Chapter 7
Container Seedlings

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Abstract

Container southern pine seedlings offer an alternative to bareroot stock, especially when short production times are required, the planting season is to be extended, or adverse sites are to be planted. Acceptable container seedlings can be produced under various degrees of environmental control and in several container types. However, seedling quality depends on the quality of the seeds sown and proper use and timing of cultural practices, especially sowing techniques, growing-medium moisture, and seedling nutrition. Shoot and root morphology can be controlled when seedlings are grown in containers to produce stock of desired characteristics for outplanting under specified conditions. Handling and planting methods used with container southern pines depend on the time of year and physiological condition of the seedlings.

7.1 Introduction

Pine forests in the South are usually established by planting bareroot seedlings, although natural regeneration and direct seeding are used to a limited extent (see chapter 3, this volume). However, planting container seedlings offers land managers a regeneration technique proven beneficial for establishing hard-to-regenerate pine species, regenerating difficult sites, and extending the planting season.

An overview of the merits and methods of producing container pine seedlings in the southern United States is presented in this chapter, emphasizing how such methods impact seedling survival and growth after outplanting. Other valuable references for the production and use of container southern pine seedlings are publications by Guldin and Barnett [42], Guldin [41], and Barnett and Brissette [19].

7.2 Merits of Container Planting

The many advantages of container seedlings over bareroot stock have been discussed [43, 59, 101, 103, 107]. Container southern pines can be produced quickly (Table 7.1). Plantable loblolly pine (*Pinus taeda* L.) and slash pine (*P. elliottii* Engelm. var. *elliottii*) can be grown in 12 to 14 weeks, longleaf (*P. palustris* Mill.) in about 16 weeks. Such rapid production allows seedlings to be fall-planted in years when early survival checks indicate replanting will be necessary. Seedlings grown for progeny tests can be produced and outplanted the spring after seed collection. In both cases a year is saved relative to bareroot methods. Production flexibility allows container seedlings to be planted throughout an extended planting season, provided that soil moisture and climatic conditions are favorable for growth. Container seedlings tend to perform better on adverse sites than bareroot seedlings; in some cases, use of container stock may be the only way to successfully reclaim severely damaged sites such as mine spoils or to establish seedlings under droughty conditions as in shelterbelts. Because growing conditions can be better controlled, container planting offers potentially increased seed efficiency, i.e., the ratio of plantable seedlings to filled seeds. This is especially important for valuable or limited

Table 7.1. Advantages and disadvantages of container-grown southern pine seedlings.

Advantages	Disadvantages
Are quickly produced	Require more attention while growing
Are of uniform size	Are often of smaller size
Extend the planting season	May cost more
Improve performance of some species	Are bulky to handle
Perform well on adverse sites	May require more intense site preparation
Allow faster planting rates	Cannot yet reliably be specified as to ideotype because of insufficient field data

M.L. Duryea & P.M. Dougherty (eds), Forest Regeneration Manual, pp. 117–141.

seed sources, such as clonal seed-orchard lots (see chapter 11).

However, some disadvantages exist in production and use of container seedlings [10, 102]. The conditions that hasten container seedling development are also conducive to disease, nutritional imbalances, and other problems. Trees produced in containers will likely cost more than bareroot stock from existing, depreciated nurseries, but not necessarily more than seedlings from a new bareroot nursery [41]. Container seedlings are bulkier to transport and must be handled differently from bareroot seedlings (see 7.11). On sites with severe herbaceous competition, more complete site preparation may be necessary for success with container seedlings, which have smaller initial size [96].

Although biological and production advantages can be realized from growing seedlings in containers, their acceptance by foresters depends upon field performance. Survival of western conifer seedlings grown in containers has usually equaled or exceeded that of bareroot nursery stock [4, 36, 45, 103, 107, 116]. In eastern Canada, results with northern conifers indicate that seedlings grown in paperpot containers survive better but have a growth lag, compared to larger bareroot stock [54, 69, 99].

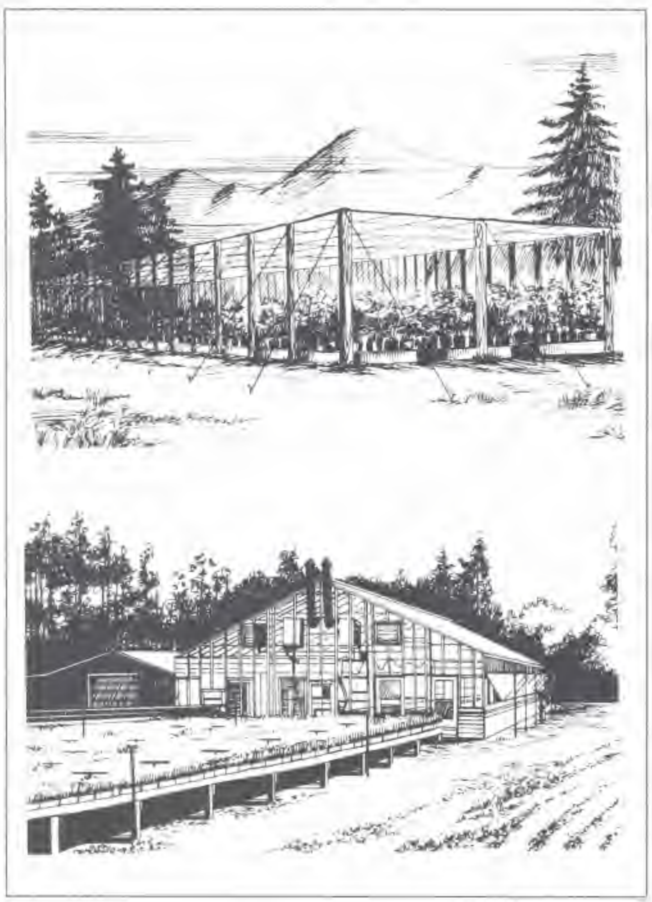


Figure 7.1. (a) Simple shadehouse suitable for producing container southern pines during much of the year and for seedling hardening during fall and winter. (b) More elaborate glass greenhouse with environmental controls suitable for producing container seedlings throughout the year (adapted from Guldin [41]).

There have been few good comparative trials with the southern pines because it is difficult to obtain stock of similar morphology and physiology. However, survival of container seedlings has generally exceeded that of bareroot nursery stock, and growth comparisons have been good [8, 14, 38, 100]. Container stock clearly outperforms bareroot seedlings when age from seed is considered [38].

When outplanted at the same time, container seedlings can perform as well as or better than bareroot seedlings when high-quality stock is used. Goodwin [39] found that after five growing seasons, container longleaf pine seedlings survived better and grew faster than 1+0 bareroot seedlings when planted on sandhill sites. He concluded that container longleaf seedlings could be used to extend the normal planting season and to replant 1+0 seedling failures in the same growing season if soil moisture was sufficient.

Amidon et al. [1] reported that, under droughty conditions, container longleaf pine seedlings survived and grew better than bareroot stock when the container seedlings were outplanted in late summer before the normal bareroot planting season. Even under severe moisture stress, container seedlings performed better than bareroot seedlings when outplanted at the same time in early spring. In a direct comparison between container and bareroot loblolly pine seedlings planted in March and May, South and Barnett [100] found no difference when soil moisture was adequate at the time of planting. However, when both stock types were in relatively dry soil, the container seedlings survived better.

7.3 Locale and Facilities for Seedling Production

7.3.1 Site Selection

Sites for container nursery facilities require much less stringent criteria than sites for new bareroot nurseries. Topography and soil constraints that may prohibit the development of a bareroot nursery would not deter construction of a container facility. Important considerations for selecting a container nursery site include management objectives, location of outplanting sites, climate, water supply and quality, road access and utilities, labor supply, and proximity to mills and other manufacturing facilities. Hahn [44] provides some valuable insights into these and other aspects of site selection; Barnett and Brissette [19] discuss aspects that are unique to the South.

7.3.2 Structures

Structures for growing container seedlings in the South may vary from benches in the open to simple shadehouses to elaborate glass greenhouses (Fig. 7.1). Generally, seedlings can be grown in the open without a structure or, at most, in semicontrolled greenhouses in the Coastal Plain areas of the South. In fact, recent research has shown that

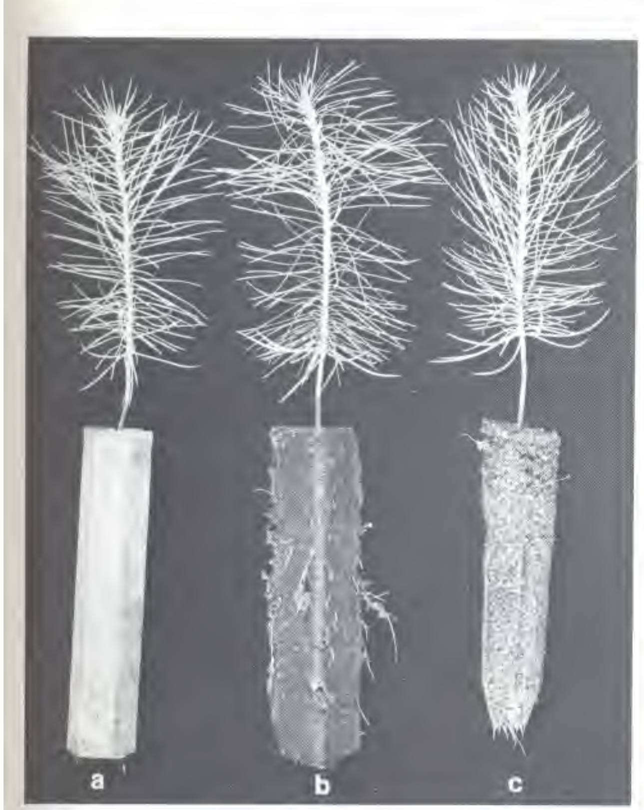


Figure 7.2. Loblolly pine seedlings grown in three container types: (a) biodegradable plastic tube, (b) peat moss-vermiculite molded block, and (c) plug from Styroblock-2.

the quality of longleaf and loblolly pines grown outside with no shade is superior to that of seedlings grown in greenhouses [18] (see 7.7.2). However, if crops are to be produced over winter, an enclosed, adequately heated structure is required.

The type of structure, or lack of it, depends on management objectives that must take into account biological, climatic, economic, and operational factors. Guldin [41] compared the economics of various combinations of facility, container type, and climatic zone for container and bareroot seedling production; McDonald [70] discusses the relative merits of greenhouses with fully controlled and semicontrolled environments.

7.4 Containers

The great impetus for container planting in North America resulted from Walters' publication [119] of his technique using the plastic bullet and planting gun. Jones [51] reported early evaluations of seedlings grown in kraft-paper containers in the South. Since those beginnings, a host of container types have emerged for forestry use, primarily for nothern and western situations. Included are products such as plastic bullets, Ontario tubes, BC/CFS Styroblocks®, Rootrainers®, extruded peat cylinders, Japanese Paperpots®, Ray Leach Single Cells®, plastic-mesh tubes, and wood-fiber blocks [110, 117]. Most of these products have been evaluated in the South [7]. In addition, kraft-paper tubes, polyurethane foam blocks, biodegradable plastic tubes, and peat-vermiculite blocks have been developed primarily for southern use [6, 21].

7.4.1 Types of Containers

Because the type of container has both major and direct impacts on seedling quality and production costs, silviculturists as well as nursery managers must be familiar with the various container types available. The many container products can be divided into three general types: tubes, plugs, and blocks (Fig. 7.2). Each type has certain merits that should be considered in relation to the intended outplanting sites before a container system is selected.

7.4.1.1 Tubes

Tubes are containers that have an exterior wall, require filling with a growing medium, and are planted with the seedlings. Their primary advantage is wall rigidity. This provides both ease of handling and sufficient impermeability to prevent seedlings from desiccating when planted in dry soil [31]. Their major disadvantage is the slow egress of roots into soil because initial contact with the soil is made primarily through the bottom of the tube. On the basis of performance evaluations with the southern pines and commercial availability, the Paperpot is probably the best tube-type container [16]. The Japanese Paperpot does not degrade rapidly. The Finnish Paperpot® is reportedly manufactured of material that allows faster root egress, but this can lead to root growth between containers during the growing phase and subsequent root damage during extraction. Therefore, only small trees or short rotations are recommended if Paperpots are used. Root spiraling also is a problem [21].

