United States
Department of
Agriculture

Forest Service

**Southern Forest
Experiment Station**

New Orleans,
Louisiana

General Technical Report
SO-59
March 1986

Producing Southern Pine Seedlings in Containers

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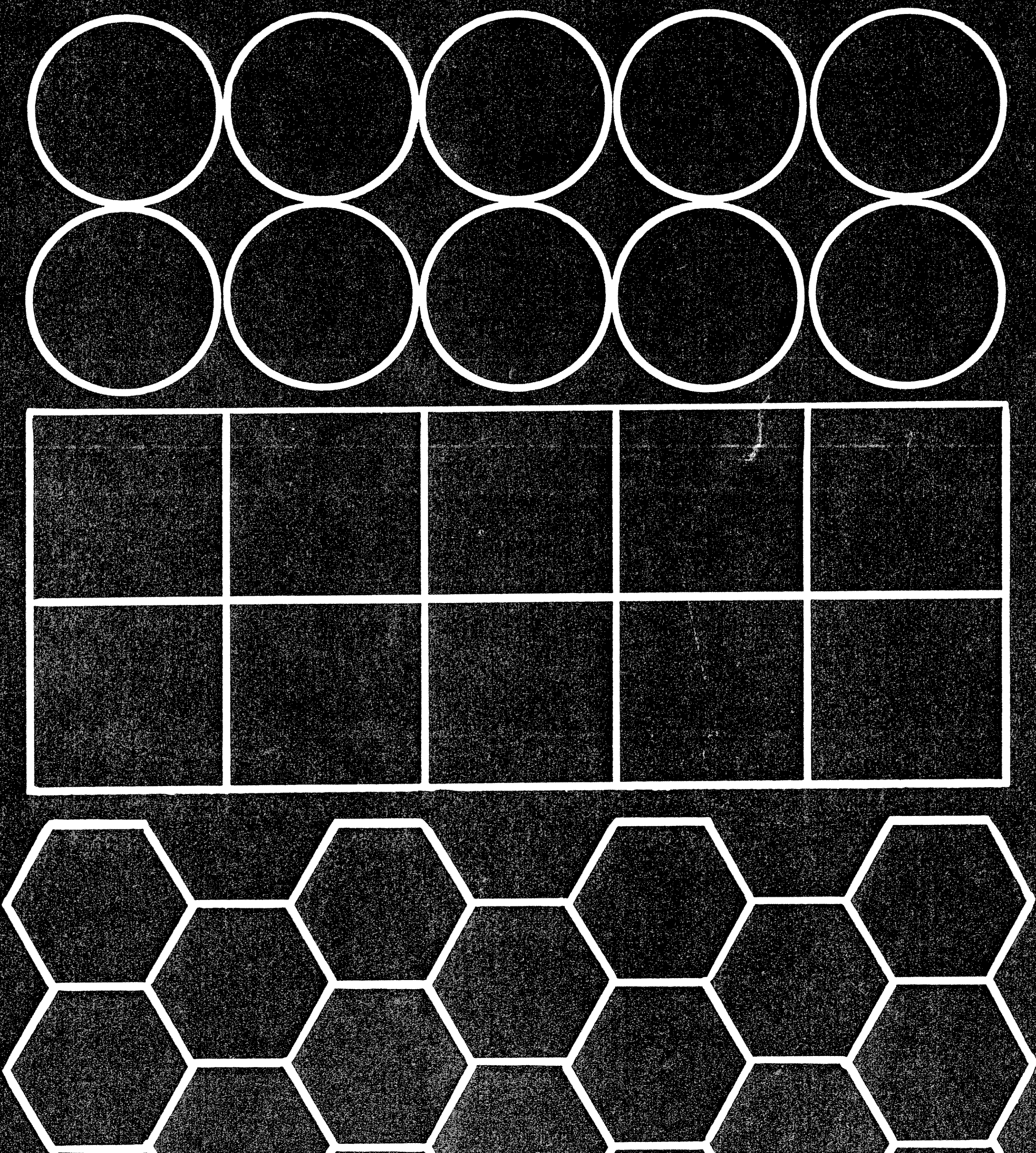

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1. INTRODUCTION

Forest lands in the South are usually regenerated by planting bare-root seedlings, although natural or artificial seeding is used to a limited extent. Despite record tree planting levels in recent years, reestablishment of southern pine forests has fallen behind the harvesting effort. The use of container-grown seedlings, which has increased dramatically in the western United States and Canada in the last few years, offers land managers an alternative to traditional regeneration techniques. Containerized seedlings account for 20 percent of the total production of conifer planting stock grown in the Pacific Northwest. The use of container-grown seedlings is more limited in other parts of the United States, but as research shows the feasibility of the system in the South and other regions, its value as a supplement to bare-root seedling production is being acknowledged.

