13 Selection of Planting Stock, Inoculation with Mycorrhizal Fungi, and Use of Direct Seeding

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INTRODUCTION

Once a decision has been made to artificially reforest rather than rely on natural regeneration, the type of nursery stock or propagule to be used must be chosen from an array of alternatives. Seedlings can be grown in outdoor beds for lifting as bareroot seedlings or transplants, or they can be grown in one of many different types of individual containers under some sort of greenhouse cover. Rooted cuttings can be grown in nursery beds or containers. Length of time in a nursery can vary from one to three growing seasons. Wildlings can be dug from forest sites or roadsides. Seedlings can be inoculated with mycorrhizal fungi, or not. Planting stock can be produced in other innovative ways or combinations of ways; e.g., planting pregerminated seed, growing bareroot seedlings in raised beds, or transplanting container seedlings into outdoor beds for lifting as bareroot plants. Direct seeding is little used today, but new technology could change this situation quickly if success at low cost were possible. Propagules raised from tissue cultures will probably be used in the future.

Seedlings differ in size, morphology, and physiological condition, and these differences affect how they perform under different situations and on different types of sites. Different species require different stocktypes to produce seedlings of comparable size. Furthermore, availability and cost of production and planting play a part in the decision of which type to use. However, the cheapest initial choice is not necessarily the most economical in the long run, because survival and growth rates can have a pronounced effect on ultimate yields or rotation lengths.

The objective of much current reforestation research effort is to develop morphological and physiological guidelines that match seedling specifications to particular types of operational environments (Rose et al. 1990b). This chapter describes the choices available, reviews the research comparing them, and provides a rationale for making decisions.

TERMINOLOGY

With the advent of different methods of producing planting stock, terminology has become con-

Table 13-1. Stocktypes most commonly used in southwestern Oregon and northern California.

Stocktype description	*Normal designation*
1-year-old bareroot	1+0
2-year-old bareroot	2+0
1-year-old transplanted for second year (bareroot)	1+1
2-year-old transplanted for second year (bareroot)	2+1
1-year-old container-grown (also called plug)	P+0
1-year-old plug transplanted for second year (bareroot)	P+1
$\frac{1}{2}$-year-old miniature plug transplanted for second year (bareroot)	MP+1

fusing. Thus, for purposes of this book, we will define our use of terms.

Seedling is used in the general sense of a very young tree regardless of where and how it is growing. *Nursery stock* and *planting stock* are synonymous terms denoting seedlings being grown or having been grown for outplanting on forest sites. A *stocktype* is a class or group of seedlings produced by one or more of the basic methods—bareroot, container, or transplant, or combinations of these—and for a particular length of time (Table 13-1, Figure 13-1). Special treatments used in production will not be considered part of the stocktype definition. For example, seedlings inoculated with mycorrhizal fungi will not be considered a separate stocktype.

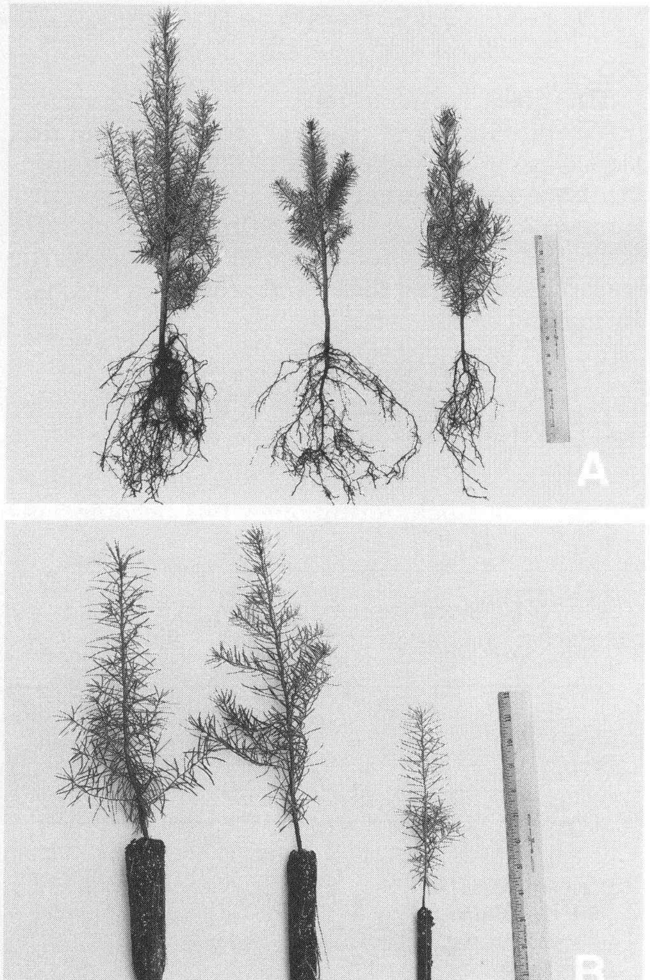

Figure 13-1. Example of typical stocktypes of Douglas-fir. (A) (left to right) Bareroot 1+1, 2+0, and 1+0 seedlings.(B) Container seedlings grown in styrene blocks with cavities of (left to right) 8, 5, and 1 cubic inches. Photos courtesy of J.H. Stone Nursery, Medford, Oregon, and Georgia-Pacific Corp., Cottage Grove, Oregon, respectively.

Seedlings produced in traditional outdoor nursery beds are lifted with their roots essentially bare of soil and are thus termed *bareroot* seedlings. *Container* seedlings are those grown in individual pots—usually, but not necessarily, in greenhouse nurseries. Most container seedlings are extracted from their containers and planted with a plug of potting mixture and roots; thus, the term *plug* seedling is used synonymously with container seedling. A *transplant* is a seedling that was started from seed in either a bed of soil or potting mixture or in some type of container and then transplanted elsewhere—usually into an outdoor bed for subsequent lifting as a bareroot seedling. A miniature plug is a seedling grown for a few months in a very small container (about 1-cubic-inch volume) and usually destined for transplanting into bareroot beds.