7.4.1.2 Plugs

Plugs are molded blocks containing cavities filled with growing medium. They are the preferred container for operational use in the Pacific Northwest and Canada and are easily planted by hand or machine. But, unlike with tubes or blocks (see 7.4.1.3), the rooted seedlings are removed from their plug containers before outplanting and are planted along with the growing medium. Because roots are not constrained after planting, they rapidly establish themselves in the surrounding soil. However, seedlings must be held in plug containers long enough for roots to bind the soil and facilitate extraction. The holding time varies with the size of the container cavity and species of tree; generally, the minimum is 3 to 5 months. Ray Leach Single Cells, Rootrainers, and Styroblocks can produce excellent plug seedlings.

Ray Leach Single Cells can be handled individually for randomization, removal of blanks, and transport. Rootrainers open to allow inspection of the root system and easy removal of the plug. The BC/CFS Styroblock was developed in Canada to overcome root-configuration problems inherent with plastic bullets. Growth of slash pine seedlings after outplanting from several container types showed that those from the Styroblock-2 (2-in.^{3} volume) equaled or exceeded all others except the block-type Keyes Peat Sticks®. The Todd Planter Flat® has square cavities with an obtuse taper for easy seedling extraction. However, with this system, lower numbers of seedlings are produced per unit area than with most other container systems.

7.4.1.3 Blocks

Block designs incorporate advantages of tubes and plugs. The block itself is both the container and the growing medium; seeds are sown in the block, and the entire package is transplanted into the soil. Blocks are usually rigid enough for mechanized planting but still allow rapid root egress upon outplanting. Of the two block-type containers evaluated with southern pines, the Keyes Peat Sticks were superior to the Gro-block® and were best among several container types tested. Unfortunately, this product is no longer commercially available.

7.4.2 Container Size

Most containers in operational use have volumes of 40 to 165 cm^3 (2.5 to 10 in.^{3}). A 10- to 12-cm (4- to 5-in.) length is generally satisfactory for the southern pines, and diameters of 2.5 to 3.0 cm (1.0 to 1.25 in.) seem minimal [7]. However, Barnett and Brissette [19] have shown that container volume is less critical than seedling density in the containers (number per unit area) (Fig. 7.3). For example, although Todd Planter Flats had 25% less volume, seedlings at time of outplanting were about twice as heavy in the Todd Planters as in the Japanese Paperpots. This difference resulted primarily from the much smaller number of seedlings grown per unit area — 312 vs. 1,657/m^2 (29 vs. 154/ft^2) for Todd Planters and Paperpots. The larger seedlings also performed better in the field. In fact, seedling development even in the small Todd Planter [25 cm^3 (1.5 in.^{3})], both in the greenhouse and field, was better than in the Paperpots [88 cm^3 (5.3 in.^{3})]. The effects of density during the growing period become even clearer when container volume remains constant.

The period for which seedlings are grown before outplanting also interacts with density (Fig. 7.4). If growing periods are limited to 8 to 10 weeks, spacing has lees effect on development because seedlings are smaller. Densities exceeding about 1,075/m^2 (100/ft^2) reduce initial development and resulting field performance of the southern pines. Although lowering of densities may continue to improve development and performance, factors such as the cost of production space will also influence the relationship of container size and density.

The species can also influence the relationship of container size and density to performance. For example, longleaf pine, which is very intolerant of shading, develops far better when grown in larger volume containers at lower densities (Table 7.2). Stem diameter of longleaf pine increased 66% when grown in Styroblock-8 instead of Styroblock-4 containers, compared to only 19% for loblolly pines.

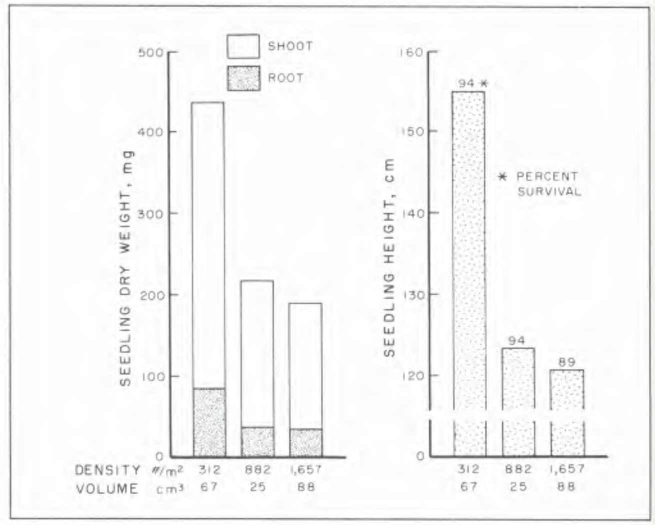


Figure 7.3. Effects of two container parameters on development and field performance of loblolly pine seedlings. Dry weights were measured at time of outplanting, height and survival after 3 years in the field.

7.4.3 Containers and Root Development

Our results with southern pines indicate that the constraint of many containers adversely affects seedling growth. The problem occurs primarily with tube-type containers that are planted with the seedling, but can also occur in seedlings that are extracted from containers before outplanting. For example, plastic bullets can limit root egress in the field to the extent that growth is stunted (Fig. 7.5a). Other container types can cause root strangulation (Fig. 7.5b) or root spiraling (Fig. 7.5c). If, however, these obvious extremes of deformity are avoided, the configuration imposed by the container may not adversely affect field performance.

Studies have also shown that the degree of root malformation in the field varies with species and soil type. Longleaf pine is more susceptible to root spiraling than loblolly or slash, probably because its early root elongation

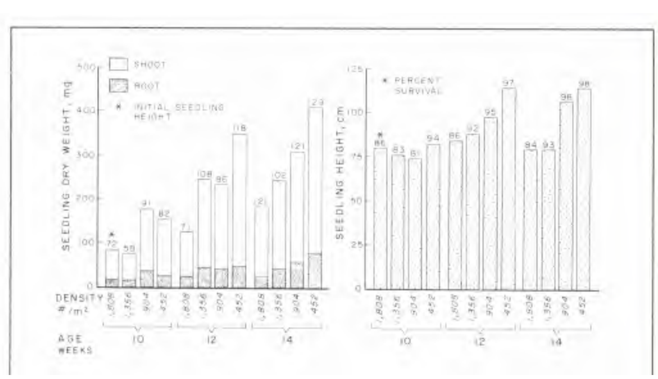


Figure 7.4. Effects of two container parameters on development and field performance of loblolly pine seedlings. Seedling characteristics were measured at time of outplanting, height and survival after 2-1/2 years in the field.

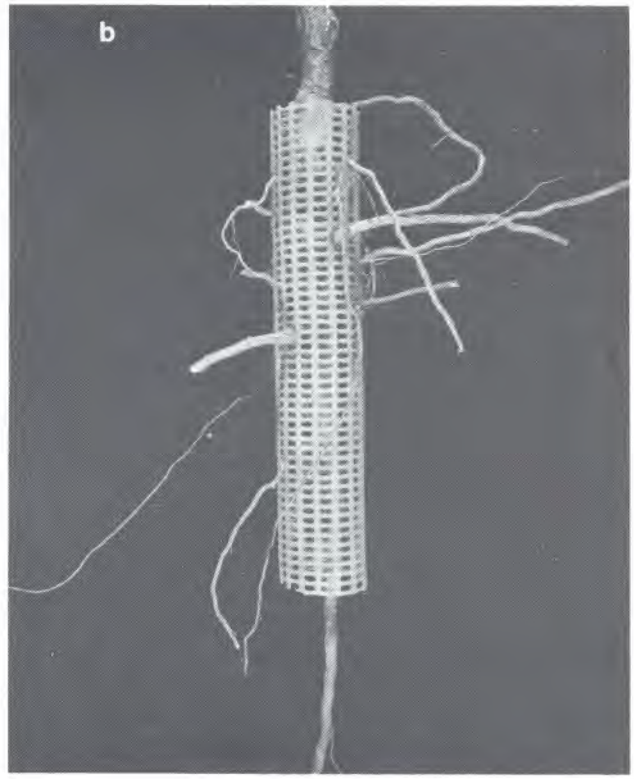
Table 7.2. Development of loblolly and longleaf pine seedlings as related to container size and seedling density.

Species[1]	Container[2]	Stem mm	Stem %[3]	Top weight mg	Top weight %[3]	Root weight mg	Root weight %[3]
Loblolly	Styroblock-4	2.6		840		162	
	Styroblock-8	3.1	19	1,482	76	237	46
Longleaf	Styroblock-4	2.9		975		135	
	Styroblock-8	4.8	66	2,185	124	364	169

[1] Loblolly and longleaf seedlings were 16 and 20 weeks old, respectively, when measured.
[2] Styroblock-4 contained 807 seedlings/m^2 (75/ft^2); Styroblock-8 contained 441 seedlings/m^2 (41/ft^2).
[3] Percent difference between the two styroblocks sizes.

is more rapid. Heavy clay soils can also increase root malformation, especially root spiraling, by limiting rapid root egress through the punched planting-hole wall [10]. However, if reasonable precautions are taken in selecting containers and planting techniques, root configuration should not adversely affect seedling growth and development.

Adverse root forms increase rapidly with the length of time seedlings are grown in containers. But if growing cycles are kept to 12 to 15 weeks, there should be no problem with properly designed containers.



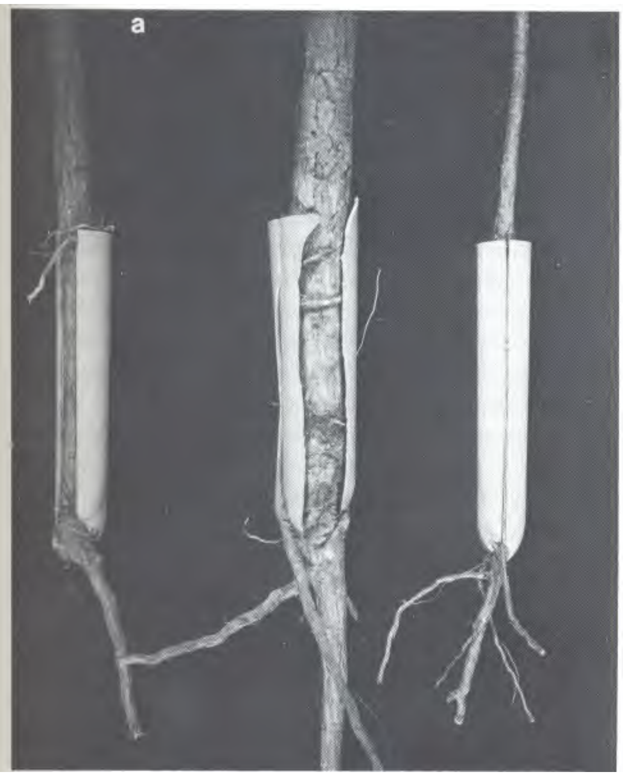


Figure 7.5. Loblolly pine seedlings (a) excavated 3 years after outplanting in plastic bullet, with stunted roots; (b) excavated 3 years after outplanting in Conwed® mesh-type container, with strangulated roots; and (c) excavated after outplanting as styroplug, with spiraling roots.

7.4.4 Containers for Specific Applications

7.4.4.1 Hand planting

Seedlings grown in plug-type containers are generally most suitable to hand planting. The planting rate of container seedlings with punch-type dibbles usually exceeds that of bareroot stock because of the tapered configuration of the root mass [114]. The planting hole does not have to be closed with the dibble as for bareroot seedlings if the punch is shaped like the container plug. Several planting tools for plugs are also designed so that the seedlings are dropped through the barrel of the tool and the planter does not have to bend over. Both tubes and blocks, being blunted at their ends, are more difficult to hand plant than plugs. Exceptions are tube containers shaped like bullets, but these still seriously constrict the root system and inhibit growth [3].

7.4.4.2 Machine planting

Although extractable plugs seem well suited to hand planting, they are not well adapted to automated planting [34]. Tube- and block-type containers lend themselves more easily to a mechanized planting system because of their rigidity and durability. Edwards [35] discusses the development of semiautomatic and automatic planters and related problems.

7.4.4.3 Forest genetics programs

Growing seedlings in containers allows efficient use of limited quantities of seeds and provides very uniform seedlings. With containerization, progeny tests could begin a year before they would be possible with bareroot techniques because container seedlings can be grown during winter if seeds have been properly extracted and can be outplanted one growing season earlier than bareroot seedlings [113].