The purpose of this manual is to establish procedural guidelines for production of container-grown pine seedlings, particularly in the southern United States. These guidelines should be helpful in container production facilities already in existence and should be particularly beneficial to organizations contemplating or beginning container-grown seedling programs.

Guidelines now available are primarily for Canadian use (Matthews 1971, Ontario Dept. of Lands and Forests 1968, Kay 1973, Carlson 1979, Walker and Johnson 1980, Scarratt and others 1982). The manual published by the North Carolina Forest Service was prepared for use specifically in their own facilities (Goodwin 1975). "How to grow tree seedlings in containers in greenhouses," by Tinus and McDonald (1979), provides an excellent overview of greenhouse facilities and growing procedures for the northern and western United States; much of it is also appropriate for the South. It should be reviewed before facilities are planned and be a basic reference for greenhouse operators and growers. Other publications that are valuable references for the production and use of containerized southern pine seedlings are the "Proceedings of the Southern Containerized Forest Tree Seedling Conference" edited by Guldin and Barnett (1982), and "Regeneration costs using container-grown southern pine seedlings" by Guldin (1983).

The guidelines offered in this publication, plus the publications by Guldin and Barnett (1982) and Guldin (1983), contain or reference most of what has been published to date about the development of container facilities for the South, the production of containerized southern pine seedlings, and the use and performance of container stock on a variety of planting sites.

The guidelines in this publication are organized into three broad topics: selecting facilities and equipment, growing high quality seedlings, and handling and planting container stock. The chapters are arranged chronologically from developing appropriate container nursery facilities to establishment practices for containerized seedlings. There is some overlap among chapters. For example, aspects of disease control are discussed both under seed handling and under seedling cultural techniques. Such overlap is necessary because many topics must be considered at different times throughout a seedling crop rotation. It is recognized that many of the recommendations given in these guidelines are provisional and will require modification as research and development continues in the southern United States.

2. MERITS OF CONTAINER PLANTING

Many of the advantages of using container-grown seedlings rather than bare-root stock have been discussed by various authors (Stein and others 1975, Tinus 1976, Mann 1977, Stein and Owston 1977, Hahn 1982a). Advantages and disadvantages most appropriate for conditions in the southern United States are listed in table 2-1.

Table 2-1.—*Advantages and disadvantages of container-grown southern pine seedlings*

Advantages	Disadvantages
Quickly produced	Require more attention while growing
Extended planting season	May cost more
Improve performance of some species	Bulky to handle
Perform well on adverse sites	May require more intense site preparation
Efficient use of limited seed	Smaller size
Uniform seedlings	

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Containerized southern pine seedlings can be produced quickly. Loblolly pine (*Pinus taeda* L.) and slash pine (*P. elliottii* Engelm.) can be grown to plantable size in 12 to 14 weeks. Longleaf pine (*P. palustris* Mill.) can be produced in about 16 weeks. Such rapid production allows seedlings to be produced and fall planted in years when spring survival checks indicate replanting will be necessary. Similarly, genetic tests can be produced and outplanted the spring after seed collection. In both cases a year is saved compared to bare-root methods. Flexibility in production is also possible because containerized seedlings can be planted throughout an extended planting season, provided soil moisture and climatic conditions are favorable for growth. Bare-root longleaf pine seedlings tend to have poorer survival and initial growth than the other southern pines, probably because of the severe root disturbance caused by lifting. Containerized longleaf pine, with intact root systems, can have better survival and begin height growth sooner than bare-root stock (Goodwin 1980, Amidon and others 1982). Container-grown seedlings tend to perform better on adverse sites than do bare-root seedlings. In some cases container-grown seedlings 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 increased seed efficiency, i.e., plantable seedlings to filled seeds ratio. When combined with rigid control of seedling density and root configuration, uniform stock will be produced, which can then be utilized in automated handling and planting systems.