The age at which a seedling is to be outplanted is designated by a two-digit code that becomes part of the stocktype description. The first digit represents the number of years (i.e., growing seasons) spent in a seedbed or container in which its seed was sown. The second digit represents years in a transplant bed. Thus, a tree left to grow in its seedbed, and intended to be outplanted as a 2-year-old bareroot seedling, is termed a 2+0 seedling. Most container seedlings are grown for only 1 year and thus, in this book, are designated as P+0s, with the understanding that 1 year is the plug age. A seedling grown 1 year in a container and then put into a transplant bed for a year is termed a P+1. Miniature plugs are designated as MP; thus, the final stocktype is usually MP+1.

SEEDLING STOCKTYPES

Size and Condition Specifications

It is not sufficient to specify only stocktype when ordering seedlings. Both growers and users are, or should be, interested in the morphology and physiological condition of their seedlings because of the relationship of these factors to field performance. Although some stocktypes have distinct characteristics (Table 13-2), sizes vary greatly within stocktypes and can often overlap among types. Furthermore, seedlings of any stocktype can be in poor to excellent condition due to environmental or nursery-culture factors. An international symposium was recently held in southwestern Oregon to present the concept of targeting seedling characteristics for specific sites and conditions. Its proceedings are recommended reading for those wanting more details (Rose et al. 1990a).

Table 13-2. Relative stocktype characteristics.

Stock-type	*Bare-root*	*Size*	*Plant-ability*[1]	*Suscep-tibility to damage*[2]	*Cost*
1+0	Yes	Small	Easy	High	Low
2+0	Yes	Average	Average	Average	Average
1+1	Yes	Large	Difficult	Low	High
2+1	Yes	Large	Difficult	Low	High
P+0	No	Small	Easy	High	High
P+1	Yes	Large	Difficult	Low	Highest

[1] Relative ease of planting in terms of the size of hole needed and the difficulty of proper root placement.

[2] Relative susceptibility to damage from animals, excessive heat, and ravel.

Those ordering seedlings usually give specifications at the time orders are placed. Common parameters used to describe seedlings are top height, stem diameter at or near the root collar (also called stem caliper), and root length. Presence of single main stems and distinct terminal buds may also be specified. Other measurements that can be used to characterize seedlings—although not often used in specifications—are dry weight, root volume, and top-to-root ratio (by weight or length). Of course, misshapen and damaged seedlings are culled at the nurseries.

In most cases, physiological condition is more important than size (Hobbs 1984). But true physiological condition is difficult to determine within the short time frame that people need answers. Thus, most physiological specifications used in the past have been very general; e.g., healthy, dormant, and non-chlorotic as determined from visual observations. However, procedures for assessing individual components of physiological quality are now in use, and techniques are continually being developed and tested. The most common indicators currently used are measurements of plant moisture stress (PMS), whole-plant stress resistance, root regeneration potential (RRP), and cold hardiness. These assessments have their place, but each also has at least one characteristic that makes it difficult to use as a specification for ordering seedlings—it gives only a partial picture of seedling condition, or requires a long testing period, or both.

Nurseries should have monitored PMS during lifting and packing. General recommendations are to not lift bareroot stock when PMS exceeds 10-15 bars and to keep PMS to less than 5 bars during grading and packing. We advocate that reforestation foresters have ready access to a pressure-chamber device for measuring PMS when seedlings arrive from the nursery and again at the time of planting. Stock in good condition should have PMS of less than 5 bars immediately after removal from a shipping container. We also advocate that buyers assess seedling condition by using an overall stress test or by testing separately for RRP and cold hardiness. Technology for these tests is being improved continuously; seedling buyers should contract with firms that conduct physiological testing or acquire seedlings from nurseries that do such testing themselves. Keep in mind, however, that answers may not be available for up to 1 month after a test is initiated, and poorly handled stock can deteriorate in the meantime. Because correlations between results of seedling tests and subsequent field performance are not well developed, the tests are useful primarily for identifying obviously poor stock. For more details of seedling quality assessments, see Duryea (1985) and Rose et al. (1990a).

Comparative Characteristics and Uses

Most planting stock used in southwestern Oregon and northern California is produced in nurseries that are either in the region or within a day's drive. Several directories are available that include names, addresses, and brief production information for most of these nurseries (American Association of Nurserymen 1987, USDA Forest Service 1991).

Bareroot stocktypes

Because bareroot stock lacks root contact with soil between lifting and planting, it is imperative that the seedlings be dormant while they are lifted, handled, stored, and planted. It is also critical that the roots be protected and kept moist to prevent desiccation. Part of the root systems of bareroot seedlings are cut off in the lifting process, and roots may be further trimmed to 8-10 inches to facilitate planting.

The seedling of choice in southwestern Oregon and northern California has traditionally been the 2+0. Its relatively compact root system is about as large as can be conveniently and quickly planted on most forest sites, and its top is commonly in reasonable morphological and physiological balance with its root system. Usually the top is 10-18 inches tall and the stem is relatively sturdy, about 0.2 inch in diameter at the root collar. This stocktype performs well on sites with average environmental stresses for this region. Minimum size specifications are difficult to define because of species and site differences, but a rule of thumb is that the height should be at least 6 inches and the stem diameter at least 0.16 inch.

A whole "reforestation culture" has built up around the production and planting of 2+0 seedlings, and other stocktypes are invariably spoken of in terms of how they compare to the 2+0. One notable exception, however, has been the use of 1+0 ponderosa and Jeffrey pine in northern California. The major pine nurseries in the area have been able to produce 1+0 stock that is comparable in size and performance to the 2+0 seedlings from more northerly nurseries.