It may be desirable to sow seeds for progeny tests in containers larger than normally used operationally so that high-quality seedlings develop in a relatively short time. Ray Leach Single Cells are ideal because placement of individual trees can be randomized in the greenhouse, blank cavities can be removed, and seedlings per unit area and other factors affecting seedling quality can be easily controlled.

1.4.4.4 Problem species and sites

Longleaf pine is often difficult to grow in bareroot nurseries. Because of its dormant epicotyl or "grass stage" growing characteristic, roots of longleaf develop early; when bareroot longleaf seedlings are lifted, a large proportion of their root system is lost, and the resulting field survival is usually lower than for other southern pine species. However, when longleaf are grown in containers, their root systems remain intact when planted.

Table 7.3. Survival and growth of longleaf pine seedlings on two dry sites following extremely harsh drought conditions in summer 1980 (adapted from Amidon et al. [1]); measurements taken in January 1981.

Production	Survival		Root-collar diameter	
	Louisiana	Texas	Louisiana	Texas
Late-summer planting (August 1979)[1]				
	%		mm	
Container type				
Kys-Tree-Start®	70	38 c	10 b	10 c
Styroblock-4	70	66 b	10 b	13 b
Styroblock-8	88	77 a	13 a	15 a
Site average	76 a	60 b	10 b	13 a
Spring planting (March 1980)				
	%		mm	
Bareroot seedlings	7	43 b	10 a	10 a
Container type				
Todd-150-5	33	60 a	8 a	8 a
Styroblock-4	37	70 a	10 a	8 a
Styroblock-8	23	66 a	10 a	10 a
Site average	31 b	65 a	10 a	10 a

[1] Within columns for each planting date, means followed by the same lower case letter are not significantly different at the 0.05 level.

Certain site and soil types are difficult to plant with success: (1) dry, sandy soils, (2) mine spoil banks, (3) highly erodible soils, and (4) poorly drained soils. Many of the dry, sandy soils throughout the South were originally longleaf pine sites, but difficulties in planting have slowed regeneration of these areas. Amidon et al. [1] showed that container longleaf seedlings did much better than bareroot seedlings on these harsh sites (Table 7.3). Mine spoils represent a relatively small total acreage, but they are very difficult sites to regenerate in parts of the South. Davidson and Sowa [30] demonstrated that container seedlings may do well on these areas, particularly when seedlings are inoculated with mycorrhizae adapted to these soils [63]. Dickerson [32] also reported that container seedlings gave promising results on forest sites severely eroded by poor agricultural practices. Early-summer planting of container seedlings is a practical means of regenerating many of the low-lying poorly drained soils too wet to plant in winter.

7.5 Growing Medium

A number of workers have evaluated combinations of soil mixes for containers [33, 38, 46, 68, 83, 90]. Almost without exception, the best combination included sphagnum peat moss and vermiculite. Sphagnum moss provides good water-holding and buffering capacities, low pH, and high cation-exchange capacity. Vermiculite provides pore space, thus ensuring well-aerated roots. The ratio of peat to vermiculite most often used is 1:1 but may be 2:1.

Domestic peat moss is generally unsatisfactory because the quantities of nutrients, especially nitrogen, are variable, and because it is usually too decomposed to provide the necessary structure and water drainage [90]. Canadian peat moss is recommended, but because of the transportation costs to the South, alternative materials have been evaluated.

Because pine bark is readily available and relatively inexpensive, it has been suggested as an alternative to peat moss in growing media [98]. Results to date have indicated that bark does have physical properties that make it a possible alternative to peat moss [27, 91], allows excellent mycorrhiza development [95], and may inhibit disease organisms [83]. In the study that compared bark to commercial media [83], seedling losses were greatest in commercial media with pHs above 6.0, and losses increased as the water-holding capacity of the medium increased. Bark maintained pH and water in a range that limited disease development. However, pine bark also has some disadvantages. Nitrogen deficiency may develop in bark-amended media, causing some researchers to discourage its use [80]. Milled bark in plug-type containers does not bind well with roots and makes extraction difficult. Bark also has low water-holding capacity; therefore, seedlings need more frequent watering during the growing phase and dry out more readily when outplanted [49]. Until more information is available, bark should be used only as a partial replacement for peat in the growing medium, and then only if composted first. Current data indicate that the peat-vermiculite blend is still the most satisfactory (Table 7.4).

A number of commercial growing media are available for container seedling production. Almost all of these are based on the Cornell mixes, which consist of various ratios of peat moss, vermiculite, and perlite [26]. However, these blends have been developed for horticultural and vegetable use and are unsuitable for conifers unless precautions are taken to reduce the pH to levels optimum for conifers. Some manufacturers will custom blend and reduce the amount of limestone so that pH is more satisfactory; the advantage of peat-vermiculite mixes without limestone over commercially blended peat-vermiculite mixes (Jiffy Mix®) produced for horticultural use is evident (Table 7.4). Although nutrients in Cornell-type mixes are sufficient for the first several weeks, supplemental fertilizers must then be added.

Table 7.4. Growth of 12-week-old shortleaf pine seedlings in three types of media (adapted from Pawuk [83]).

Medium[1]	Medium final pH[2]	Seedling characteristic[2] Weight, mg	Height, cm
Peat moss			
PV-50	5.4 c	523 a	10.87 a
Commercial (PV-50)	6.4 a	383 b	9.72 b
Pine cone			
CV-50	5.9 b	301 c	7.85 c
CV-70	6.0 b	259 de	7.46 cd
C-100	5.8 b	125 ij	6.08 fg
CS-70	5.9 b	270 cd	7.79 c
Pine bark			
BV-50	5.4 c	216 f	6.18 fg
BV-70	5.0 d	201 fg	6.15 fg
B-100	4.9 d	175 gh	5.63 g
BS-70	5.3 c	224 ef	6.96 de
Jiffy 50-50 (BV-50)	6.4 a	90 j	5.54 g
Jiffy 70-30 (BV-70)	6.5 a	154 hi	6.62 ef

[1] P = peat moss; V = vermiculite; C = cone chips; B = bark; S = soil. The number following the designation indicates the percentage of medium present.
[2] Within a column, means followed by the same lower case letter are not significantly different at the 0.05 level.

7.6 Seedlot Selection

7.6.1 Collecting and Processing Seed

The high-quality seeds essential for growing container seedlings are obtained when cone and seed collecting and processing are carefully controlled [9]. Complete removal of unsound seeds should be specified when seedlots are purchased; when seedlots are small, it is often convenient for growers to process their own seeds with the small laboratory cleaners or aspirators available [25]. (For more information about seeds, see chapter 4, this volume.)

7.6.2 Disease Problems

In the past, fungi borne on southern pine seeds have not been a major concern because most observations indicated that these fungi were saprophytic and did not affect germination [23]. However, with the advent of container culture, it is apparent that seed-borne fungi can be an important cause of seedling mortality.

Many seedlots contain infested seeds. For example, 8 to 20% of the seeds from five longleaf seedlots tested for *Fusarium* were found to be infested, and all five species of *Fusarium* recovered were pathogenic [82]. *Fusarium* has since been isolated from seedcoats of shortleaf *(P. echinata* Mill.), slash, and loblolly pine seed [84]. Pathogens may also be present inside pine seeds [79]. Such infected seeds germinate poorly, and damping-off losses are increased. In addition to *Fusarium*, Mason and Van Aarsdel [67] have identified *Trichothecium* as a pathogen on loblolly pine seeds.

Microorganisms infesting conifer seedcoats can be controlled by surface sterilizing or coating with fungicides. Techniques for using seed sterilants and fungicides on southern pine seeds were reviewed by Barnett and Brissette [19]. (For more information on insects and diseases, see chapter 20, this volume.)

7.7 Environmental Controls

The degree of environmental control needed to produce southern pine seedlings depends on whether they are grown in or out of phase with the normal growing season. For seedlings grown in phase, minimum environmental control is necessary; the primary concerns are to avoid overheating seedlings grown in greenhouses and to provide adequate soil moisture. For seedlings grown out of phase, the levels of light, moisture, and temperature must all be maintained within acceptable ranges.

The following discussion primarily is a general guide to the environmental conditions resulting in best germination and seedling performance of the southern pines. Detailed descriptions of equipment and facilities are available in Tinus and McDonald [109].

7.7.1 Germination Period

Seed germination depends on adequate light and moisture and favorable temperatures. The lack of optimum germination conditions can be offset in some species by lengthening the stratification period. For example, loblolly pine germination is more prompt and complete under simulated field conditions [16°C (60°F), 11-hour photoperiod] when the stratification time is increased from 30 days to 45 or 60 days.

7.7.1.1 Light

Southern pine seeds require light for germination [76, 81, 111]. However, the intensity of that light is relatively unimportant; slash and loblolly pine seeds germinate as well at 1,600 lux (150 footcandles) as at 3,200 lux (300 footcandles) [50]. Instead, it is the length of the photoperiod that is generally important. Although slash pine germinates equally well under 8-, 12-, and 16-hour photoperiods, loblolly pine germinates better when the photoperiod is increased from 8 to 16 hours.

7.7.1.2 Moisture

Containers must be watered frequently during the germination period. The force of the sprinkler spray must not dislodge the seeds from direct contact with a moist medium. When a misting system is used, the mist should not be so light as to allow the potting mixture to dry at the bottom of the container. Controls for watering systems that reflect environmental changes, such as the Mist-A-Matic® [37], are more desirable than time clocks that water on a predetermined schedule regardless of need.

During the germination period, the moisture content of the potting mixture should remain near field capacity. Any moisture stress beyond —2.5 bars (-0.25 MPa) reduces germination of southern pine [5]. There is some variation among species under drier conditions, however; germination of longleaf pine is better than that of slash pine seeds at moisture stresses of —8 to —14 bars (-0.8 to —1.4 MPa).

7.7.1.3 Temperature

Germination responses of southern pine seeds to temperature vary by species, seedlot, and both use and length of stratification [13]. Most longleaf pine seedlots have no stratification requirements, but unstratified seeds germinated well only at 18°C (65°F) and 24°C (75°F) (Fig. 7.6). The responses of slash, loblolly, and shortleaf seeds to temperature were similar (Fig. 7.6); the temperature at which unstratified seeds of these three species reached peak germination was 24°C. Unstratified slash pine seeds were less affected by temperature extremes than were unstratified loblolly or shortleaf seeds. Stratified slash pine seeds had a wide range, 18 to 29°C (65 to 85°F), at which germination was > 70%.

The above data [13] were obtained under standard laboratory conditions with constant temperatures. Additional evaluations were made with fluctuating temperatures that better represent actual conditions. Longleaf pine was the only one of the four species adversely affected by temperatures alternating between 24°C (75°F) and 35°C (95°F) (Table 7.5). If unusually low or high temperatures are anticipated during the germination period, or if greater uniformity of germination is desired, then the period of stratification should be lengthened. For loblolly and shortleaf pines, stratification for 45 to 90 days not only hastens germination over that of the standard 30-day treatment, but also results in better germination under adverse conditions [13, 75].

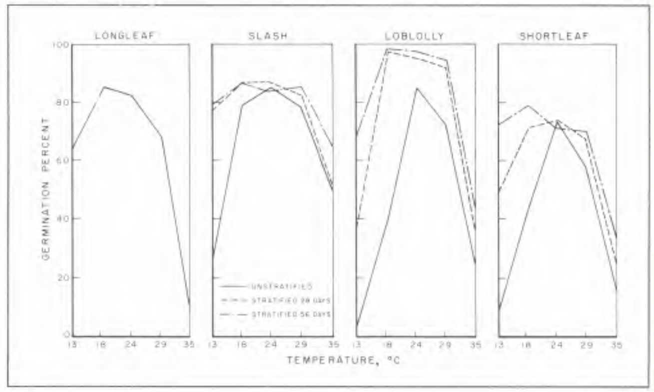


Figure 7.6. Germination of southern pine seeds at five temperatures following pregermination treatments (adapted from Barnett [13]).

Table 7.5. Germination of southern pine seeds under various temperature regimes.

Species	Seed stratified?	Germination,%		
		24°C	24–35°C[1]	35°C
Longleaf	No	79 a[2]	61 b	12 c
Slash	No	84 a	83 ab	71 b
	Yes	80 a	72 ab	66 b
Loblolly	No	88 a	89 a	27 b
	Yes	97 a	96 a	46 b
Shortleaf	No	78 a	76 a	42 b
	Yes	46 a	45 a	30 b

[1] 18 hours at 24°C, 6 hours at 35°C.
[2] Within rows, means followed by the same lower case letter are not significantly different at the 0.05 level.