There are, however, some disadvantages to the production and use of container-grown seedlings (Stein and Owston 1975, Barnett 1978a). Because of the relatively small volume of growing medium, the technique requires more demanding day-to-day attention to moisture and temperature regimes than is required for producing bare-root stock. The conditions that hasten containerized seedling development are also conducive to disease, nutritional imbalances, and other problems. Trees produced in containers will likely cost more than bare-root stock from existing, depreciated nurseries, but not necessarily more than seedlings from a new bare-root nursery (Guldin 1983). It has not been conclusively established that any extra cost will be fully offset by reductions in planting costs or gains in survival and early growth. Container-grown seedlings are bulkier to transport and must be handled differently from bare-root seedlings (see chapter 12). On sites with severe herbaceous competition, more complete site preparation may be necessary for success with containerized seedlings because of their smaller initial size (Ruehle and others 1981).

3. COMPARATIVE PERFORMANCE

Although there are biological and production advantages to be realized from growing seedlings in containers, the key to success depends on field performance. There are few good comparative trials. Western conifer containerized seedlings usually equal or exceed survival of bare-root nursery stock (Tinus 1976, Stein and Owston 1977, Arnott 1981, Hahn and Smith 1983, Gardner 1982, Vyse 1982). In eastern Canada, results with northern conifers indicate that paperpot-grown containerized seedlings survive better but have a growth lag when compared to larger bare-root stock (Krause 1982, Mattice 1982, Scarratt 1982).

In the South, survival has generally exceeded that of nursery stock, and growth comparisons are good (Goodwin 1976, Barnett 1975, 1980a). Container stock clearly outperforms nursery seedlings when age from seed is considered (Goodwin 1976). Comparisons of container-grown and nursery seedlings that are outplanted at the same time indicate that container-grown seedlings can perform as well or better when high-quality stock is used. Goodwin (1980) found that after five growing seasons, containerized longleaf pine seedlings survived better and grew faster than 1+0 nursery seedlings when planted on sandhill sites. He concluded that containerized longleaf seedlings can be used to extend the normal planting season and to replant 1+0 seedling failures in the same growing season if there is sufficient soil moisture.

Data comparing regeneration methods with loblolly and slash pine indicate that containerized seedlings planted in the late spring or early summer have growth comparable to bare-root seedlings planted during the preceding winter (table 3-1). These results are not unique, but reflect frequent observations (Barnett 1980a).

Amidon and others (1982) report that under droughty conditions container-grown seedlings survived and grew better than nursery stock when the containerized seedlings were outplanted in the late summer before the normal bare-root planting season. Even under severe moisture stress, container-grown seedlings performed better than bare-root seedlings when outplanted at the same time in early spring.

Table 3-1.—*Container-grown and bare-root seedling performance after 3 years*[1]

Stock type	Loblolly pine		Slash pine	
	Height	Diameter	Height	Diameter
	m	*cm*	*m*	*cm*
Container (12-weeks old)	0.84	1.45	0.91	1.78
Bare-root (1+0)	0.82	1.24	0.98	1.83

[1]Bare-root stock planted in Feb. 1978; containerized seedlings planted in late May 1978.

4. FACILITIES FOR SEEDLING PRODUCTION

4.1 Site Selection

Site selection criteria for container nursery facilities are much less stringent than for a new bare-root nursery. Topography and soil constraints that may prohibit the development of a bare-root nursery would not influence construction of a container facility. Considerations that are important when selecting a site for a container nursery include: management objectives, location of planting sites, climate, water supply and quality, road access and utilities, labor supply, and proximity to mills and other manufacturing facilities. Hahn (1982b) provides some valuable insights into these and other considerations of site selection.