As costs of reforestation have risen in recent years, foresters have begun to search for the most cost-effective stocktype in terms of stocked acres for specific types of sites. As a result, more small 1+0s, especially Douglas-fir and pines from nurseries in the northern part of the region, are being used because of their low initial cost. Production of this stocktype has been made possible by improvements in nursery practices to the point where small but plantable seedlings can be grown in one season. With a minimum root-collar diameter of 0.10 inch, 1+0s are smaller and less sturdy than 2+0s, but they are easier to plant, and their root systems are more open and natural-appearing. Use of 1+0 Douglas-fir is restricted to sites that are easy to regenerate—only moderately droughty, with little likelihood of animal damage, low to moderate shrub competition, and no problems with grasses and forbs.

Transplants are generally bigger and sturdier and have more fibrous root systems than 2+0s. Transplants can be used on sites where problems with animal damage, vegetative competition, ravel, or drought are anticipated. The higher initial cost and greater difficulty of planting are often, but not always, offset by improved survival and faster growth. The most common transplant is the 1+1. Its use is dramatically increasing throughout the forests of the West Coast because demands for reforestation success are increasing and the 1+1, in general, has good performance potential. The 2+1s are probably too large for use on droughty sites because of their poor top-to-root ratio, and they have no other advantage to make up for higher production and planting costs.

Another reason for the increasing use of transplant stock is the high cost of tree seed. Transplanting from both bareroot seedbeds and containers results in lots with low cull factors, largely because of increased growing space and uniform distribution of seedlings in the transplant beds.

Container stocktypes

In the early 1970s, nurseries in the Pacific Northwest began growing seedlings in relatively small containers. The main impetus behind this development was the attraction, for some, of a more automated and economical system of reforestation, and for others, of a perceived biological advantage of an undisturbed root system. Because of their relatively undisturbed roots, container seedlings can be planted when the seedlings are not fully dormant and can be "lifted" from their greenhouse nursery on demand—allowing for a longer planting season than is possible with bareroot stock. Furthermore, the relatively small size of the seedlings and their compact root systems make them easier to plant than bareroot seedlings. However, the plugs of potting mixture and roots make container-grown seedlings bulky to ship and handle. Container seedlings should have a top height of at least 4 inches and a stem diameter near the root collar of at least 0.10 inch. Well-grown seedlings should be able to reach 6 inches or more in height and 0.16 inch in stem diameter. The plugs of potting mixture and roots should hold together well when the seedling is extracted from its container.

Species such as true firs, which are usually grown in relatively small quantities and which often grow more slowly than Douglas-fir and ponderosa pine, lend themselves to container production systems. Small seedlots can be readily handled in greenhouses, and the controlled environment usually yields more rapid growth than that which occurs in outdoor beds, particularly for species such as western hemlock and high-elevation true firs, which benefit from the extended photoperiods greenhouses make possible.

Combination stocktypes

Transplanting of 1-year-old plug seedlings is another way to produce large, sturdy P+1 stock in 2 years or less (Hahn 1984 and 1990). This technique, taking advantage of the high growth potential of plug seedlings that have been grown in semi-controlled environments, produces the largest seedling, with the most fibrous root mass, possible within two growing seasons.

Miniature plugs of several different shapes are being tried as transplant stock. Several systems have been described (Hee et al. 1988, Hahn 1990). Seedlings are grown in their containers for only a few months, usually through fall and winter, and then are transplanted into bareroot beds for lifting as MP+1 seedlings as little as 1 year after being started from seed. MP+1s can grow as big as 2+0 seedlings, and the technique makes use of greenhouse facilities at a time, winter, when they would otherwise be idle. The 1-year production time reduces costs and increases flexibility in reforestation planning (Tanaka et al. 1988). Plug transplants are particularly useful to organizations that have developed a plug-oriented nursery and planting system but also find it necessary to have larger stock for some sites.

Seedling Production

The challenge to seedling users is to accurately specify planting stock that is well suited to its intended planting site. The challenge to nursery managers is to consistently and cost-effectively grow seedlings in good physiological condition and in the quantities and sizes that meet specifications.

Field nurseries

Nursery managers need to know at time of sowing what product they are to grow. Cultural practices, starting with sowing density, vary depending on whether stock is to be lifted as 1+0s, 2+0s, or transplants.

The usual procedure is to sow drilled rows of stratified seed in the spring in pre-formed seedbeds that have been fumigated to reduce problems from weeds, insects, and diseases. Other common cultural practices at these nurseries include periodically growing cover crops, fertilizing, irrigating, weeding, thinning, treating for known or suspected pathogens and insects, root pruning, stressing to induce dormancy, and, sometimes, top-mowing of tall Douglas-firs. Readers wanting the details of bareroot nursery practices should consult Duryea and Landis (1984).

Seedbed density is one of the main factors controlling seedling size. A balance must be struck between producing large numbers of seedlings and growing them to adequate size. Densities for 2+0 seedlings in the Pacific Northwest range from 15 to 30 per ft^2 of seedbed. According to a published graph (Thompson 1984), the number of plantable seedlings with minimum caliper of 0.16 inch was 22.5 seedlings when sown at 30 per ft^2, and only 2.5 seedlings more when sown at 40 per ft^2—not very efficient use of valuable seed.

Root pruning, or undercutting, is a common practice used to concentrate root growth in the upper 8 to 10 inches of soil, or that portion of the root system that is retained on the seedling after lifting. Although this practice did affect seedling morphology in several southwestern Oregon studies, field performance was not significantly affected (Stein 1984, Hobbs et al. 1987).

Top mowing is sometimes used in Pacific Northwest nurseries that grow Douglas-fir because improved cultural practices can result in superoptimal height growth. Seedlings that are too tall tend to have poor top-to-root ratios, and they are more expensive to handle during storage, shipment, and planting. A study in southwestern Oregon and northern California showed that top mowing did not significantly affect field performance (Duryea and Omi 1987), but most plant physiologists and field foresters have an intuitive dislike of the practice. We recommend it only as a last resort after other nursery practices have failed to keep height growth within specified limits.

To meet the recent increase in the demand for 1+1 planting stock, seedlings 1 year old or younger are transplanted into outdoor beds for a second growing period at relatively low densities (12 to 16 per ft^2) for lifting as bareroot stock. This procedure is not only more space-efficient than growing seedlings at low density from seed, but the root systems of 1+1s are more compact and fibrous than those of seedlings grown in place for 2 years.