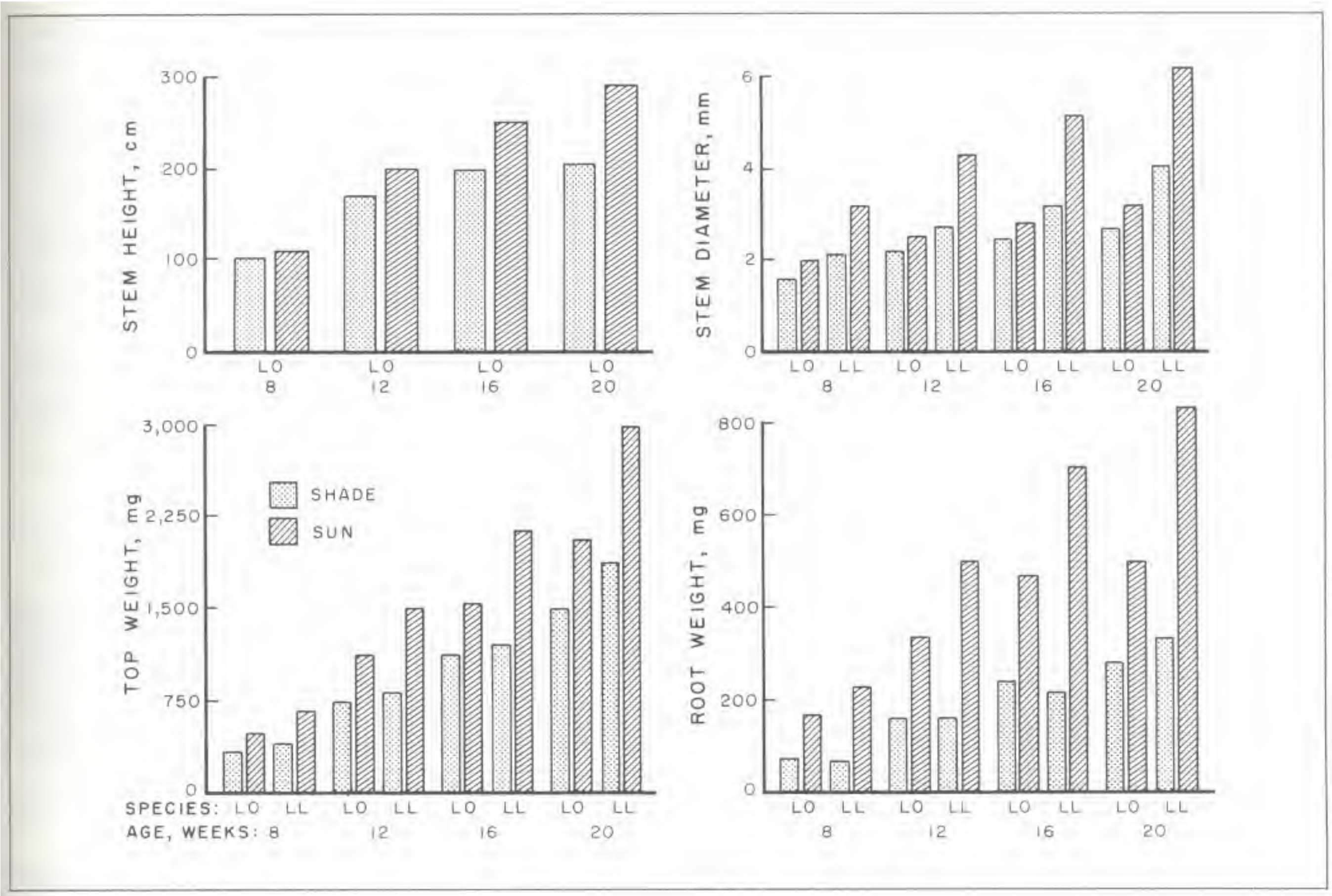


Figure 7.7. Development of longleaf (LL) and loblolly (LO) pine seedlings at different ages grown under either full sun or 30 to 50% shade (adapted from Barnett [18]).

7.7.2 Post-germination Period

7.7.2.1 Light

Photoperiod can either be lengthened or shortened, depending on the type of facilities available. Extending the photoperiod with low-intensity light at intermittent intervals generally produces larger seedlings during winter when natural photoperiods are relatively short. An extended photoperiod can prevent early budset, lengthen internodes, increase foliage size, and promote earlier change from primary to secondary needles.

Limited data are available on the effect of an extended photoperiod on southern pines. However, ponderosa pine (*P. ponderosa* Dougl. ex Laws.) seed sources from 33° N latitude (about the latitude of Dallas, Texas; Jackson, Mississippi; and Savannah, Georgia) are quite photosensitive [108]. Seedling height growth and dry weight were increased when the photoperiod was extended by incandescent lighting at intensities of 270 lux (25 footcandles) for 1 minute out of every 30 during the night.

Because short days are important in developing cold hardiness, some growers shorten the photoperiod by covering the greenhouse with black cloth part of each day during late summer or early fall. This technique, which is being used operationally in Canadian container nurseries, stimulates early budset and frost hardiness.

Otherwise, shading is used commonly to help control excessive temperatures, particularly in late spring and summer. By reducing incoming solar radiation, shadecloth can lower greenhouse temperatures 5°C (9°F) or more. Recommended levels of shading have ranged from 30 to 55% [109]. But recent results have shown that seedling development, particularly of longleaf pine, is markedly affected by the shading [18]. Longleaf seedlings grown at 30 and 50% shade were significantly smaller in stem diameter, top weight, and especially root weight (Fig. 7.7). Loblolly seedlings followed the same trends as longleaf, but the magnitude of differences between sun and shade exposures was not as great.

These results have strong implications for producing longleaf pine in containers. Growing longleaf seedlings in full sun, or at the lowest level of shade possible, is highly desirable. The best way to apply this technology is to sow seeds in containers in late spring (May or early June) and grow them in the open throughout the summer. Seedlings with larger diameters and (perhaps more important to field performance) greater root systems are then available for planting in late summer or fall. Not only are seedlings of better quality, but they are produced more economically because a greenhouse structure is not required. Although most appropriate for longleaf pine, this technology benefits loblolly and other southern pines as well.

7.7.2.2 Moisture

Heavy, infrequent waterings should characterize the post-germination period. Such a regime allows the surface of the medium to dry between waterings and reduces the chance of damping-off. Less frequent waterings also lower the water content of the medium, which increases aeration, absorption of minerals, and root growth.

7.7.2.3 Temperature

If seedlings are to be produced during winter, a heated greenhouse will be required. Heat can be provided either overhead or under seedling benches. Greenhouses must also be cooled during warm weather to provide optimum growing temperatures. Evaporative cooling is common in greenhouses utilizing exhaust fans and wetted pads or lava rock; shading can also help maintain cooler temperatures. Tinus and McDonald [109] provide a thorough discussion of various systems of greenhouse heating and cooling. However, although many workers have searched for specific optimum temperatures for growth, the complex relationship between temperature and growth makes determining optimums difficult.

Day and night phases of a temperature regime, and the differences between them, have been found to affect growth. Kramer [52] subjected 1-year-old loblolly seedlings to various day and night temperature combinations. He reported that growth of shoots increased with rising day temperature and decreased with increasing night temperature. The difference between day and night temperatures appeared to be the most important factor; his seedlings were tallest when the difference was about 12.5°C (22°F) and shortest when there was no difference. Perry [89] also reported generally increased height growth of loblolly seedlings with increasing day temperature. Growth with a day temperature of 23°C (74°F) was lowest for night temperatures ranging from 20 to 26°C (68 to 79°F) and highest for night temperatures ranging from 10 to 17°C (50 to 63°F).

In one of the most extensive studies of temperature effects on loblolly seedling growth, Greenwald [40] measured shoot heights and dry weights of shoots and roots when seedlings were 6 and 9 months old. A 23/17°C (73/63 °F) day/night combination produced maximum height growth and shoot dry weight, with a rapid decrease through 26/20°C (79/68°F) to a low at 29/23°C (84/73°F). Yet Bates [22] suggested that container loblolly seedlings grown for periods of about 12 weeks should be subjected to 29/23°C (84/73°F) day/night temperatures for 4 to 6 weeks, then 26/20°C (79/68°F) or 26/17°C (79/63°F) for the remaining time. This regime would take advantage of the fast start, but would slow shoot growth while maintaining high total weight. Bates' [22] optimum temperatures for seedlings 3 months old are quite different from Greenwald's [40] for seedlings > 6 months old. Apparently, as seedlings develop, the temperatures optimum for growth shift.

Bates [22] also reported the effects of varying day/night temperature combinations on development of container-grown longleaf pine seedlings. Day/night temperatures of 23/17°C (73/63°F) appeared to be the best combination for increasing seeding dry weight, a characteristic important for successful handling and planting. Warmer temperatures resulted in better top appearance but produced weaker, finer roots.

Although such strict temperature control is not possible under operational conditions, growers should be aware of the importance that diurnal temperature fluctuations have for seedling growth.

7.8 Cultural Practices

The cultural techniques necessary to optimize growth and quality of container seedlings are not as well understood as they are for bareroot stock. The following description of cultural practices is intended to provide the forester with information as to why certain techniques are used and how they affect seedling quality.

7.8.1 Filling Containers

To produce a uniform crop, the containers must be filled uniformly, each cavity holding the same volume of growing medium settled to the same level. Before containers are filled, the medium should be moistened so that it is not dusty but does not clump. Slightly moist medium is easier to handle, fills more uniformly, and can be wetted to field capacity more readily than dry medium.

Containers can be filled by hand or machine. The simplest hand method is to set a number of blocks or trays on a paved surface and use a shovel to spread medium over the top. Any excess can be swept off and used for the next batch. To settle the medium, each block or tray should be dropped from a height of 15 to 30 cm (6 to 12 in.) two or three times. The containers can then be topped off. They should be watered before seeding to settle the medium below the container tops and to ensure that the medium is moist. Machines are available that will allow a set amount of medium to be deposited into containers passing on a conveyor. These machines often vibrate the container to settle the medium.

7.8.2 Sowing Techniques

7.8.2.1 Number of seeds per container

Seedlots with low germination require multiple seeding to reduce the number of vacant cavities. On the other hand, containers with excess seedlings usually must be thinned. To help minimize these problems, Pepper and Barnett [88] suggest a sowing scheme in which varying numbers of seeds are sown per cavity. For instance, 30% of the containers could receive three seeds, 20% two seeds, and the remaining 50% one seed. Mixed sowing schemes are generally more cost-efficient than the standard constant-number approach but still require some thinning to achieve one seedling per container.

7.8.2.2 Sowing methods

Methods of seed sowing vary from hand seeding or use of simple templates to elaborate seeding machines. Many container operations use some type of vacuum seeder, which consists of a seeding head, connected to a vacuum cleaner or pump, with holes drilled to match the container arrangement. Even the most efficient seeders occasionally leave blank containers, so growers should visually check the cavities.

7.8.2.3 Seed covering

The effect of covering southern pine seeds varies with the type of watering regime used [117]. Germination is usually most complete and rapid when seeds remain uncovered and are watered by a misting system [11]. If seeds are watered less frequently, a seed covering, typically a layer of medium, facilitates germination through a mulching effect that retains water near seeds. In general, larger seeds can be covered to a greater depth than smaller ones.

7.8.2.4 Mycorrhizal inoculation

Mycorrhizae are the structures resulting from the colonization of a host root by a suitable fungus. They increase availability and absorption of nutrients, especially phosphorus, which is often the most limiting nutrient on Coastal Plain sites in the South. Ectomycorrhizae also protect fine absorbing roots from being attacked by pathogens [60]. On sites without natural populations of mycorrhizal fungi, pines will not survive or grow well. Indeed, the benefits of having visible mycorrhizae on the root systems of bareroot seedlings when they are outplanted are well documented [61].