4.1.1 *Management Objectives*—The actual area needed to develop a container nursery will depend on the present and anticipated future demand, the type of container used, and the number of seedling rotations that can be produced annually. Annual production from each 319 m^2 (3,425 ft^2) of growing space will vary from 330 thousand to 1,890 thousand seedlings in one to three crop rotations, depending on the facility and container (Guldin 1982). Obviously, many factors must be considered before an accurate determination of the needed area can be made. The single most important factor is the container used, and containers are discussed in detail in chapter 5. Other important factors are discussed in the following sections.

4.1.2 *Location of Planting Sites*—Container-grown seedlings are bulky, so the growing facility should be located centrally to the intended planting sites to minimize transportation costs. Shipping costs per 1,000 seedlings are equal for container and bare-root stock for distances up to 161 km (100 miles), provided the containers are shipped on pallets fitted with racks (Guldin 1983). Extracting containerized seedlings before shipment can also reduce bulk and costs but certain precautions must be followed (see section 12.2).

4.1.3 *Climate*—The geographic location of a container nursery will largely determine what type of structures and facilities will be required. The South has been divided into three climatic zones, based on length of the frost-free growing period and how long during this period daily maximum temperatures exceed 32 °C (90 °F) (Guldin 1983) (table 4-1 and fig. 4-1). These climatic variables, combined with management objectives, will determine the degree of environmental control needed and the number of rotations that can be produced annually. In facilities with minimum environmental controls or none, both the length of the frost-free growing season and the likelihood of temperatures above 32 °C (90 °F) will restrict the period of optimum seedling growth. Therefore, with minimum environmental control, it may be possible to start crops both in the spring and fall in Zone A, but in Zones B and C it is likely that only one crop would be produced annually. With increasing control over the seedling growing environment, the climatic factors become less important, but energy needs, and consequently production costs, rise.

Table 4-1.—*Climatic zones for containerized seedling production and planting (from Guldin 1983)*

Climatic factor	Climatic zone A	Climatic zone B	Climatic zone C
Date of last spring frost	February 20 to March 10	March 20 to 30	April 10 to 20
Period when daily air temperature exceeds 32 °C[1]	More than 90 days (June 1 to September 15)	60–90 days (June 1 to September 7)	30–60 days (June 15 to September 1)
Date of first fall frost	November 20 to December 10	October 30 to November 10	October 20 to 30

[1]90 °F

4.1.4 *Water Supply*—An adequate and dependable supply of water for irrigation is essential for producing containerized seedlings. Approximately 16 to 20 liters per hour per square meter of growing area (0.4–0.5 gal/hr/ft^2) is needed to adequately water 20 cm (8 in) deep containers (Tinus and McDonald 1979). If the facility is used year-round, this will be equal to an annual water need of 1,222 to 1,630 liters per square meter of growing space (30–40 gals/ft^2). Additional water will be needed for domestic, and possibly cooling, needs. Detailed information for calculating total water and water rate needs is provided in Tinus and McDonald (1979). The quality of water available for irrigation is an essential part of site selection. Because implications of water quality go beyond site selection, this topic is covered in detail in section 4.2.

4.1.5 *Other Considerations*—Road access and availability of utility services need to be considered when selecting container nursery sites. Larger facilities require better road access than small facilities because of the size of vehicles that will make deliveries and pickups. Utility needs depend primarily on heating and cooling requirements. The availability of a local labor supply, especially a temporary force during peak periods, must be considered. The proximity of the container nursery to wood processing and other manufacturing plants can impact seedling production. Mills and woodyards may harbor potential seedling pests such as pales weevil (*Hylobius pales* Herbst.), and some manufacturing plants may emit pollutants that can adversely affect seedling growth.

4.2 Water Quality

Irrigation water quality is a critical factor in management of container growing facilities. The definition of water quality depends on its use, but for agri-

