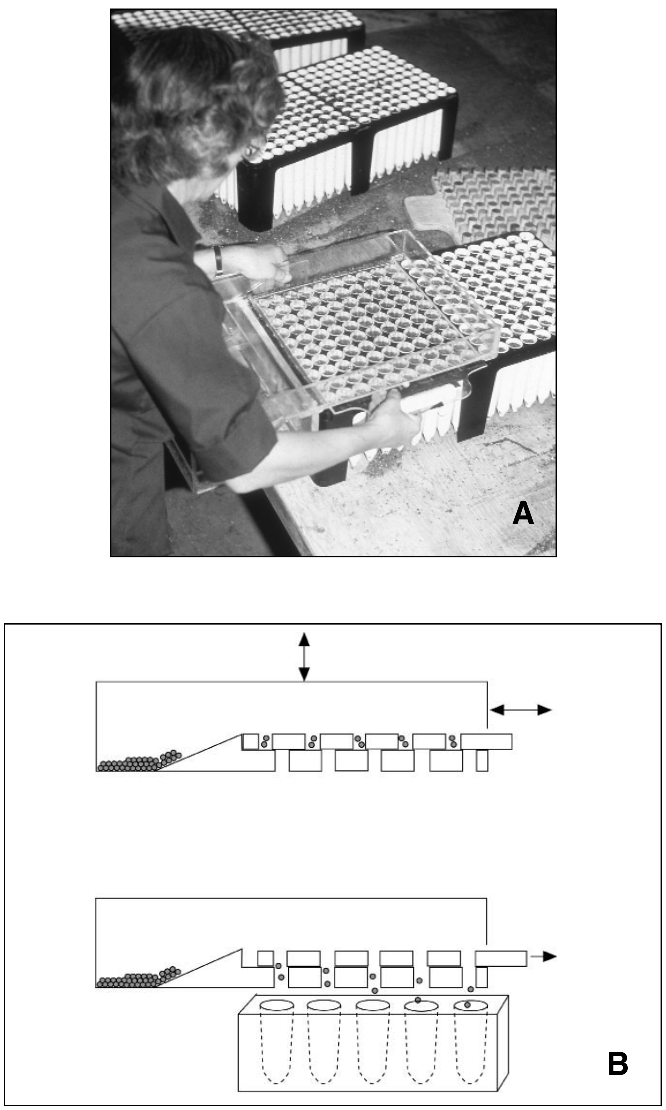
The number of seeds to sow per container cavity is calculated using the seed germination percentage, with the objective of having no empty cavities. Containers can be sown by hand, which is necessary for very large or irregularly shaped seeds, or with various sowing machines. The shutterbox (figure 16A) consists of a template with a set of predrilled holes that correspond to the pattern of the individual container cavities. The size of the holes in the shutter control the sowing rate, usually from 2 to 6 seeds per hole depending on seed quality (figure 16B). Vacuum seeders have plates or drums that hold a certain number of seeds until they are released into the containers. Precision sowing machines can accurately control the sowing density down to

1 seed per cavity. Although expensive, this equipment saves valuable seeds and eliminates the need for thinning.

The final stage in the sowing process consists of covering the sown seeds with some type of mulch such as perlite, grit, or coarse vermiculite. Light-colored mulches are preferred because they reflect sunlight and thus do not heat up as much as darker materials. Seed mulches restrict the growth of algae, mosses, and liverworts and also prevent weeds from becoming established. The depth of seed covering is very critical—if it is too deep, the seeds will not germinate; if it is too shallow, the seeds will dry out. The recommended depth is 2 to 3 times the width of the seeds.

Sown containers are moved into the growing area where they are placed on specially designed pallets or benches that promote air-pruning of the root system. Some benches are constructed on rollers so that they can be moved together when access is not required. This feature is popular because it saves valuable growing space. As in bareroot nurseries, the identification of each seedlot and its location is carefully monitored during the nursery process.