Development of some species of mycorrhizal fungi may be limited on heavily fertilized seedlings [62, 64], and less fertilization — about one-half of what would normally be considered optimum — may be necessary to encourage mycorrhizal inoculation. When container nurseries are located near forested areas where airborne mycorrhizal spores are abundant, natural inoculation may be sufficient. Barnett [15] found that *Thelephora terrestris* developed on seedling root systems in containers from airborne spores, and high fertility did not seem to inhibit its development. Evaluations of the field performance of shortleaf and longleaf seedlings indicated that initial seedling size was more closely related to growth than amounts of mycorrhizae on roots [15].

Considerable evidence suggests that inoculation with mycorrhizae improves seedling performance on difficult sites such as arid soils, reclamation areas, and pine plantings in the southern Great Plains where natural inoculum may be scarce or lacking [14, 15, 30, 32, 39, 61, 62]. Therefore, it is important that root systems of container seedlings destined for such sites be inoculated with mycorrhizae before they are outplanted.

Marx and his coworkers [63, 66] have developed techniques to produce mycelial inocula of *Pisolithus tinctorius* in a vermiculite culture. These techniques have made it feasible to propagate and manipulate this fungal symbiont. A simple and less expensive means of inoculation with *P. tinctorius* is through basidiospores, the primary agents for disseminating many ectomycorrhizal fungi. Several workers have used spores of specific fungi as inoculum for synthesis of mycorrhizae on pine [65, 105]. *Pisolithus tinctorius* produces large basidiocarps (puff balls) that contain billions of spores. Spores are usually mixed with the peat-vermiculite medium before containers are filled, but Theodorou [105] found that coating seeds of Monterey pine *(P. radiata* D. Don) with freshly harvested basidiospores was an easy, effective way to introduce mycorrhizal fungi into soils. International Forest Seed Company of Birmingham, Alabama, has a commercial process for pelletizing southern pine seeds with *P. tinctorius* spores. After pelletized seeds are sown, the container should be drenched with water to ensure that the inoculum is washed from the seedcoat; otherwise, the pellet may inhibit germination. Perhaps the greatest problem in using spores for mycorrhizal inoculation is the lack of a technique for evaluating spore viability.

Inoculation of the container growing medium with mycorrhizal fungi necessitates some modification of the normal cultural regime. As previously stated, the high fertility levels should be reduced about one-half, to encourage mycorrhiza development [62, 64]. The use of fungicides, which can be either harmful or beneficial to mycorrhiza development, should be monitored. Pawuk et al. [87] evaluated the effects of seven fungicidal drenches on development of *P. tinctorius* and *T. terrestris* mycor-

Table 7.6. Effect of fungicide treatment on ectomycorrhiza development on longleaf pine seedlings grown in *Pisolithus tinctorius-infected* and airborne-infected (primarily by *Thelephora terrestris) media* (from Pawuk et al. [87]).

Fungicide treatment	*Pisolithus*-infected		Airborne fungi infected	
	Mycorrhizal	Non-mycorrhizal	My-corrhizal	Non-mycorrhizal
		%[1]		
Banrot®	26.21 a[2]	0.00	4.95 b	5.23 b
Benlate®	25.00 ab	0.00	6.16 b	13.55 a
Mertect®	19.97 bc	0.00	5.66 b	11.84 a
Truban®	14.59 d	0.00	4.61 b	1.77 c
Dexon®	10.65 e	0.00	10.07 a	11.03 a
Captan®	6.80 e	0.00	4.71 b	7.38 b
Terraclor®	0.00 f	0.00	1.98 c	0.88 c
Control	17.53 cd	0.00	6.27 b	7.66 b

[1] Percentage of short roots forming ectomycorrhizae.
[2] Within a column and treatment, means followed by the same lower case letter are not significantly different at the 0.05 level.

rhizae on roots of container longleaf pine. The degree of mycorrhiza development differed significantly among fungicide treatments (Table 7.6); only seedlings drenched with Banrot® and Benlate® had greater development than the control (no fungicide).

7.8.3 Transplanting and Thinning Germinants

Empty containers can represent a significant loss because they cost as much as a seedling to maintain through a growing cycle. On the other hand, growing multiple seedlings per container often reduces seedling quality. These problems are best avoided by careful seedlot selection and proper sowing techniques. However, some situations may require transplanting, thinning, or both.

As a general recommendation, the grower should (1) use only the best quality seeds available, (2) thin multiple seedlings to one per container, and (3) transplant only vigorous germinants. Both thinning and transplanting should be completed as soon as possible after germination.

7.8.3.1 Transplanting

If 5 to 15% of cavities contain ungerminated seeds, germinants from cavities with multiple seedlings or from germination flats should be transplanted to the empty cells. Up to 5% empty cells 4 weeks into a rotation will have little practical effect on costs. If more than 15% of cells are empty, however, seed should be sown in additional containers.

Pawuk [85] studied the effect of transplanting on initial seedling growth and development. Transplanting longleaf pine germinants, regardless of their radicle lengths, is detrimental to subsequent diameter growth compared to growing trees from seed (Table 7.7). Total dry weight of both longleaf and shortleaf pine at 15 weeks was directly and significantly related to radicle length when seedlings were transplanted. Control (seeded) seedlings were heaviest; their average weight was about double that of transplants with short radicles.

Height of shortleaf pine seedlings at 15 weeks was directly related to radicle length at the time of transplanting, with control seedlings being tallest (Table 7.7). After transplanting, only seedlings originating from germinants with the shortest radicles were significantly smaller than those from all other treatments. Sown seedlings were 1 to 2 weeks older than transplants and therefore larger. Likewise, transplants with long radicles were probably older than transplants with shorter radicles.

Table 7.7. Effect of radicle length at time of transplanting on growth of longleaf and shortleaf pine seedlings after 15 weeks (adapted from Pawuk [85]).

Treatment	Longleaf [1] Root-collar diameter, mm	Longleaf [1] Dry weight, mg	Shortleaf [1] Height, cm	Shortleaf [1] Dry weight, mg
Radicle length, cm				
1.5–2.0	1.12 a	168 a	8.61 a	137 a
3.0–3.5	1.20 a	210 b	9.36 b	173 b
4.5–5.0	1.28 a	237 c	9.48 b	188 b
Seeding (control)	1.48 b	342 d	9.93 b	280 c

[1] Within a column, means followed by the same lower case letter are not significantly different at the 0.05 level.

Transplanting should be done once an empty cavity becomes evident, usually about 10 to 14 days from sowing. Although better growth after transplanting is related to increased radicle length, it is better to transplant soon after sowing when the radicles are not so long and not so susceptible to damage. If transplanting is delayed much beyond 14 days, germinants with longer radicles should be used because smaller seedlings are quickly suppressed. However, unless care is taken to avoid damage to the radicles, transplanting of older germinants is generally not as successful.

7.8.3.2 Thinning

If cavities contain several seedlings, then the grower must decide whether or not to thin. Longleaf pine seedlings were more seriously affected by multiple seeding than loblolly or slash seedlings [19]. The most marked effect was on longleaf seedling development, measured as dry weight: at the end of 14 weeks, dry weights of multiple-grown seedlings were reduced by one-half or more. In addition, the smaller, multiple-grown seedlings had poorer survival than those grown with only one seedling per cavity. Because longleaf pine seedlings are more intolerant than other pines to higher seedling densities [21], multiple sowing should be minimized and any cavities with more than one seedling thinned.

The effects of multiple sowing are less drastic with slash and loblolly pine. However, initial seedling development was reduced by multiple seeding without thinning. Although size differences were not significant among treatments after 3 years in the field, differences became greater each year — slash seedlings grown one per cavity were 3% taller than those grown three per cavity after 1 year but 8% taller after 3 years.

No long-term data are available on the effects of planting containers with multiple seedlings; however, results from 15-year-old multiple-seeded spots indicate the trend [29]: leaving two or more seedlings per spot significantly reduced height and diameter growth relative to one seedling per spot.

7.8.4 Growing-Medium Moisture

The effects of different moisture levels on development of loblolly and longleaf pine seedlings were determined by measuring root and shoot dry weights after a 10-week growing period (Fig. 7.8). Peat-vermiculite mixtures with moisture contents between 300 and 500% (dry-weight basis) produced the best seedlings.

Growing-medium moisture content can readily be evaluated with the container weighing method [71], which

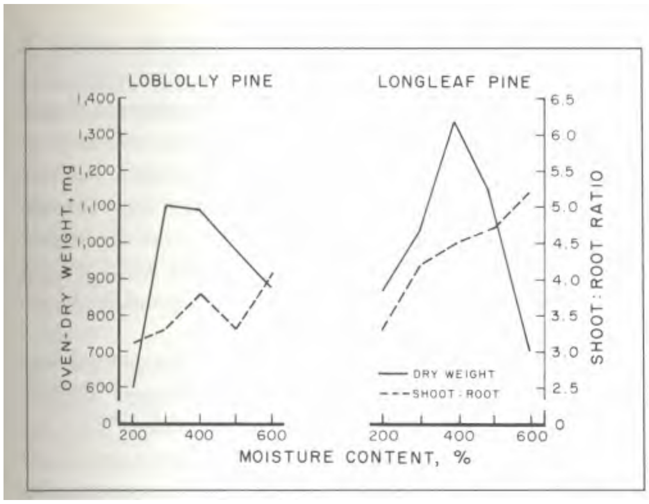


Figure 7.8. Characteristics of loblolly and longleaf pine seedlings grown for 10 weeks at various moisture contents in peat-vermiculite mixture (1:1).

also is useful for monitoring irrigation. When the weight of a filled container declines to some predetermined percentage of the weight of container when medium is saturated, the crop is watered. This percentage is often around 75 to 80% of the container weight when medium is at field capacity, depending on the type of container, type of growing medium, and species. Container weight must be adjusted for seedling weight periodically during the growing season.

7.8.5 Seedling Nutrition

Information about special nutritional needs of container southern pine seedlings is very limited. Fortunately, the range of nutrient concentrations that provide good growth is quite broad, and most coniferous tree species have similar requirements. Macronutrients are needed in relatively large amounts; not only is the total concentration of each macronutrient element important, but also the relative proportion of each. Micronutrients (or trace elements) also are critical to seedling growth but are only needed in very small amounts. Recommended concentrations of macronutrients and micronutrients for southern pines are summarized in Table 7.8.

The six macronutrients - nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) - have been studied in some detail. In one study [104], recommended nutrient levels for bareroot southern pine nursery soils were 25 to 38 ppm of P, 75 to 100 ppm of K, and 300 to 600 ppm of Ca. In another study [73], growth of slash pine in sand culture was best when concentrations of N and K were both > 125 ppm but < 625 ppm. According to literature on other conifers, concentrations of Mg should range from 15 to 73 ppm, of S from 20 to 150 ppm [109].

Work with the micronutrients iron (Fe), boron (B), manganese (Mn), chlorine (Cl), zinc (Zn), copper (Cu), and molybdenum (Mo) has been extremely limited. Recommendations for Scots pine *(Pinus sylvestris* L.) and Norway spruce *[Picea abies* (L.) Karst] are 0.93 ppm of Fe, 0.17

Table 7.8. Recommended nutrient concentrations in growing media for southern pines (consolidated from [48, 73, 104, 109]).

Nutrient	Concentration, ppm
N	125–625
P	25– 38
K	75–625
Ca	300–600
Mg	15– 73
S	20–150
Fe	0.93
B	0.17
Mn	0.17
Zn	0.02
Cu	0.02
Mo	0.003

[1] These recommended nutrient concentrations should not be considered optimum but can be used as a basis for fertilization until more complete information is available.

ppm of B, 0.17 ppm of Mn, 0.02 ppm of Zn, 0.02 ppm of Cu, and 0.003 ppm of Mo [48]. The availability of these nutrients is highly dependent on pH of the medium. Growth for most conifer seedlings is optimum in the pH range 5.0 to 6.0 [53].

7.8.5.1 Fertilizer formulations

Incorporating slow-release fertilizers into the growing medium or adding granular fertilizer as a "top dressing" to containers is a common horticultural practice, although the use of such techniques in seedling operations is limited because of the small top-surface area of the container. Osmocote® formulations have often been incorporated, and Osmocote 18-6-12 has worked well with southern pines. However, incorporation may result in overfertilization and limit the grower's ability to stop height growth and harden seedlings when desired. This may be less of a problem when spring outplanting is anticipated and the need for hardening is not as great.