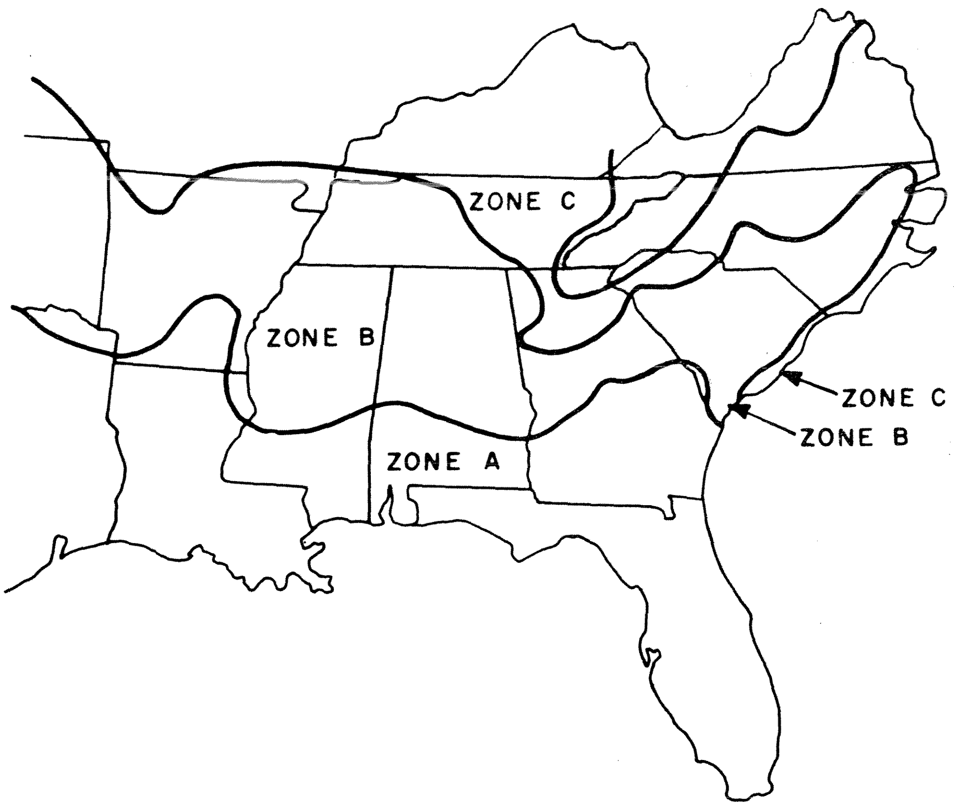

Figure 4-1.—*Climatic zones for southern pine container-grown seedling production (from Guldin 1983).*

cultural purposes, the concentration and composition of dissolved salts determine its value for irrigation (Landis 1982). All plants are susceptible to salt injury under certain conditions, but tree seedlings, conifers in particular, are very sensitive to soluble salts. Levels of dissolved salts high enough to cause concern are rare in the Southeast, but salinity problems can develop in containerized seedling operations when irrigation and fertilization are improperly applied. Water quality can be a problem along the western edge of the southern pine ecotype.

Soluble salts can cause injury to containerized seedlings in several ways: 1) by reducing moisture availability, 2) through direct toxicity, and 3) by altering nutrient availability (Fuller and Halderman 1975, Landis 1982).

The total concentration of dissolved salts in irrigation water is generally expressed as electrical conductivity, which is measured in units of conductance (micromhos/cm) at a standard temperature (25 °C, 77 °F). Dissolved salts decrease the free energy of water molecules and reduce their availability to plants. This osmotic inhibition is a function of total salts regardless of the specific ions.

The salinity hazard has been divided into four ratings based on observed effects on plant growth (table 4-2). The salinity of irrigation water is not a true index of salt damage, however, because plants respond to salt concentrations in the soil solution. Salt levels in the root zone are typically many times as concentrated as in the water supply.

Three ions have been observed to directly injure plant tissue; sodium, chloride, and boron. Sodium and chloride can be absorbed either through the foliage or by the root system. Boron must normally come from the soil. Foliage injury is particularly severe under sprinkler irrigation systems. In general, trees and other woody perennials are sensitive to rather low concentrations of sodium and chloride compared to annual crops. Boron toxicity is hard to predict because the range between beneficial and toxic concentrations is narrow for some plants (Eaton 1966).

Saline irrigation water can also change the availability and utilization of plant nutrients. This effect is particularly difficult to define because of the complicated chemical interactions in soil chemistry and

Table 4-2.—*Salinity hazard ratings*

Rating[1]	Electrical conductivity
	(micromhos/cm)
Low	250
Medium	250–750
High	750–2250
Very High	2250

[1]USDA Salinity Lab (1969).

seedling physiology. Excess calcium can chemically immobilize phosphorus and inhibit uptake by plants. Iron chlorosis is a complex nutritional disorder of woody plants and has been associated with an abnormal accumulation of salt ions in conifer seedling foliage.