Seedlings should be transplanted while buds are tight and stems and foliage are not succulent, but while the soil in the transplant bed is warm enough to support root growth. Transplanting in the fall of the first year usually results in larger seedlings than transplanting in the spring of the second year. The choice depends on such factors as desired sizes, species, nursery work schedules, and the weather.

Seedlings must be conditioned for lifting during the last half of the last growing season. Drought and fertilizer stress are often used to induce bud set, which, in turn, results in additional stem-diameter and root growth as long as growing temperatures occur. Dormancy and coldhardiness then develop as days shorten and temperatures drop.

At lifting, culling of seedlings that do not meet specifications can be extensive—cull factors of 25 to 35 percent are not uncommon for 2+0 seedlots. To determine if grading standards were accurately identifying potentially poor performers, a study was conducted using seedlings from three regional nurseries. Results supported the practice of culling seedlings with taproot wounds resulting from the tearing off of lateral roots during lifting (Owston and Whiting, personal communication 1990; data on file at USDA Forest Service, Pacific Northwest Research Station, Corvallis, Oregon). Seedlings with root-collar diameters of between 0.12 and 0.16 inch survived and grew satisfactorily on hot, dry sites as long as the root systems were well balanced with the tops. Thus, clients are generally advised to specify a minimum diameter of 0.16 inch, but not to be overly concerned about slightly smaller seedlings as long as they pass visual estimates.

Bareroot seedlings are usually lifted when they are fully dormant. Jenkinson (1984) has developed a procedure for determining the "lifting window" for a given species from measurements of root regeneration potential, and has made such determinations for several of the nurseries and many of the ecotypes used in southwestern Oregon and northern California. In Jenkinson's procedure, the capacity of specific seedlots for root growth is measured at different lifting dates under controlled, standardized conditions to establish a period of time when the seedlots can be lifted with reasonable assurance that seedlings will regenerate roots after planting.

Bareroot seedlings must be stored carefully after lifting, especially if they will not be planted for some time. Seedlings are commonly stored at 33-34°F, but sometimes they are stored at slightly below freezing when the time before planting is expected to be lengthy. In this case, careful thawing and handling are required.

Container nurseries

Container seedlings are produced by sowing seeds into individual plastic containers or cavities in styrene-foam blocks filled with a potting mixture of peat moss and vermiculite. The containers used most commonly are from 4 to 10 cubic inches in volume. The seedlings are grown for one season in a greenhouse or a shelterhouse (a greenhouse with walls that can be removed or retracted during the warm part of the season). Cultural practices include thinning, manual weeding, fertilizing through the irrigation system, control of insects and diseases, and induction of bud set by drought stress. Readers wishing more details on production methods should see Tinus and McDonald (1979) and a new set of manuals being published by the USDA Forest Service as Agricultural Handbook 674; three volumes have been completed so far (Landis et al. 1989a, 1989b, and 1990).

Container seedlings, like bareroot stock, should be kept dormant until planting. Because of their aboveground exposure in the nursery and their relative lack of cold tolerance, roots of container seedlings must be protected from extremely cold temperatures. Seedlings growing in foam-block containers withstand the cold better than those in single cells because the styrene foam around the former insulates the root systems. Seedlings are usually kept over the winter in greenhouses that are unheated unless subfreezing temperatures occur. When temperatures begin to warm in late winter, container seedlings must be placed in cold storage to await planting. They are shipped to the field either by packing them with containers still around them or by pulling them from their containers at the nursery and packing them into plastic bags for storage and shipment.

Consistency of Stock Production

Obtaining seedlings of a consistent quality, and in a consistent quantity, from year to year is essential for efficient reforestation. A survey made on one National Forest in the region in 1986 illustrates that users often do not get the seedlings they order, in terms of both quantity and quality (G.A. Walters, personal communication; data on file at USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Redding, California). In 1986, 125 lots of eight species and five stocktypes were produced in eight nurseries. For only 62 percent of the seedlots did the number delivered come within ±20 percent of the desired amount—30 percent had fewer seedlings (five lots had no seedlings) and 8 percent had more than requested. Consistency of 1+0s was lowest; 2+0s and container stock were about equally consistent. Data for 3 years from one ranger district on the Forest illustrate the year-to-year variability that can occur (Table 13-3).

Of stock delivered to ranger districts, in only about 45 percent of Douglas-fir and ponderosa pine seedlots did at least 90 percent of the seedlings meet Forest Service grading specifications. By stocktype, 91 percent of 2+0 lots had

Table 13-3. Production consistency by stocktype: percentage of seedlots in which the number of seedlings delivered fell within ±20 percent of the number of seedlings ordered by one ranger district on a National Forest in the region over a 3-year period.

			Stocktype		
Year	*1+0*	*2+0*	*1+1*	*2+1*	*P+0*
			%		
1984	50	82	100	-	50
1985	50	29	83	100	100
1986	33	71	25	-	0

90 percent of seedlings within size specifications; 54 percent of container lots and 33 percent of 1+0 and 1+1 seedlots met this goal. Only 39 percent of the seedlots ordered for the 1986 planting season met both quantity and quality requirements.

If these data are typical—or even if inconsistency occurs only sporadically—it is obvious that quality control must be improved. For successful reforestation, timing is critical. If the right seedlings are not available in the right quantity when they are needed, expensive site preparation might have to be repeated, or seedlings might have to be planted after competing vegetation and animal populations have rebounded from earlier treatments. Even more likely, less suitable seedlings will be substituted for the good ones, or seedlings will be planted too widely to obtain adequate stocking. Field foresters should keep in close contact with nursery managers throughout the crop cycle so that problems can be identified early and plans modified wherever possible. The very best communication results from exchange visits to nurseries and field sites.