Figure 16—Chapter 7, Nursery Practices: shutterbox seeders are custom-made for each type of container (**A**). Sowing consists of filling the precisely spaced holes in the shutter with seeds (**B, top**) and then moving it laterally to allow the seeds to drop into the containers (**B, bottom**).



After 3 to 4 weeks, when seed germination is complete, workers thin multiple germinants down to 1 per cavity and remove any weeds that may be present. Extra seedlings are either pulled or clipped, depending on their size. Larger seedlings must be clipped because pulling them may uproot the crop seedling. If the sowing calculations were inaccurate, some containers may be empty. Resowing is an option, but late-sown seedlings would rapidly be overtopped by their neighbors and usually remain stunted. Single-cell containers such as the Ray Leach® system can be consolidated to remove empty cavities, saving valuable growing space.

Irrigation and Fertilization

Water quality is the most critical site selection factor for container nurseries, but because these nurseries can use a well-drained, slightly acid growing medium, they are better able to manage marginal water quality than are bareroot nurseries.

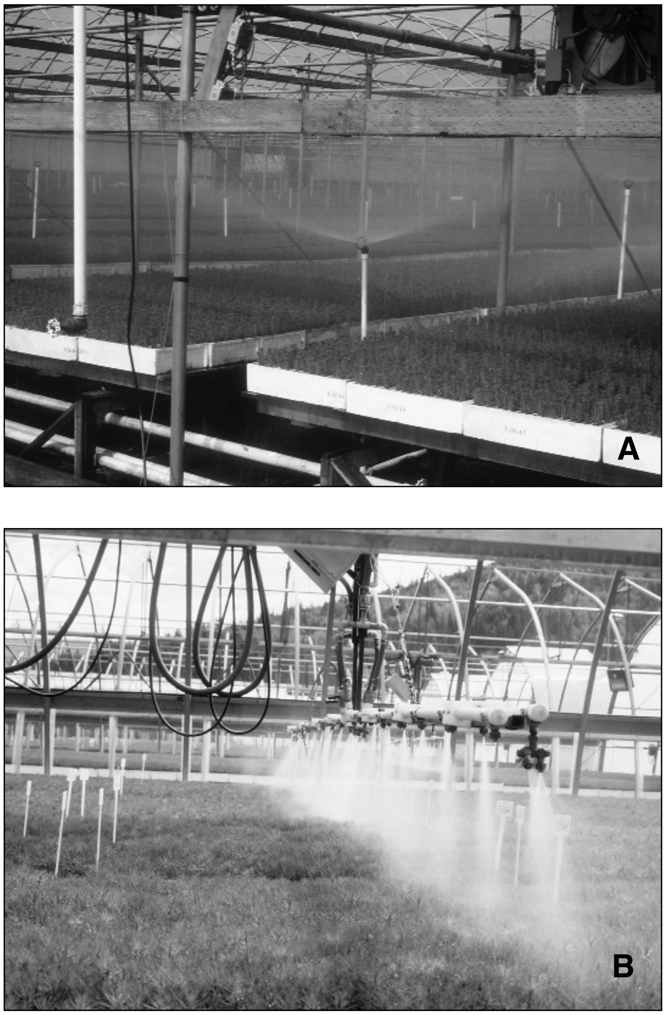
Eliminating water stress is crucial to achieving good seedling growth, and container nurseries use either stationary overhead sprinklers or mobile boom irrigation systems. Stationary systems consist of sprinkler heads set in a regular pattern that distribute water in a circular pattern (figure 17A), whereas mobile systems have a horizontally mounted boom that moves back and forth to deliver a uniform amount of water to the crop (figure 17B). Determining when and how much to irrigate is particularly difficult in a container nursery because seedlings use up water quickly in the small containers and it is difficult to directly observe moisture conditions. The best irrigation monitoring technique is to weigh containers between irrigations, as the relative wetness of the growing medium can be correlated to container weight.