Irrigation water quality is rarely the sole cause of salinity problems but rather one in a series of interacting conditions. Other factors such as media drainage, irrigation method, cultural practices, climatic conditions, and crop salt tolerance are equally important. A nursery manager must consider all these factors before designing an irrigation program, and this becomes increasingly more important as water salinity increases (Landis 1982).

Water quality and its effects on seedling growth and development can be much more easily managed in a container nursery than in a bare-root nursery. Although salt ion removal is still uneconomical for irrigation water, the effects of these ions can be reduced by controlling water pH and by leaching the growing medium at intervals. In many locations, water pH is higher than desired for optimum germination and growth. Water pH of 7.5 to 8.0 is not uncommon but it can be acidified and lowered to more optimum levels. Acidification procedures to reduce irrigation water pH are discussed in section 9.5. In addition, container potting medium can be mixed for maximum permeability, thus reducing the likelihood of salt accumulation. Vermiculite, perlite, and other coarse materials can be used to generate pore space in the growing medium. Chapter 6 discusses the selection and preparation of growing media.

However, there are some inherent dangers in container seedling production that relate to irrigation water quality. Because of the large amount of irrigation water used in most greenhouses, there is a real potential for salt accumulation in the potting soil. This danger is amplified when nutrients are injected into irrigation water, because fertilizer salts add to the total salinity level (see section 9.5.3). The only solution is to insure that excess salts are leached from the potting soil during each irrigation by watering until leachate drains out the bottom of the container (see section 9.5.3). The best control for saline water problems is to minimize them in the first place by a comprehensive examination of water quality.

4.3 Structures

Structures for growing containerized seedlings in the South may vary from simple shadehouses (fig. 4-2) to elaborate glass greenhouses (fig. 4-3). The type used depends on the management objectives for the facility. Biological, climatic, economic, and operational factors must be considered in deciding what kind of tree growing facility to construct. The economics of various facility, container type, and climatic zone combinations of containerized operations are compared to bare-root nursery production by Guldin (1983). His analyses indicate that container nurseries utilizing structures with limited environmental control and various container types and climatic zone

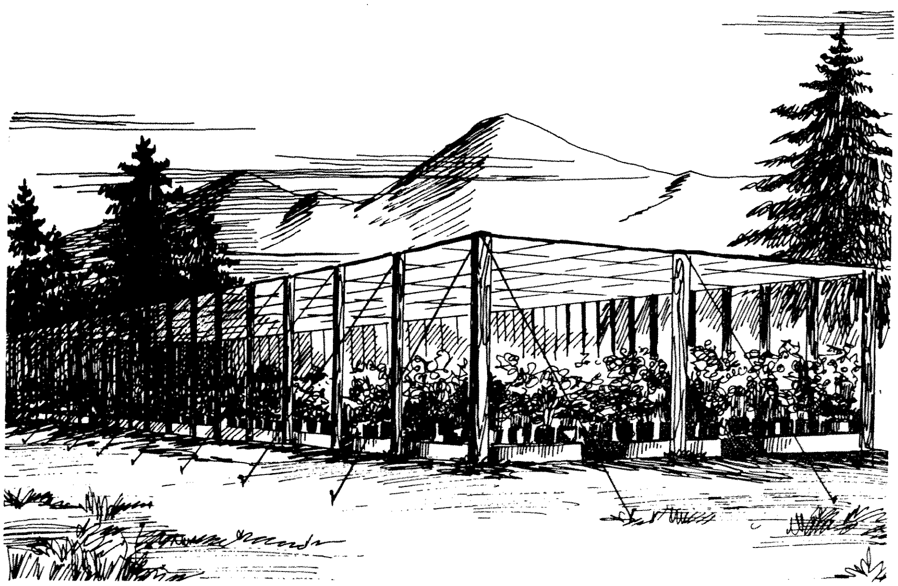

Figure 4-2.—*A simple shadehouse suitable for production of containerized southern pines during much of the year and for seedling hardening during the fall and winter (from Guldin 1983).*