Most seedling operations use commercial soluble fertilizers, which are dissolved in water and injected into the irrigation system or sprayed over the trees by hand. These fertilizers, produced by a number of manufacturers, are available in numerous types, formulations, and proportions of macronutrients and micronutrients. Peters Peat-lite Special® formulations work well with southern pines grown in peat-vermiculite media. Some fertilizer manufacturers offer custom formulations based on their analysis of local water samples and crop needs.

Growers can also custom-mix nutrient solutions by adding various amounts of technical-grade chemical components to water according to the optimum nutrient regime for the species, potting mix, and water composition. Tinus and McDonald [109] developed a format for determining the chemical formulation best suited for an individual nursery situation.

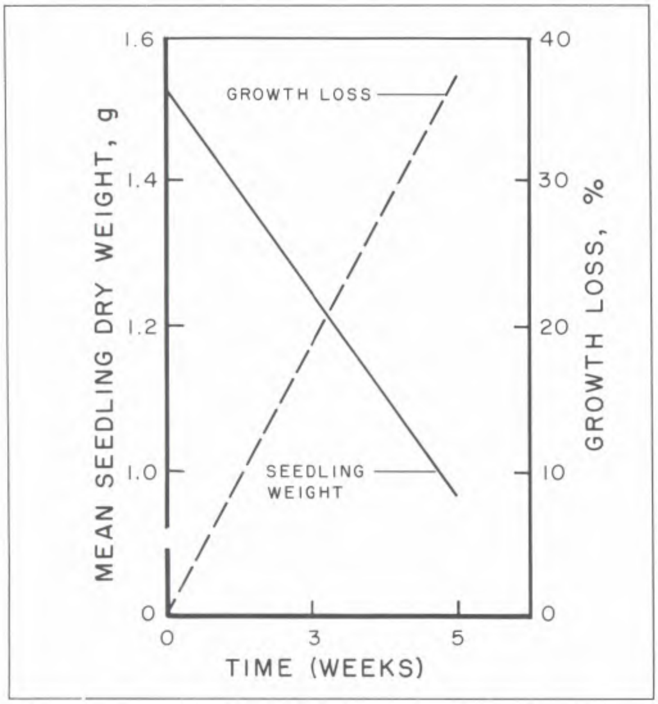


Figure 7.9. Effects of timing of initial fertilizer applications and dry weights of loblolly pine seedlings grown for 20 weeks.

7.8.5.2 Timing and initial application

Traditionally, adding nutrients during germination has not been recommended because they are supplied by the seed and may increase losses due to damping-off fungi [109]. Fertilization is usually scheduled to begin after cotyledons have shed their seedcoats (about 3 weeks). However, this delay can substantially affect seedlings, for example, reducing loblolly pine seedling development by nearly 20% (Fig. 7.9). If the crop is on a short rotation, however, fertilization at the time of seeding may be desirable. Even if germinants cannot effectively utilize nutrients at this early stage of development, those nutrients are available as soon as they are needed, which may hasten growth. If a short growing period is not critical, delaying fertilization until after germination may be beneficial from a disease-management viewpoint.

7.8.6 Pest Management

7.8.6.1 Soilborne diseases

Species of *Fusarium* especially *F. moniliforme,* are the fungi most commonly cultured from diseased seedlings and growing media [84]. *Fusarium* has been cultured from air and water samples in and around greenhouses, but always at low levels; most of these fungi probably are spread from infected seedlings during watering. *Fusarium* often produces abundant spores on infected seedlings; once spread to the soil, infection builds up over time. Apparently, seedlings become more resistant to infection as they mature. (For more information on pest management, see chapter 20, this volume).

Rhizoctonia is a common soil fungus that spreads in nature by movement of infected soil or plant debris from one area to another. Though its source is unknown, it could easily be brought into greenhouses, like other soil fungi, by workers or on tools and equipment. *Rhizoctonia* has been observed attacking seedlings in germination trays in a seed testing lab [84] and on the foliage of container longleaf pine seedlings. In all cases, it developed when seedling foliage was wet for extended periods and spread from seedling to seedling, its mycelia clearly visible.

Water molds such as *Pythium* and *Phytophthora* may enter container nurseries through contaminated irrigation water or by methods previously mentioned. They are favored by wet, poorly drained soils and cause root rot and damping-off of young seedlings. As seedlings mature, they become more resistant, but root development and seedling growth may still be reduced.

Some cultural practices can help prevent loss of seedlings to disease. The medium should be pathogen free from the start and well drained. Seedlings should not be overwatered. Several available fungicides, if applied promptly and correctly, will control damping-off and root rot; however, there is no one fungicide cure-all.

7.8.6.2 Foliage diseases and rusts

Foliage diseases have not been a problem on container southern pine seedlings, probably because of the short period necessary to grow plantable seedlings and the absence of prolonged periods when foliage is wet. The same can be said for the rusts, although seedlings could be infected with *Cronartium* rusts and symptoms would probably not be observed before seedlings were shipped.

The possibility of rust infection should not be overlooked. Spraying with fungicides to prevent rust infection is not necessary in closed greenhouses. However, during spring, seedlings should be watered early in the day so foliage is dry by night, especially during wet weather when rust spores are released. Pawuk [84] observed rust infection on slash pine seedlings in an experimental greenhouse in Louisiana. Seedlings were purposely watered in the evening so foliage would be wet overnight to favor rust infection. Infection was only 3%, compared to 65% for seedlings similarly treated and grown in an adjacent, open shadehouse. The low rate of greenhouse infection was probably due to the absence of sufficient inoculum, since air movement into the greenhouse was minimal. As long as foliage remains dry and greenhouses are closed at night, rust should not be a problem. When container seedlings are grown or held outside, seedlings should be sprayed to avoid rust infection.

7.8.6.3 Algae

Many blue-green and green alga species develop on container growing medium [12]. Once algae dry, a crust develops, creating a barrier that interferes with irrigation, fertilization, and pesticide application [109]. One effective algae control is a perlite or grit covering on the surface of

Table 7.9. Alga development on shortleaf pine seedlings grown in containers drenched with Maneb® and Dichlone® (adapted from Pawuk [86]).

Variable	Alga rating [1]	Seedling characteristics Height, cm	Dry weight, mg
Treatment			
Control	2.7	14.5 c	412 c
Maneb	1.5	16.7 a	528 a
Dichlone	1.9	16.0 b	474 b
Time applied			
Week 3 and 8	1.6 b [2]	16.4 a	505 a
Week 3 only	1.8 a	16.4 a	512 a
Week 5 only	1.7 b	16.2 a	486 a
Drenmch rate, mg/cm [2]			
0.4 [3]	2.0	15.8 b	489 a
0.6	1.7	16.4 ab	502 a
0.8	1.6	16.7 a	508 a
1.0	1.5	16.6 a	505 a

[1] 0 = no algae present, 1 = algae present but barely detectable, 2 = algae forming a pale green film, 3 = algae forming a thin mat <0.5 mm thick, and 4 = algae forming a thick mat >0.5 mm thick.
[2] Within columns, means followed by the same lower case letter are not significantly different (Duncan's Multiple Range Test, 0.05 level).
[3] Drench rates and pesticide interacted in the alga development data. Maneb was better than Dichlone at the 0.8 or 1.0 mg rate, but not at the others.

the growing medium. However, because this may affect seed germination, chemical control of algae may be desirable.

Chemicals that control algae in water are not labeled for treatment of growing media, so the greenhouse manager has no guidelines for selecting appropriate chemicals to treat the soil. In a greenhouse screening study, Pawuk [86] reported that both Maneb® and Dichlone® reduced alga development (Table 7.9). Alga control was better when fungicides were applied at either weeks 3 and 8 or at week 5 alone than when applied at week 3 alone. At each drench schedule, alga development decreased as Maneb concentration increased, a trend absent from the Dichlone treatments. Neither Maneb nor Dichlone inhibited the growth of shortleaf pine seedlings; indeed, growth was greater in many treatments, especially Maneb, than in the control. Maneb and Dichlone may also have protected the seedlings from pathogenic soil fungi.

7.8.6.4 Weeds

Where sterile growing media are used and tree seed is weed free, weeds in the containers should not be a problem. However, outside production areas and greenhouses with gravel floors can develop a considerable growth of weeds, and weed seeds from the air or outside production areas can be drawn into greenhouses through the ventilation system or carried in on workers' feet, germinating on floors or in containers. Because weeds may harbor other pests, any that germinate should be removed by hand. Those that develop in hard-to-reach places, such as between and under benches, should be treated with nonvolatile, broad-spectrum herbicides such as simazine; however, any herbicide should be very carefully applied in a closed greenhouse. Generally, weed problems can be minimized by controlling weeds close to the greenhouse and through proper sanitation.

7.8.6.5 Rodents

Mice are considered the principal pest; they can eat or cache large numbers of seeds from containers in a short time and can also clip young, succulent seedlings. The main defenses are construction of physical barriers, minimizing rodent cover, and trapping or baiting. Production areas should be free of debris or plants that will shelter or provide food for rodents. A greenhouse should be tightly enclosed at the base, and all doors should automatically close when released. Elimination of any habitat for mice, combined with barriers to greenhouse entry, will usually prevent serious rodent problems. Some limited trapping or baiting may be necessary, however. Warfarin@ as treated oat bait is the most commonly used rodenticide at present [109].

7.8.6.6 Insects

Most common insect pests, such as grasshoppers, ants, and caterpillars, are not serious threats to seedling culture and can usually be controlled by sanitation, barriers, and baiting. Serious insect pests, including aphids, whiteflies, scales, thrips, and mites, typically enter the greenhouse through the ventilation system. Under greenhouse conditions, these insects can reproduce rapidly and cause extensive damage. Large insects occur less frequently; more obvious, they are easier to identify and control.

If harmful insects are present, approved insecticides should be used to eradicate them. If management is alert and observant, the "see, identify, and treat" program should be best. The mode and timing of application and the chemical used should be designed for the target insect. (See also chapter 20, this volume).

7.8.7 Controlling Seedling Morphology

7.8.7.1 Shoot morphology and budset

Top pruning of container seedlings is normally not necessary and cannot be routinely recommended. However, when seedling development has not been adequately controlled by cultural regimes, pruning may be desirable to obtain a better seedling balance. It may be beneficial to clip the needles of longleaf pine to allow all seedlings to be uniformly exposed to light; even at low seedling density, needle development in containers can be so great as to cause shading problems in this very intolerant species.

Needle clipping or top pruning reduced initial seedling size and weight of longleaf, loblolly, and slash pine (Table 7.10). Clipping longleaf needles did not improve seedling field performance; but of the clipped seedlings, those that

Table 7.10. Effect of top pruning and needle clipping southern pine seedlings on initial development and field performance [17].

Pruning treatments, by species	Initial seedling characteristics: Height, mm	Diameter, mm	Top wt., mg	Root wt., mg	Field performance [2]: Survival, %	Diameter or height, cm
Longleaf [1]						
Control	–	3.4	1,100	158	51	1.52
10, 15 cm	–	2.9	393	122	48	1.17
10, 20 cm	–	3.3	668	148	44	1.40
10, 15, 20 cm	–	3.3	526	144	54	1.50
Loblolly						
Control	229	2.6	722	188	76	58.2
10 weeks	176	2.7	745	203	81	54.3
12 weeks	141	2.7	605	183	78	52.4
14 weeks	133	3.0	499	180	77	49.1
Slash						
Control	275	3.0	1,166	212	73	62.8
10 weeks	163	2.8	621	171	78	55.5
12 weeks	136	3.0	590	213	81	56.4
14 weeks	131	2.8	457	179	75	52.1

[1] Longleaf needles were clipped to 10 cm at about 8 weeks; some were further clipped to 15 or 20 cm at 2-week intervals.
[2] Loblolly and slash seedlings were pruned to 12.5 cm at 10, 12, and 14 weeks. Field performance was measured 2 years after outplanting: root-collar diamter of longleaf, total height of loblolly and slash.

were clipped early performed best. For all three species, pruning did not markedly improve field survival or growth; in fact, field growth 2 years after outplanting was closely correlated (0.967, 0.956, and 0.923 for longleaf, loblolly, and slash pine, respectively) with seedling size at outplanting [17]. Hence, the larger seedlings performed as well as or better than those pruned.