Most container nurseries fertilize through the irrigation system, a process sometimes called "fertigation." Liquid fertilizer solutions are injected into the irrigation lines in the headhouse and applied to the crop through nozzles. The ability to supply all 13 essential mineral nutrients allows seedlings to grow at an exponential rate, and nutrient injection systems can supply the proper nutrient concentration and ratio at exactly the right time.

Hardening

When container seedlings have reached their desired height, the nursery manager changes the growing environment to initiate hardening. The most critical environmental

Figure 17—Chapter 7, Nursery Practices: container seedlings are typically irrigated either with stationary sprinklers (**A**) or moving irrigation booms (**B**).



factors for inducing hardiness and dormancy are cooler temperatures, mild moisture and nutrient stress, and shortened photoperiod. Seedlings in fully enclosed greenhouses are often moved to a shadehouse at this time, where the change in temperature and humidity aid the hardening process. Growers with shelterhouses permanently raise the sides to expose the crop to ambient conditions. At the same time, the photoperiod lights are shut off and the fertilizer mix changed to a special low-nitrogen hardening formula.

Harvesting, Grading, Storing, and Shipping

The harvesting method is related to the type of seedling storage. Some nurseries store their container seedlings outside to overwinter in sheltered storage, being particularly careful to insulate the root systems against cold. Seedling roots are much less cold-tolerant than shoots and can be damaged or even killed at temperatures that are only a few degrees below freezing. Other nurseries grade their seedlings and ship them directly to the outplanting site in the growth container. This procedure is necessary where freezer storage facilities are not available, but the seedlings still must be protected and maintained at the outplanting site.

Refrigerated storage is becoming increasingly popular. Like bareroot seedlings, container stock is usually harvested during the dormant period unless conditions on the outplanting site require otherwise. Cold hardiness tests can be used to determine when seedlings are ready for harvesting. Research has shown that these tests are a good indication of overall hardiness and dormancy. Nurseries pull seedlings from the growth container and wrap or bag them in bundles (figure 18A). The bundles are placed in moisture-proof boxes and stored under refrigeration (figure 18B). Container seedlings of cold-tolerant species can also be freezer-stored and treated essentially the same as bareroot stock. Container stock should be shipped to the outplanting site in refrigerated vans whenever possible and always kept out of direct sunlight and protected from drying winds.

Pest Management

The objective in both bareroot and container nurseries is to optimize the potentially limiting factors that control seedling growth to create the perfect propagation environment. Like all things in life, however, there is a trade-off. In this case, there is an increased risk of pests and abiotic stresses—increased succulence means greater risk of abiotic injury (frost injury is a prime example). The perfect propagation environment is also, unfortunately, a perfect breeding ground for many fungi, insects, and other pests.

A disease occurs anytime a seedling is not completely healthy. Both biotic pests and abiotic stresses can cause disease. Typical nursery pests include fungi, insects, and even weeds or moss, which compete with the seedling for light, nutrients, and water. Abiotic stresses include temperatures that are too high or too low and moisture and nutrient stresses. Although most people would think that biotic pests cause the most injury in nurseries, that is not the case (figure 19). Abiotic diseases are actually more common, especially in bareroot nurseries and open growing compounds, where seedlings are subject to the vagaries of the weather.

All pest problems can be prevented much more easily than they can be cured, so nurseries should set up a regular monitoring program. Nursery workers should constantly be on the lookout for anything unusual and notify the manager immediately if they notice a potential problem. Careful monitoring can distinguish between biotic and abiotic diseases (table 3) and make control much more effective. There

Figure 18—Chapter 7, Nursery Practices: many container seedlings are harvested by pulling them from the containers (**A**), wrapping them in plastic film or placing them in bags, and then storing them under refrigeration (**B**).