Performance Comparisons

Numerous stocktype comparisons have been made in southwestern Oregon and northern California, as well as in other regions with similar sites and species. These vary from carefully controlled experiments using identical seed sources to simple comparisons of operational plantings where the information represents a mixture of species and sites. All these comparisons, however, are empirical tests of unique situations. Furthermore, it is our feeling that stocktype, by itself, does not determine seedling performance. The critical factor is how well the morphological and physiological characteristics of the stock are matched to the environment on the planting site. Thus, stocktype is important mostly in its correlation with morphology and physiological condition—and that correlation applies only in very general ways. Our approach to presenting this large body of data will be to describe a few recent, relatively large studies in some detail, and then to assess all the comparative tests in the region for which data were available to us.

Reforestation systems study

Several Douglas-fir stocktypes were planted as part of a large, comprehensive study designed to quantify reforestation results in the Siskiyou Mountains of southwestern Oregon. Other treatments tested were different regeneration methods and site-preparation and plantation-care alternatives. Eleven sites, six on south-facing slopes and five on north-facing ones, were planted between 1983 and 1988. Location of the sites ranges from near Glendale, Oregon, in the north, to near Ruch, Oregon, in the south. Treatments were a factorial combination of (1) clear-cutting versus shelterwood regeneration methods, (2) site-preparation methods that involved burning versus leaving sites unburned, (3) four different stocktypes, and (4) several different post-planting practices, including shading of seedlings on south-facing clearcuts and placing tubes around seedlings on north-facing clearcuts and in shelterwoods to reduce animal damage. The stocktypes were 2+0 bareroot seedlings grown at about 30 seedlings per ft^2 of nursery seedbed (standard practice in most nurseries), 2+0 bareroot seedlings thinned to 15 per ft^2 prior to the second growing season, P+0 container seedlings, and P+1 transplants. On five of the replications, the shelterwood overstories were removed and the data summarized 6 years after planting.

Overall survival was 53 percent after 6 years; average height of all seedlings on all plots was 34 inches (Table 13-4). These are tough sites, and only minimal vegetation control was practiced; thus, survival is lower than would be expected on an average site under more intensive management.

Table 13-4. Average sixth-year survival and total height for stocktypes planted on five tough sites in the Siskiyou Mountains in southwestern Oregon. Control of competing vegetation was minimal.

Stocktype	*Survival (%)*	*Height (in)*
2+0, high bed density	54	34
2+0, low bed density	57	35
P+0	48	30
P+1	54	38

The main stocktype observation to date is that the average survival and height of P+0s is less than for the other types; i.e., even on these droughty sites with shallow soils, the seedlings that were larger initially are performing better.

Bareroot vs. container seedlings in northern California

Stocktype comparisons of ponderosa pine, Jeffrey pine, Douglas-fir, and California white fir planted 10 years earlier on three sites in northern California showed that the container stock survived better in all situations, without exception (P.M. McDonald, personal communication; data on file at USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Redding, California). Furthermore, P+0 seedlings were as tall as or taller than the bareroot stock (1+0 for white fir, 2+0 for the other species), except for two of the species on one site. Diameter of container seedlings equaled or exceeded that of bareroot seedlings of all species at all locations, without exception. McDonald attributes the success of the container seedlings to their early ability to capture site resources.

Regeneration potential study

This large study in southwestern Oregon was designed to better define the potential for artificial reforestation of the lands withdrawn from the allowable-cut base of the Medford District of the Bureau of Land Management (O.T. Helgerson, personal communication; data on file at College of Forestry, Oregon State University, Corvallis, Oregon). Sites were classified by their summer solar radiation and water characteristics, and selected sites were planted over several years with bareroot and container Douglas-fir and ponderosa pine of various ages.

On 34 sites where both P+0 and 2+0 Douglas-fir were planted, average survival after 5 years was 70 percent for the plugs and 71 percent for the bareroots. The higher average survival on these sites compared to that in the reforestation systems study described above (53 percent) is probably due to more intensive control of competing vegetation. On two sites planted with different ponderosa pine stocktypes, survival after 5 years was 90 percent for P+0 and 96 percent for 2+0. Average fifth-year heights by site ranged from 16 to 63 inches for Douglas-fir and from 16 to 47 inches for ponderosa pine. For both species, median heights were greater for 2+0s than for P+0s.

Douglas-fir stocktypes on skeletal soil

After 5 years, P+0 and P+1 stocktypes were surviving significantly better than 2+0 stock on a harsh, droughty site in southwestern Oregon (Hobbs et al. 1989). However, annual growth and morphological characteristics of shoots and roots did not differ significantly. The authors concluded that stocktype designation alone may not be adequate for predicting field performance. But they did note that the plugs were relatively easy to plant, which could improve performance in operational plantings in rocky soils.

Analysis

Almost 80 sites, including the ones discussed above, are represented in various comparisons of P+0 and 2+0 stocktypes. The variation in sites, species, test ages, seedling quality, weather, and so forth makes the presentation of overall averages rather meaningless. Instead, we present frequency diagrams of survival and height that compare the number of individual tests in which one of the stocktypes did better, worse, or about the same as the other (Figure 13-2). All tests were 2-10 years old; most of them were over 5 years old.

Types were considered to have similar survival rates if their averages did not differ by more than 10 percentage points in one scenario or 20 percentage points in another. Most often, survival differences did not exceed the arbitrary thresholds. When they did, 2+0s were the better stock almost as often as P+0s. For height, the threshold values used were 10- and 20-percent differences between