7.8.7.2 Root morphology

Early results from container-seedling studies showed the desirability of restricting root egress from the container during the culture period. Copper paint [97] or screening [20] inhibited root growth from the bottom of containers, increasing seedling survival. However, allowing roots to air prune when they grow out of the container was found to be a more efficient means of eliminating root growth from containers. The key to effective air pruning of roots is providing easy air access around the container drainage holes. Root spiraling, the most prevalent problem for southern pines in containers, can largely be eliminated by proper container selection. Although a vertically oriented root system is common in plug-type containers, the rapid root growth from the lower portion of the plug does not seem to result in root deformity. In fact, it probably improves seedling survival and growth on adverse sites [16]. However, the early development of roots from the bottom of plugs may slow mycorrhiza development; the microenvironment and soil associates of these more vertically egressed roots are not as favorable as those surrounding more laterally developed roots nearer the soil surface [94].

Certain techniques can change or control the pattern of root morphogenesis in plug-type containers. Burdett [28] has reported that copper carbonate in acrylic latex paint applied to container walls will stop root growth at that wall. With this technique, a small amount of copper carbonate (30 to 100 g/L) is mixed with acrylic latex paint, and the inside of the container is painted with the mixture before being filled with medium. When seedling root tips reach the container wall, many of the lateral roots stop growing, instead of turning and continuing to grow down the walls to the root egress hole. The laterals that stop often develop a series of secondary roots, which also stop growing at the container wall. Upon removal from the container, these root tips resume growth outward from the sides of the root "plug," promising better lateral root anchorage and access to water and nutrients. However, extraction from the container becomes more difficult because there are fewer roots on the plug surface to bind the medium together. McDonald et al. [72] also evaluated some synthetic auxin compounds that gave results similar to those for chopper carbonate.

7.8.8 Conditioning Seedlings

Most seedlings will cease height growth and set bud when exposed to moisture stress and short photoperiods. Reducing the nitrogen provided to seedlings also helps to slow growth. Although the ease with which growth is stopped depends upon the season, it can be stopped any time of year. The length of time allowed for the initial hardening stage, during which growth ceases, stems lignify, and buds set, depends on the environmental conditions expected at the time of outplanting.

7.8.8.1 Moisture stress

As seedlings approach the desired size, moisture level of the growing medium should be allowed to decline to begin the hardening process. Midday plant water potential should be reduced to between -12 and -15 bars (-1.2 and -1.5 MPa) to impair height growth and help initiate hardening. The time required for plant water potential to drop to the desired level depends on moisture content of the growing medium and evaporative demand.

Water status can be evaluated indirectly by weighing containers to determine moisture content or directly by measuring plant water potential with a pressure chamber. Weighing is appropriate while the seedlings are small and water represents a major portion of their total weight; a pressure chamber is recommended for larger seedlings. To maintain plant moisture stress at safe levels, careful monitoring of water potential is important.

7.8.8.2 Nutrition

Once the seedlings have reached about 80% of the desired height [about 13 cm (5.5 in.)], reducing the nitrogen concentration in the fertilizer solution helps to slow stem height growth. The frequency of nutrient applications also should be reduced. An increase in rates of phosphorus and potassium may foster continued root and stem diameter growth [109]. Yet Timmis [106] found that a rather extreme potassium-nitrogen imbalance strongly reduced the ability of containerized Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] seedlings to harden. He determined that the K:N ratio must be < 1.0 to permit maximum cold hardening after an 11.5-week hardening regime.

7.8.8.3 Cold hardening

Once growth has ceased and stems have lignified, additional hardening is needed if late-fall or winter outplanting is planned. In this case, seedlings are gradually exposed to more severe conditions, primarily low temperatures, that will bring about physiological changes enabling the trees to tolerate the new conditions. Temperatures of 1 to 5°C (34 to 41°F) generate considerable cold hardiness.

Mexal et al. [78] found that approximately 42 days of hardening are required to induce sufficient cold hardiness in an Arkansas source of loblolly pine to enable seedlings to survive late fall and early winter outplanting. When soil moisture is adequate, partially hardened stock may be planted successfully in September or October. Seedlings can be hardened by exposure either to low temperatures or to short photoperiods, but exposure to low ambient temperatures and decreased fertilization are the most feasible cultural practices (see also chapter 8, this volume).

7.9 Growing Schedules

The "growing schedule" is a chart of the conditions to be maintained and operations to be performed as a function of calendar date from seed preparation to shipment of seedlings from the nursery [109]. As a planning aid, it should incorporate much of what is known about the growing of a particular crop and the hardening required to have it in proper physiological condition on the required shipping date. A growing schedule shows the environmental conditions surrounding the seedling at any given time (Fig. 7.10). By reading the season line and estimating the time needed for each of the indicated management activities beneath it, the grower can estimate the periods for the different growth stages. The time required for each stage can be easily determined if the nursery manager has growth curves and a table of optimum conditions for the desired species.

7.10 A Proposed Ideotype

We have insufficient data to specify target characteristics for the ideal container southern pine seedling — that is, the ideotype. Our best information is for loblolly pine, but it is from studies not designed to provide predictive equations relating initial seedling quality to field performance. However, these data will give some indication of the relationship between morphology and growth.

Certain seedling characteristics that relate to field performance are easier to measure, and more reliable, than others. Dry weight and shoot:root ratio are not as easy to determine as is seedling height or diameter. However, measurement might be simplified because these various morphological attributes are related [74]. For example, seedling stem diameter at the time of outplanting is closely related to initial height (Fig. 7.11a) but also to seedling height in the field roughly 2 and 3 years after planting (Fig. 7.11b). Initial stem dry weight correlates well with height after outplanting (Fig. 7.11c); initial height correlates with height in the field roughly 1, 2, and 3 years later (Fig. 7.11d).

The correlations of seedling diameter, stem weight, and height at the time of outplanting in Figure 7.11 all indicate that, within the range of the data, field performance improves as seedling size at outplanting increases. However, these results reflect a limited range of initial seedling heights — from 7.6 to < 23 cm (3 to 9 in.). Undoubtedly, a point exists after which larger seedlings do not result in greater field growth. Additional data with initially taller seedlings (18 to 33 cm) suggest no correlation between initial and field heights. Thus, there are practical biological, as well as economic, limitations to how large seedlings should be at outplanting.

As long as the type of container and cultural treatment remain constant and produce good-quality seedlings, height at the time of outplanting seems to be the best single morphological indicator of field performance. In addition, it is easily measured. Other visual criteria, such as presence of secondary needles and woody tissue, should also be considered. Additional information clarifying, for example, the relationship between morphology and field performance as it is affected by site quality is needed so that container seedling ideotypes can be more accurately defined.

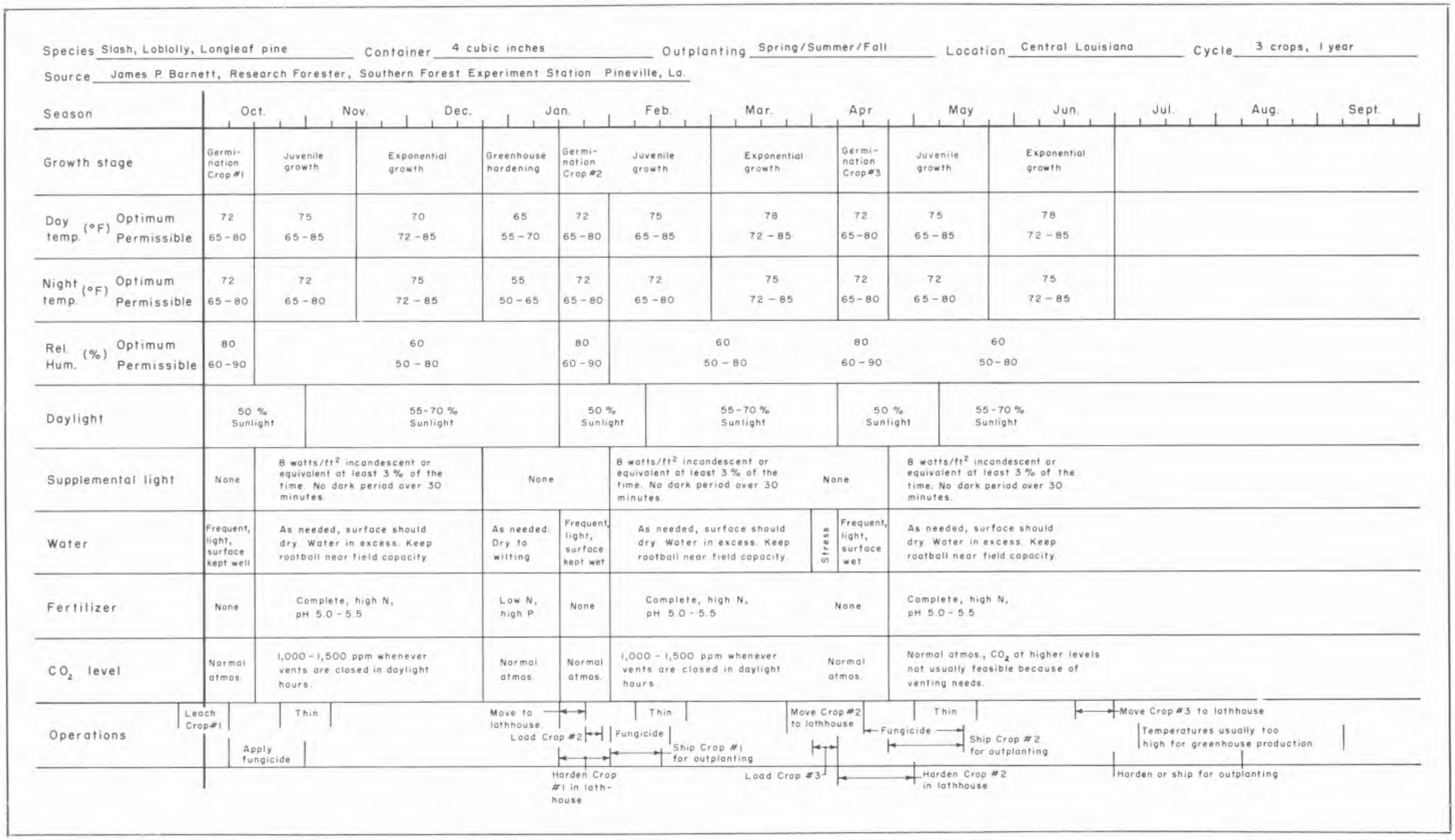


Figure 7.10. Sample growing schedule for producing three crops of southern pine per year (adapted from Tinus and McDonald [109]).