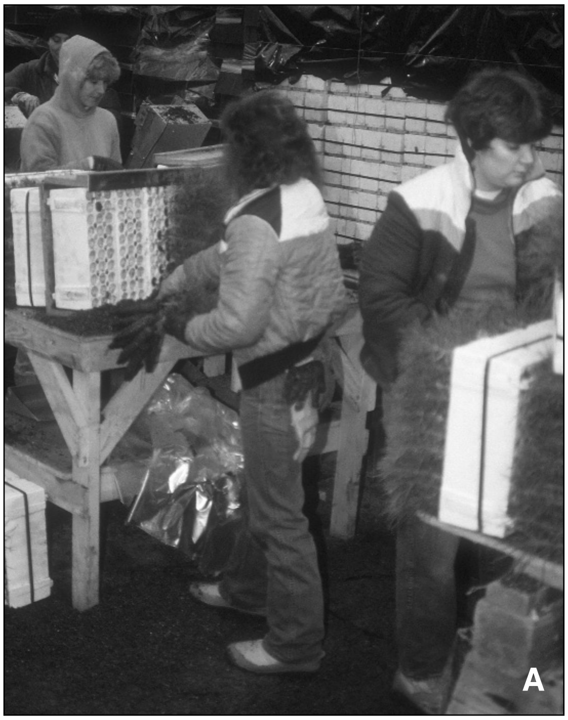
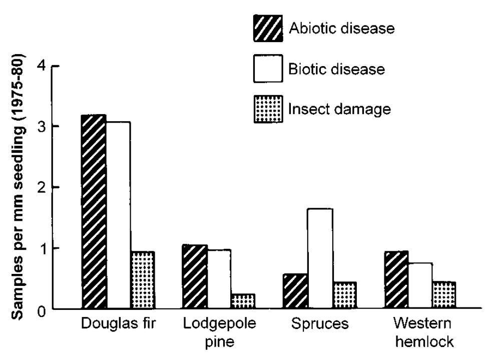


Figure 19—Chapter 7, Nursery Practices: abiotic diseases are usually more common than damage from biotic pests in forest and conservation nurseries (modified from Sutherland and others 1982).



are a couple of good references that can help improve diagnostic skills. For bareroot seedlings, readers are referred to *Forest Nursery Pests* (Cordell and others 1989), and for container seedlings, to volume five of the *Container Tree Nursery Manual* (Landis and others 1989).

Once a pest has been confirmed and the population has exceeded the allowable limit, growers should take immediate action. All controls should be part of an integrated pest management (IPM) program that uses cultural as well as chemical controls. Many pest problems, such as *Botrytis* blight, can be almost completely controlled using proper irrigation and sanitation measures. Fungicides and insecticides are often needed however, especially when a problem has gotten out of hand. Pesticides are usually injected through the irrigation system in container nurseries or with tractor-drawn sprayers in bareroot beds. In recent years, some new biocontrol agents have proven useful in controlling insect pests, such as fungus gnats in greenhouses.

Weeds are a much more serious concern in bareroot nurseries, where they must be controlled either mechanically

Table 3—Chapter 7, Nursery Practices: careful observation of disease development can aid in diagnosis

Characteristics	Abiotic disease	Biotic disease
HOSTS	Often affects several species, or ages of seedlings	Usually restricted to one species or age class
SYMPTOMS		
Patterns	Regular: spatially related to some environmental factor	Random locations at first
Rate of development	Rapid & uniform	Relatively slow & uneven
Signs	No evidence of a pest	Pests or indirect evidence present
Spread	Related to one incident, with no secondary spread	May spread over time under favorable conditions

Source: modified from Sutherland and Van Eerden (1980).

and chemically. Hand-weeding and mechanical cultivation can keep weed populations low and are especially effective if done before weeds are allowed to go to seed. Most nurseries apply a pre-emergence selective herbicide immediately after sowing and then at intervals during the growing season. Another option is to apply non-selective contact herbicides directly to the weeds with wick applicators or shielded sprayers.