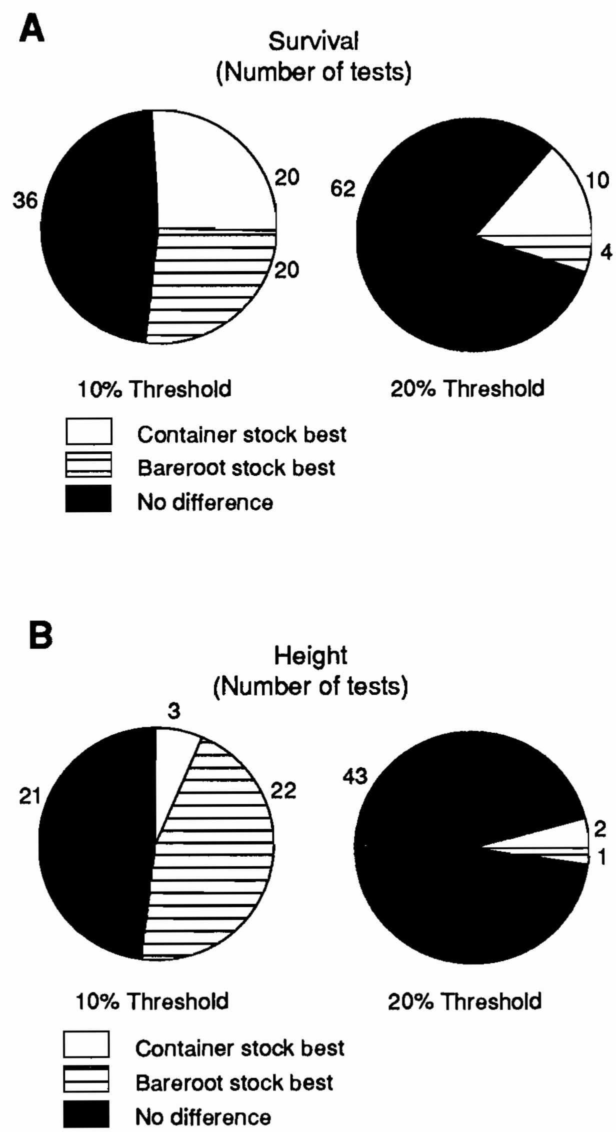

Figure 13-2. Number of individual tests in southwestern Oregon and northern California in which (A) survival between bareroot and container stocktypes did or did not differ by more than 10 or 20 percentage points (all tests were 2 to 10 years old); and in which (B) total height between container and bareroot stocktypes did or did not differ by more than 10 or 20 percent (all tests were 3 to 10 years old).

the stocktypes. Height data were available from 46 of the individual comparison tests. Twenty-one of the tests showed less than 10 percent difference between stocktypes, but in 22 tests the bareroot seedlings were more than 10 percent taller than container stock. However, at the 20-percent threshold level, where difference probably starts to be important, stocktypes did not differ in 43 of the tests (93 percent).

Cost Comparisons

Stock production costs alone are only a small part of the picture. When extensive site preparation and animal damage control are needed, or when seedlings must be planted on rough, steep terrain, stock may account for as little as 10 percent of the total reforestation cost per acre (Owston and Turpin 1991). Nevertheless, stock cost should not be overlooked. The data given in Table 13-5 illustrate the wide differences in costs among stocktypes.

Rationale for Choice

Consideration of the empirical evidence, the weight of experience, what we know of physiological principles, logistical and economic concerns, and common sense lead to some general conclusions about the selection and use of stocktypes for reforestation.

1. No matter what stocktype is used, the seedling must always be treated as the living organism it is—not an inanimate object that can be subjected to environmental stresses without being affected. Any of the production techniques that result in healthy seedlings can be used successfully if seedlings are carefully matched to the operational environment.
2. Selection of the nursery stock must be planned in advance and with consideration of the other components of the reforestation system—the harvest and site-preparation methods and protection methods to be employed—as well as the anticipated environmental stresses, including drought, frost, animals, and plant competition.
3. Test results show lack of consistent differences in survival among stocktypes, high survival under some circumstances for essentially any stocktype tested, and no stocktype with clear growth advantages. Better indicators of survival and growth are probably freedom from pests, good physiological condition, and morphological characteristics—traits that are relatively independent of stocktype *per se*. Thus, in most cases, selection can be made on the basis of cost, availability, and the track record of particular nurseries.

The above points notwithstanding, there are some general guidelines for selecting the right stocktype:

- Determine the best size and condition of seedling for the site to be reforested—and only then consider what stocktype to use.
- Use P+0s when rocky or debris-covered ground makes planting large stock difficult, when seedlings are needed a year sooner than anticipated, or when planters are inexperienced—but only when frost heaving, vegetative competition, animal damage, and heat damage are either expected to be light or will be controlled.
- Use transplants or large, sturdy seedlings of any stocktype on sites where competition and animal damage are expected to be heavy and control measures can be applied only at a medium level. Use transplants also if planting is delayed and stock must be held over an extra year.
- Consider using 1+0s on easy sites when a known source of good-quality stock is available.
- Don't bother planting anything on tough sites if no follow-up protection is planned.
- Keep attuned to new techniques.

Table 13-5. Examples of seedling costs by stocktype in USDA Forest Service nurseries in Oregon and Washington in 1990. From Owston (1990).

Stocktype	*Avg. cost per M*
1+0	$125
2+0	152
1+1	233
2+1	304
P+0 (small)	125
P+0 (large)	228

MYCORRHIZAE AND SEEDLING INOCULATION

In all soils, roots of forest trees form associations with specialized soil fungi. These symbiotic, mutually beneficial root associations are called "mycorrhizae" (literally, "fungus roots"). The fungi serve as extensions of the root system and perform a major role in a plant's uptake of nutrients and water. Indeed, seedlings depend on rapid development and functioning of their mycorrhizae for survival after outplanting. Hence, the mycorrhizal condition of seedlings prior to outplanting can also be an important indicator of seedling performance and should be considered when assessing seedling quality. For more-detailed information on the biology and ecology of mycorrhizae of forest trees, see Trappe (1977), Molina (1981), Molina and Trappe (1984), and Perry et al. (1987).