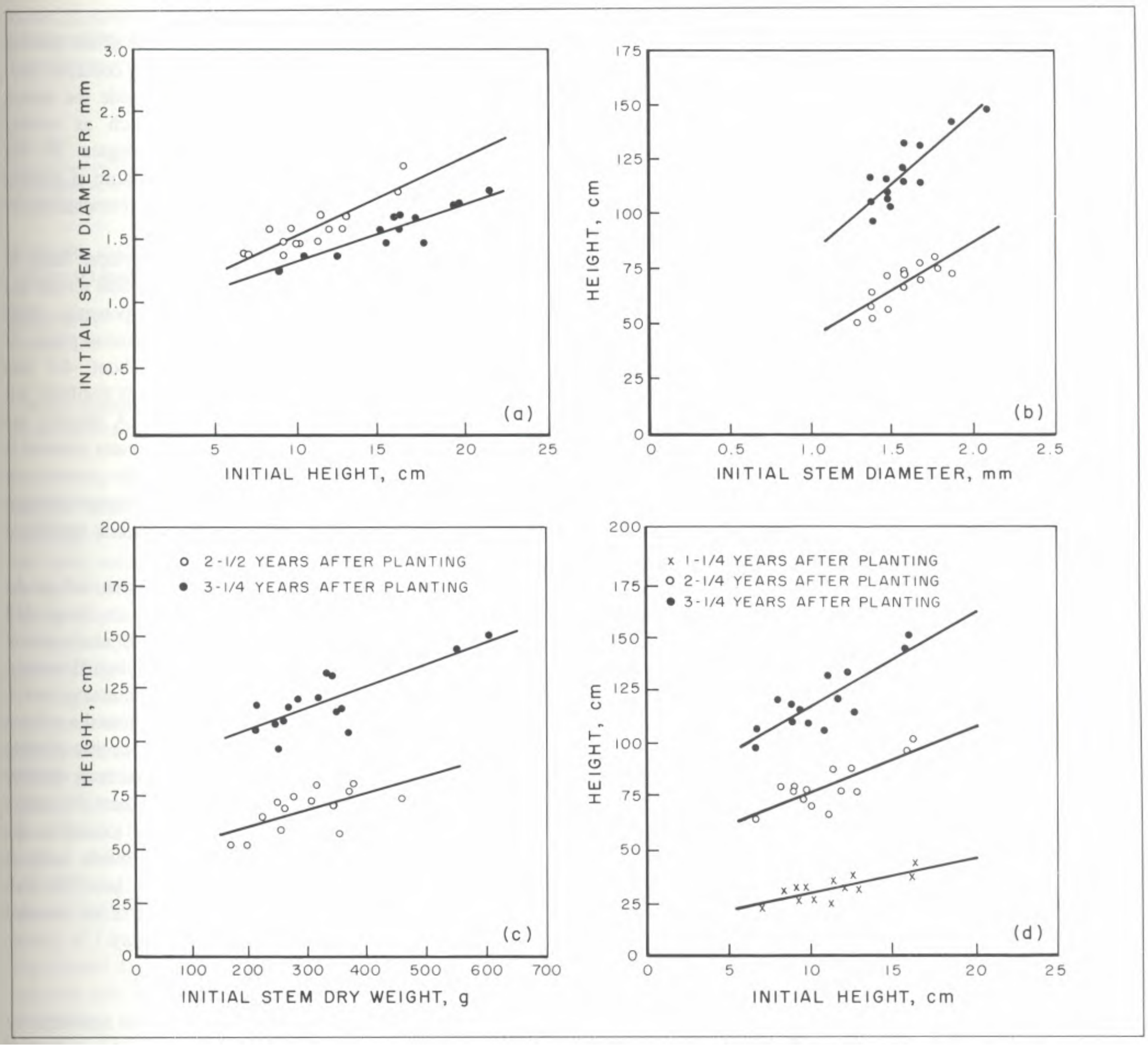


Figure 7.11. Relationships of various morphological attributes of loblolly pine seedlings to survival and growth in the field (adapted from McGilvray and Barnett [74]).

7.11 Handling and Planting

7.11.1 Extraction from Containers

How stock is handled before planting depends on the type of container. If seedlings are grown in tubes or blocks, they are shipped and planted in their containers. If seedlings are grown in plugs, growers must decide whether to extract the seedlings from the containers before shipment.

For plug seedlings extracted before shipping, the required shipping and storage volumes are considerably less. Seedling roots as well as shoots can be graded, and there are no containers to return to the nursery. However, stock quality can be seriously impaired during cold storage and handling if extracted seedlings are not completely dormant and cold hardy [551; that is, succulent, extracted container stock can be planted if handled carefully but should not be stored.

For seedlings shipped in their containers, the shipping and storage volumes are considerably greater and include empty cells, only seedling shoots can be graded, and containers must be returned to the nursery, which is expensive and invariably damages some of the containers. Although root plugs will be maximally protected, succulent shoots must still be carefully handled.

For economy and efficient use of space, trucks or trailers should be fitted with racks or stacking pallets [41, 58].

Seedling boxes must be designed for proper stacking strength and seedling size. At the nursery, pallets can usually be loaded onto trucks with a forklift. At the planting site, unloading requires the truck or trailer to be fitted with a hydraulic tailgate and small swiveling crane. Truck and trailer beds used for seedling transport must be clean and clear of gasoline, diesel fuel, pesticides, and sharp implements; these items can kill or injure seedlings, tear seedling boxes, or damage containers. (See also chapter 16, this volume, for more details on care and handling of stock.)

7.11.2 Care of Seedlings in the Field

Intermediate storage of seedlings between the nursery and the planting site should be avoided. Prompt planting, especially when seedlings are not hardened, is often the key to reforestation success. However, temporary storage, either en route or at the planting site, is common because of weather or changes in planting schedules. If seedlings are shipped in a refrigerated vehicle, that vehicle makes an excellent temporary cold-storage facility. If refrigerated storage is not available, a simple lean-to, an unheated barn, or even a shady spot is better than exposing seedlings to direct sun. Air circulation must be adequate to prevent overheating. Monitoring the temperature of seedlings stored in boxes or bags is especially critical; for loblolly pine, temperatures above 27°C (80°F) can initiate mold and decay, and 48°C (118°F) for 2 hours is lethal [112]. (For more information about seedling handling, see chapters 16 and 17, this volume.)

In cold weather, container seedlings must be protected from freezing. Under natural conditions, seedling root systems are well insulated by the soil and do not attain the same level of cold hardiness as shoots. However, container seedlings waiting to be planted in the field may be subjected to low temperatures that will be lethal to their roots. Moreover, because cold damage to roots is not as obvious as that to shoots, root mortality will not be observed until shoots are placed in an environment favorable to growth. In an Arkansas study, survival was 50% for container seedlings exposed to —10°C (14°F) in February, compared to > 90% for seedlings from the same crop that were moved inside before the low temperature [77]. Styrofoam-type containers provide greater insulation from temperature extremes than hard plastic ones.

Because of the relatively small volume of medium in which container seedlings are grown, seedlings are very susceptible to desiccation and must be protected from the drying influences of the sun and wind. Extracted and packaged seedlings should be handled much like bareroot seedlings; that is, they should be kept shaded and packages reclosed once opened and watered if necessary to keep the root plugs moist. Seedlings shipped in the container should be thoroughly watered at the nursery and rewatered as necessary to maintain the medium at field capacity until planting.

7.11.3 Site Suitability

Several environmental factors that will affect planting success must be considered before planting container seedlings, especially on adverse sites or outside the normal planting season: soil characteristics such as texture, moisture, and nutrient availability; degree of site preparation; probable air and soil temperature at planting time and during seedling establishment; competition for moisture and light; and seedling pests [47].

Available soil moisture is the most critical factor in evaluating a site's suitability for planting. Soil texture and moisture content determine the soil water potential, which is a measure of the availability of soil water to plants. At field capacity, soil water potential is about —0.3 bars (-0.03 MPa). As soil moisture becomes less available, soil water potential becomes more negative. A planting site should be considered high risk if its soil water potential is —10 bars (-1.0 MPa) or less [47]. Soil water potential can be best estimated by obtaining predawn pressure-chamber measurements of plant water potential from established vegetation on the site.

Pressure chamber readings do not, however, indicate the rate at which soil water potential is likely to change. Soil water potential will decrease more rapidly in sandy soils or hot, dry weather than in clay soils or cool, humid weather. With advanced planning, soil-moisture retention curves, which indicate the rate of water depletion from the soil, can be developed by a soils laboratory for specific planting sites or general soil types. Tensiometer or pressure chamber readings can then be used to determine where the current soil-moisture potential of a given site is located on the curve, providing an estimate of how much water is available in the soil and how long it will last [57]. Such detailed evaluation is especially valuable if the intended planting site is particularly severe or droughty.

7.11.4 Planting Techniques

Despite their bulk and weight, container seedlings are easy to plant by hand or machine because of their uniformly shaped root systems. Descriptions of available hand-planting tools and planting machines have been compiled by Larson and Hallman [56]. (For more information, see also chapter 17, this volume.)

7.11.4.1 Hand planting

Container seedlings can be hand planted with conventional bareroot planting tools **or** with tools designed for specific container types. Specially designed planting tubes, such as the Finnish Pottiputki® and the Walter's gun from British Columbia, have been used to plant container stock at rates twice those of hand planting bareroot stock [2, 114, 115]. These tools work by displacing or dibbling the soil to make room for the seedling root ball. Although their effectiveness depends greatly on the soil type and soil moisture, they work well on midrange soil types such as sandy loams, loams, and silt loams [34]. For clays, tools

Table 7.11. Average survival of loblolly pine seedlings planted by two methods in three different soil types [14].

Soil type	Planting method	Survival, % At 2 months	Survival, % At 18 months
Beauregard series (silt loam)	Dibble	86 ab[1]	74 ab
	Core	90 ab	76 a
Wrightsville series (heavy silt loam)	Dibble	85 ab	64 b
	Core	93 a	80 a
Ruston series (sandy loam)	Dibble	83 bc	73 ab
	Core	70 c	63 b

[1] Within columns, means followed by the same lower-case letter are not significantly different at the 0.05 level.

must be designed to avoid soil compression or case hardening of the side walls when the hole is opened. For very sandy soils, the tool must prevent the side walls from caving in before the seedling can be properly planted. Hand-held power augers can also be used for planting container seedlings and are particularly effective for stock grown in large containers.

Coring (removing a soil core with the same configuration as the containerized seedling plug) results in better seedling performance in heavy or compacted soils. In Louisiana, loblolly pine seedlings planted in a heavy silt loam soil survived better when the planting hole was cored rather than dibbled (Table 7.11) [14]. In Saskatchewan, Canada, survival and height growth of lodgepole pine *(Pinus contorta* Dougl. ex Loud.) were best when a soil core was removed before planting in a compact clay loam with bulk density of 1.9 g/cm^3 or higher [24]. In both studies, seedlings planted in dibbled holes on lighter textured soils or in soils with bulk density of < 1.6 g/cm^3 performed as well as or better than seedlings planted in cored holes.

When container seedlings are properly hand planted, their roots should grow into the adjacent soil in a spatially uniform manner. From 26 plantations on various soil types in Oregon and Washington, Douglas-fir trees were dug up 2 to 4 years after being planted as plug seedlings and the root systems classified longitudinally and radially into 13 zones. On the 325 seedlings excavated, egressed roots were found in an average of 11 of the available zones of the plug mass [92]. In general, root egress was poor only where soils had been compacted, aeration was poor, or seedling vigor was markedly reduced because of factors other than soil texture.

7.11.4.2 Machine planting

Most mechanical planters designed for bareroot seedlings can be adapted for container stock with only minor modifications. Conventional planting machines may be either of the continuous-furrow or intermittent-furrow type and are usually manually fed. For continuous-furrow machines, only operator technique would need to be modified; for intermittent-furrow machines, the holding mechanisms for seedlings might need to be changed. (See also chapter 17, this volume.)

7.11.4.3 Planting depth

As with bareroot stock, planting container seedlings to the proper depth is important to ensure good survival and growth after outplanting. Container seedlings should be planted deep enough that the top of the root plug is covered with about 1 cm (0.4 in.) of soil. Covering the container reduces drying of the root plug caused by the "wicking effect" of moist growing medium exposed to the air. Planting below the groundline also prevents frost heaving of fall-planted container stock [118].

Care must also be taken not to plant container seedlings so deep that the shoot is covered up, especially during machine planting. Control of planting depth is more critical and can be more difficult with container than with bareroot seedlings [93].

7.11.4.4 Planting season

One of the greatest potential benefits of using container seedlings is that the planting season can be extended. In central Louisiana, container seedlings have been planted throughout the year. For summer-planted loblolly, slash, and longleaf pines, survival and subsequent growth have been good, even under droughty conditions [1, 14]. However, winter-planted southern pines must be sufficiently hardened before outplanting.

Trends in field performance were similar for both loblolly and slash pine container seedlings outplanted monthly from January to September on a silt loam soil [21]. The poor survival of loblolly pine planted in January was attributed to improperly hardened stock. The greater average height of bareroot, compared to container, trees of both species indicates that the bareroot seedlings had maintained their size advantage at planting throughout the three growing seasons of the study.

Caution must be exercised if planting under droughty conditions. Soil moisture should be estimated to ensure it is adequate for seedling establishment and survival (refer to 7.11.3); in addition, weather forecasts should be considered during the normally hot and dry months of late spring, summer, and early fall. Adequate planning and operational flexibility are essential if planting over an extended season is to prove successful.

7.12 Conclusions and Recommendations

Reforestation success can best be assured when the forester and nursery manager both understand that seedling quality and the environment at the planting site determine field performance. When evaluating container stock for regeneration, both foresters and managers should:

* Consider using container seedlings for conditions under which bareroot stock or natural or direct seeding is not

expected to do well.

* Take advantage of the flexibility of container production methods to tailor the growing period, container type, and cultural practices to provide the desired seedling characteristics at the intended planting date.
* Specify the use of only high-quality seeds in container production to avoid empty cells and minimize transplanting and thinning, thereby ensuring high-quality, uniform seedlings.
* Provide the least amount of environmental control necessary to produce the required seedling characteristics at the lowest production costs.
* Be aware that the relatively small rooting volumes within containers make the timing and application of cultural practices, especially irrigation and fertilization, critical.
* Adjust handling and planting methods to the planting season and to seedling morphology and physiology.

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