Beneficial Microorganisms

Mycorrhizae develop from a symbiotic relationship between a beneficial fungus and the roots of the host seedling. Although mycorrhizae have been a popular topic for many years, there seems to be a variety of opinions as to their value in forest and conservation nurseries. Some people believe that mycorrhizae are essential for both nursery culture and successful outplanting, whereas other nursery and reforestation specialists are more skeptical. Almost 50,000 research studies have been done on mycorrhizae, and most confirm the benefits of reducing root disease and increasing seedling tolerance to drought and other environmental extremes. Results of operational nursery and field trials have been more variable, however, depending on the species of mycorrhizal fungus used and soil fertility and types of indigenous fungi on the outplanting site.

Inoculation with mycorrhizal fungi can be worthwhile, but the timing of inoculation and species of fungus should be matched to nursery and outplanting objectives (table 4). In particular, the fungal species should be selected for either the nursery or the outplanting site. There is no "all-purpose" fungus that will perform well under all conditions. Most fungal species that are adapted to wildland conditions will not survive under the high moisture and high nutrient nursery environment and vice versa. However, some genera of fungi, including *Thelephora, Laccaria,* and *Rhizopogon*, have strains or ecotypes that are adapted to either nursery or forest soils.

The species of fungus, type of inoculum, and timing of the inoculation will vary with the objectives of the treatment (table 4). Inoculants that are meant to prevent diseases or increase seedling growth in the nursery should be applied to seeds, incorporated into the soil or growing medium or applied as a spore suspension (figure 20). However, if the objective is to increase seedling survival and growth after outplanting, then a species of fungus adapted to the outplanting site should be applied late in the growing season or as a root dip during processing (table 4).

Therefore, when considering inoculation, it is extremely important to define objectives. Mycorrhizal fungi and other beneficial microorganisms can make a good seedling better but they shouldn't be expected to be a "cure-all" that will solve every nursery and outplanting problem.

Summary

Anyone considering propagating forestry and conservation species must be familiar with the unique characteristics of these plants. Unlike most other crops, seedlings from forest nurseries are typically outplanted on relatively harsh sites without subsequent care. This difference is significant because seedling quality is defined by environmental conditions on the outplanting site. There is no such thing as an "all-purpose" tree seedling. Bareroot and container seedlings have different applications, and the choice of approach depends on the available resources, the nursery climate, and the conditions on the outplanting site.

Table 4—Chapter 7, Nursery Practices: nurseries and seedling customers must consider their reasons for inoculating with mycorrhizal fungi because their objectives determine the species of fungus and the type and timing of inoculation

Type of mycorrhizal inoculation	Timing in the nursery crop cycle	Objectives of inoculation *	
		Nursery	Outplanting
Coating seeds with spores	Before sowing	1) Increased growth 2) Disease prevention	None
Incorporating mycelia into the growing medium	Before sowing	1) Increased growth 2) Disease prevention	None
Liquid drench with spores	Establishment or rapid growth phases	1) Increased growth 2) Disease prevention	None
Liquid drench with spores	Hardening phase	1) Disease prevention 2) Increased growth	1) Increased survival
Root dip with spores	During packing or before outplanting	None	1) Increased survival 2) Increased growth

* Regardless of the biological objectives, mycorrhizal inoculation may have marketing advantages.

Figure 20—Chapter 7, Nursery Practices: seedlings can be inoculated during the growing season with a liquid suspension of spores from a beneficial mycorrhizal fungus.

Forestry and conservations plants are typically propagated by seed, although vegetative propagation is used for some species. Direct seeding is by far the most common, although sowing germinants or transplanting is used for species that have complex germination requirements or other operational restrictions. Although specific practices differ for container and bareroot seedlings, a successful cultural regime must be designed to reflect the biological requirements of the species and the available resources of the nursery.