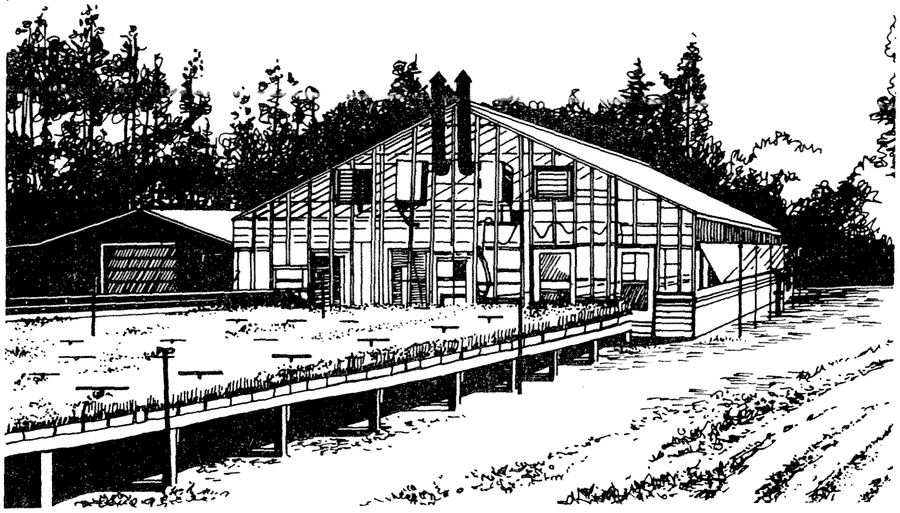

Figure 4-3.—*A more elaborate glass greenhouse with environmental controls suitable for containerized seedling production throughout the year (from Guldin 1983).*

combinations can give an annual production of at least 3 to 4 million seedlings. McDonald (1982) provides a valuable discussion of the relative merits of fully controlled and semicontrolled environment greenhouses. Generally, semicontrolled greenhouses are adequate in the Coastal Plain areas of the southern United States (zones A and B, fig. 4-1). However, if crops are to be produced over winter, a structure sufficiently controlled to provide adequate heating would be required. Temperature requirements for seedling germination and growth are discussed in sections 8.1.3, 8.2.3, and 9.1.2.

The design of seedling growing facilities is beyond the scope of these guides. Greenhouse design is covered adequately in other publications (Ekblad 1973, Kelsoe 1975, Husely 1973, Tinus and McDonald 1979, Cameron 1982, Siemens 1982). Hahn (1982b) provides some practical guidelines for developing containerized seedling facilities and operational programs. The environmental conditions necessary for optimum germination and seedling development, regardless of the growing facility, are discussed in chapter 8.

5. CONTAINERS

5.1 Developments in the Use of Containers

Isolated references to ball or container planting go back to 1725 (Toman and Hocking 1973), but McLean's (1959) more recent use of the Ontario tube seemed to stimulate development of the idea in North America. The great impetus for container planting resulted from Walters' publication of his technique based on the plastic bullet and planting gun in 1961 (Walters 1961). Jones (1967) reported early evaluations of seedlings grown in kraft-paper containers in the South. Since these early beginnings, a host of container materials have emerged for potential forestry use. Many of these have been developed primarily for northern 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 (Waldron 1972; Tinus and others 1974). Most of these products have been evaluated in the South (Barnett 1974b). In addition, kraft-paper tubes, polyurethane foam blocks, biodegradable plastic tubes, and peat-vermiculite blocks have been developed primarily for southern use (Barnett 1974a, Barnett and McGilvary 1981).

5.2 Types of Containers

The many container products can be divided into three general types: tubes, plugs, and blocks (fig. 5-1). Each type has certain merits that must be considered before a container system is selected.