Fungus Selection and Seedling Inoculation

Seedling roots can be inoculated with mycorrhizae in the nursery. Trappe (1977) stressed the need to select fungi for inoculation that are adapted to the planting site. He envisioned a technology wherein a forester could select a fungus for a particular reforestation zone, as seeds are selected today. While this continues to be a long-term research goal, early efforts concentrated on developing technology to inoculate nursery seedlings with pure strains of mycorrhizal fungi. In several studies, Molina and others (Molina 1982, Molina and Chamard 1983, Hung and Molina 1986a and 1986b) found that vegetative mycelium of the mycorrhizal fungi *Laccaria laccata* and *Hebeloma crustuliniforme*, grown and introduced in a vermiculite carrier, was highly effective in colonizing container seedling roots. *L. laccata* also formed abundant mycorrhizae on container-grown Douglas-fir and pine even at the high fertility levels common to container nurseries (Molina and Chamard 1983). This was significant, because high levels of soluble fertilizer typically retard mycorrhiza development. In follow-up studies, Hung and Molina (1986a and 1986b) tested commercially prepared inoculum of *L. laccata* and *H. crustuliniforme* in nurseries under operational conditions and found it to be as effective as laboratory-produced inoculum. However, these fungi have not enhanced the field performance of seedlings very much; the isolates were not well adapted to test sites and were quickly replaced by other mycorrhizal fungi.

In a search for fungi well adapted to and highly competitive on stressful outplanting sites, Parke et al. (1983) examined the residual fungus inoculum on variously disturbed sites and the physiological responses to drought stress of seedlings inoculated with particular mycorrhizal fungi. She found that Douglas-fir seedlings mycorrhizal with the fungus *Rhizopogon vinicolor* were more drought-tolerant than either seedlings with no mycorrhizae or seedlings mycorrhizal with *L. laccata* or *H. crustuliniforme*. At about the same time, Castellano et al. (1985) began to develop methods of inoculating Douglas-fir seedlings with spores of *Rhizopogon* species after Molina (1980) showed that vegetative mycelia of several *Rhizopogon* species were not effective inoculum. Not only were the spores highly effective and easily applied, but survival and growth of *Rhizopogon*-inoculated Douglas-fir seedlings were significantly enhanced (Castellano and Trappe 1985).

Castellano (1987) then developed techniques to successfully inoculate over 6 million container seedlings at a nursery near Cottage Grove, Oregon. Spores were injected into the overhead mist irrigation system and applied in the same way as soluble fertilizer. Stem caliper was significantly larger on inoculated seedlings in some seed lots, yielding a reduction in cull rate. Bareroot seedlings were also easily inoculated with spores of *Rhizopogon*. Current research is examining ecotypic variation among *R. vinicolor* spore sources from a variety of locations and the effectiveness of other *Rhizopogon* species, particularly for inoculating *Pinus* and *Abies*.

For a complete review of mycorrhiza management and inoculation technology in seedling nurseries, see Castellano and Molina (1989).

Performance of Inoculated Seedlings in the Field

The successful mycorrhiza research program with *Pisolithus tinctorius* in the southeastern

United States (Marx et al. 1984) prompted similar research in southwestern Oregon. Although results were highly variable, Castellano and Trappe found in general that *P. tinctorius*, whether from a commercial or a local source, seldom improved survival or growth of seedlings (M.A. Castellano and J.M. Trappe, personal communication; data on file at USDA Forest Service, Pacific Northwest Research Station, Corvallis, Oregon). Where outplanting performance was improved, it was always associated with the local spore source rather than with the commercially produced strain, isolated originally in Georgia. These trials emphasized the need to use local fungus strains adapted to intended planting sites.

Thus far, the most successful outplanting trials have been with Douglas-fir seedlings inoculated with *Rhizopogon vinicolor*. After 5 years, the oldest plantation continues to follow the same trend reported after 2 years with significantly increased survival (Castellano and Trappe 1985). In an ongoing cooperative study with Lone Rock Timber Co. on land near Roseburg, Oregon, inoculations with *Rhizopogon* are enhancing seedling survival by as much as 50 percent, although not, apparently, on north-facing slopes, a finding consistent with observations of other outplanting sites. Inoculation of Douglas-fir container seedlings with *R. vinicolor* spores improved seedling survival on two sites in the western Siskiyou Mountains. The difference between inoculated and non-inoculated seedlings was most pronounced on the more droughty site (P.W. Owston and S.D. Hobbs, personal communication; data on file at USDA Forest Service, Pacific Northwest Research Station, Corvallis, Oregon).

Rhizopogon vinicolor is the best candidate for inoculation of nursery seedlings. It is easily inoculated, aggressively colonizes roots and competes well against other mycorrhizal fungi, and produces abundant quantities of hyphal strands that extend long distances into the soil to help seedlings take in water and nutrients. Furthermore, *R. vinicolor* persists and spreads on root systems of seedlings after outplanting so that seedlings can continue to benefit for several years. Refinements in the practical application of *R. vinicolor* inoculation will continue over the next several years, as will the search for other ecologically well-adapted and easily inoculated fungus species.

Perry et al. (1987) emphasized that mycorrhizal inoculation may be necessary only for seedlings destined for extremely harsh or degraded sites. On severely disturbed sites, or those left for several years without ectomycorrhizal hosts, the natural inoculum potential can decline, limiting formation of mycorrhizae (Perry et al. 1989). If resident populations of mycorrhizal fungi are disturbed as little as possible during harvest, and if cut-over sites are planted soon after harvest, populations of residual mycorrhizal fungi typically remain adequate to ensure rapid colonization of nursery stock.

DIRECT SEEDING

Uses and Results

Direct seeding has several potentially attractive features: it is much less expensive and much faster than producing and planting seedlings; seeds can be easily placed on ground that is too rocky for good planting; seeding can be done early in the fall when it is too dry to plant but access to sites is good; and resulting seedlings have more natural, faster-developing, and wider-spreading root systems than planted seedlings (Stein 1978). For reasons that will become evident below, we do not recommend direct seeding as a reforestation method. However, we present a review of pertinent regional literature in order to give a complete picture of propagule options.

Direct seeding has prevailed as a reforestation method on the West Coast during several periods, especially from the mid-1930s to the early 1940s and from the mid-1950s to the mid-1960s (Schubert and Adams 1971). Several developments contributed to the latest decline in the use of direct seeding: legal constraints on chemicals such as endrin, used to protect seed from rodent and bird predation; the high cost of tree seed from tree-improvement programs; improvements in the quality of nursery stock; and the introduction of container seedlings. In 1989, fewer than 3,000 acres of forest land in Oregon and California were direct-seeded, while more than 300,000 acres were planted (USDA Forest Service 1990).