Seedlings must be properly handled and stored from the time they are harvested until they are outplanted. Exposure of the root system is particularly damaging to seedling quality. Because warm temperatures rapidly bring seedlings out of dormancy, refrigerated storage is recommended whenever possible. The time between removing the seedlings from the storage area and outplanting them is one of the most critical in the entire nursery and reforestation process. Seedlings are susceptible to many abuses, with desiccation from exposure to direct sun and overly warm temperatures the most serious. Seedling users need to understand that seedling quality only decreases after the seedlings leave the nursery and all mistakes and abuses are cumulative.

References

Cordell CE, Anderson RL, Hoffard WH, Landis TD, Smith RS Jr, Toko HV, tech. coords. 1989. Forest Nursery Pests. Agric. Handbk. 680. Washington, DC: USDA Forest Service. 184 p.

Duryea ML, Landis TD, eds. 1984. Forest nursery manual: production of bareroot seedlings. Boston: Kluwer Academic Publishers. 385 p.

Landis TD, Simonich EJ. 1984. Producing native plants as container seedlings. In: Murphy PM, comp. The challenge of producing native plants for the Intermountain Area. Proceedings, Intermountain Nurserymen's Association Conference; 1983 August 8–11; Las Vegas, NV. Gen. Tech. Rep. INT-168. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station. 96 p.

Landis TD, Tinus RW, McDonald SE, Barnett JP. 1989. The container tree nursery manual. Volume 5, The biological component: nursery pests and mycorrhizae. Agric. Handbk. 674. Washington, DC: USDA Forest Service. 171 p.

Landis TD, Tinus RW, McDonald SE, Barnett JP. 1990. The container tree nursery manual. Volume 2, Containers and growing media. Agric. Handbk. 674. Washington, DC: USDA Forest Service. 87 p.

Landis TD, Tinus RW, McDonald SE, Barnett JP. 1994. The container tree nursery manual. Volume 1, Nursery planning, development, and management. Agric. Handbk. 674. Washington, DC: USDA Forest Service. 188 p.

Landis TD, Tinus RW, McDonald SE, Barnett JP. 1999. The container tree nursery manual. Volume 6, Seedling propagation. Agric. Handbk. 674. Washington, DC: USDA Forest Service. 167 p.

Lantz CW, tech. coord. 1989. A guide to the care and planting of southern pine seedlings. Mgmt. Bull. R8-M–39. Atlanta: USDA Forest Service, Southern Region. 44 p.

Lantz CW, ed. 1985. Southern pine nursery handbook. Atlanta: USDA Forest Service, Southern Region. Unpaginated.

Lowman BJ, Landis TD, Zensen F, Holland B. 1992. Bareroot nursery equipment catalog. Prog. Rep. 9224-2839-MTDC. Missoula, MT: USDA Forest Service, Missoula Technology and Development Center. 204 p.

South DB, Mexal JG. 1984. Growing the "best" seedling for reforestation success. Auburn: Alabama Agricultural Experiment Station, Auburn University, Forestry Department. 11 p.

Sutherland JR, Van Eerden E. 1980. Diseases and insect pests in British Columbia forest nurseries. Joint Rep. 12. Victoria: British Columbia Ministry of Forests and Canadian Forestry Service, Pacific Forest Research Centre. 55 p.

Sutherland JR, Lock W, Benson LE. 1982. Diseases and insects and their management in container nurseries. In: Scarratt JB, Glerum C, Plexman CA, eds. Proceedings, Canadian Containerized Tree Seedling Symposium, 1981 September 14–16, Toronto. Sault Ste. Marie, ON: Canadian Forestry Service, Great Lakes Forest Research Centre: 215–223.

Thompson BE. 1984. Establishing a vigorous nursery crop: bed preparation, seed sowing, and early seedling growth. In: Duryea ML, Landis TD, eds. Forest nursery manual: production of bareroot seedlings. Boston: Kluwer Academic Publishers: 41–49.

Williams RD, Hanks SH. 1994. Hardwood nursery guide. Agric. Handbook 473. Washington, DC: USDA Forest Service. 78p