Broadcast sowing of tree seeds from the air or the ground continues to be an unwise use of resources because of restrictions on chemicals and the value of seed supplies. Spot seeding can be effective, but only when germinants can be protected from animals, insects, and disease. The technique attracts occasional attention as new ideas develop for protecting seeds. However, efficient protection technology continues to be elusive. One technique tested in southwestern Oregon utilized a device that both sows seeds and places a protective funnel over them. In a small test, however, heavy mortality was caused by unknown insects that were not checked by the funnel (H.A. Froehlich, personal communication; College of Forestry, Oregon State University, Corvallis).

Several older studies of spot seeding in southwestern Oregon and northern California have been reported. In a test involving western white pine and Shasta red fir on the Rogue River National Forest, 68 percent of the plots were stocked with pine and 36 percent with red fir 2 years after sowing in spots protected from bird and animal damage by screens; stocking in unscreened spots was 24 percent for the pine and 11 percent for the red fir (Franklin and Hoffmann 1968). Most mortality occurred the first year and was caused by a pest or pests that clipped stems and sometimes removed seedlings from the spots. Because some of this took place in screened spots, insects, which were not checked by the screens, were suspected. In a second, related study (Franklin and Hoffmann 1968), 90 percent of screened spots seeded with Douglas-fir and 77 percent of screened spots seeded with Shasta red fir were stocked with seedlings 2 years after sowing. Stocking on unscreened, shaded spots was 45 percent for Douglas-fir and 17 percent for red fir. For completely unprotected seeds, stocking was 27 percent for Douglas-fir and 10 percent for red fir. The authors concluded that, although screening resulted in significant improvement, more information was needed about protecting seeds from rodents, insects, and disease to make spot seeding dependable for regenerating upper-slope forests.

One direct-seeding success was a 45-acre pilot study in the upper South Umpqua drainage (Stein 1957). Sugar pine seeds were sown in the fall in spots at 4- by 8-ft spacing. After 2 years, 72 percent of 4-milacre quadrats were stocked, and there were 455 seedlings per acre. However, this was accomplished with the aid of three applications of rodent poison.

In direct-seeding trials of Douglas-fir in northern California, success was poor. Of 32 treatment-times-location combinations of seed spots protected with hardware-cloth screens, highest first-year survival was 10 percent (Strothmann 1971).

Guidelines for Direct Seeding

A synopsis of the literature yields the following guidelines for direct sowing of conifer seeds in southwestern Oregon and northern California:

1. Sow multiple, unstratified, high-quality seeds in the fall.
2. Choose spot seeding locations carefully. Stein (1955) lists 20 recommendations.
3. Prepare the spots; i.e., sow in bare mineral soil.
4. Protect the spots from rodent predation by some sort of physical device that does not create a lethal environment for the seedling.
5. Practice followup vegetation management and animal damage control.

Even if all these guidelines are followed, there is risk of high losses to insects—no insecticide is currently registered for this use.

SUMMARY

Many seedling stocktypes are available in southwestern Oregon and northern California. The ones used predominantly in the 1980s were 1+0 bareroot seedlings for ponderosa pine in northern California, and 2+0 bareroot seedlings for almost everything else. There was considerable enthusiasm for small container-grown seedlings in the 1970s, but they failed to outperform the 2+0s, and their use has leveled off to 15-20 percent of total stock usage in the region.

Recent trends have gone in two directions: to lower costs, more 1+0s are being planted as nursery practices have improved to the point where plantable seedlings of Douglas-fir (and ponderosa pine in Oregon nurseries) can be grown in a single season; and to improve field performance—particularly on tough sites—transplants are being used in rapidly increasing numbers. The 1+1 bareroot is the transplant most in demand, but some foresters are using P+1s if they want somewhat larger stock with even more fibrous roots, or if their nursery system includes the use of plug seedlings.

A relatively new technique of creating transplants from miniature plug seedlings is also being tried.

Numerous comparative tests of stocktypes have been installed in the region. Overall, there is no clear winner. Most often, different stocktypes have performed about equally well. In other cases, one type has been the better performer in about as many tests as has another. Our conclusion is that, for the majority of site conditions, nursery stock decisions should be made on the basis of size of seedling desired, availability, cost, and experience with or reputation of particular nurseries. However, when sites are of low stress or when planting is difficult, small seedlings may have economic or biological advantages. When vegetative competition or animal damage is expected to be severe, large stock should be used, particularly if protection measures are not taken. Container seedlings should not be used on sites prone to frost heaving.

Research on mycorrhizae in the region has concentrated on developing techniques for inoculating nursery seedlings and selecting fungus species or ecotypes that enhance seedling performance. One species, *Rhizopogon vinicolor*, made Douglas-fir seedlings more drought tolerant than those without mycorrhizae or those with mycorrhizae formed with different species of fungi. Parallel research resulted in a technique for mass inoculation of container seedlings with spores of the fungus. Field tests of seedlings inoculated with *Pisolithus tinctorius*, a success in the southern United States, proved disappointing in southwestern Oregon. On the other hand, preliminary field results of trials in which seedlings were inoculated with *R. vinicolor* have been encouraging, with survival enhanced by as much as 50 percent and with better results on droughty sites than on more mesic ones.

A review of literature indicates that direct seeding shows little promise for broadcast applications. Spot seeding requires very careful attention to site preparation and protection of the seeds and young seedlings. However, protection against drought and animals may not be sufficient, and insects can also be a significant problem. We do not recommend direct seeding.

In conclusion, nursery practices have progressed to the point where it is possible to produce high-quality stock grown to specifications and targeted for high performance on specific types of outplanting sites and situations. The challenges are to continue to refine the specifications and to perform all the reforestation steps carefully and consistently.

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