5.2.1 *Tubes*—These containers have an exterior wall, require filling with a growing medium, and the seedlings remain in the container for outplanting. The primary advantage of tubes is wall rigidity, providing both ease of handling as well as sufficient impermeability to prevent desiccation when planted

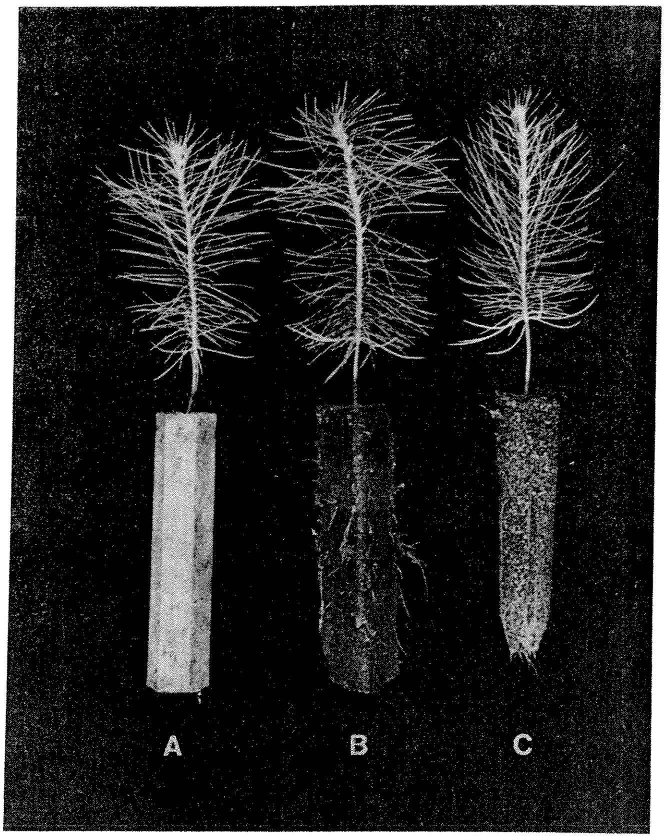

Figure 5-1.—*Loblolly pine seedlings grown in three types of containers: a biodegradeable plastic tube (A), a peat moss-vermiculite molded block (B), and a plug from Styroblock 2 (C).*

in dry soil (Day and Cary 1974). The major disadvantage of tubes is slow egress of roots into the soil because initial contact with the soil is made primarily through the bottom of the container. Based on evaluations of performance with the southern pines and on commercial availability, the Paperpot is probably the best tube-type container now available (Barnett 1981). The Japanese Paperpot does not degrade rapidly enough to allow satisfactory survival and growth. The Finnish Paperpot material now available is reportedly manufactured of material that allows faster root egress. But this leads to root penetration during the greenhouse growing period. Therefore, only small trees or short rotations are possible without root growth between containers and subsequent damage during extraction. Root spiraling also is a problem (Barnett and McGilvary 1981). Because of problems with tube-type containers, particularly under stress conditions, plug systems have generally replaced tube materials.

5.2.2 *Plugs*—Plugs are molded blocks that have a cavity filled with potting medium. They are the preferred container for operational use in the Pacific Northwest and Canada. But, unlike tubes or blocks, (see section 5.2.3), the seedlings must be removed from their containers before outplanting. The rooted seedlings, along with the growing media, are planted. Plugs provide an ideal biological setting for the seedlings, since no root constraint occurs after planting, and roots rapidly establish themselves in the surrounding soil. However, the seedlings must be held in the container long enough for the root to bind the soil to facilitate extraction. The length of time varies with the size of the container cavity and species of tree; generally the minimum is 3 to 5 months. A number of containers can be used to produce excellent plug seedlings. Examples are RL Single Cells, Rootrainers, and Styroblocks.

The BC/CFS Styroblock was developed in Canada to overcome root configuration problems inherent with plastic bullets. Seedlings grown in Styroblocks perform well when compared to those in other types of containers. Growth of slash pine seedlings after outplanting from several different containers showed that those from the Styroblock-2 (2 cubic-inch volume) equaled or exceeded all others except Keyes Peat Sticks®, discussed under block containers (table 5-1).

Other plug systems have the advantages of plug-type containers and perform well. Each specific container has certain characteristics that make it unique. The RL Single Cells can be handled individually for randomization of progeny-test material, removal of blanks, and transport. Rootrainers open to allow inspection of the root system and easy removal of the plug. The Todd Planter Flat® cavities are square, of obtuse taper for easy seedling extraction, and have lower numbers of seedlings per unit area in relation to cavity volume than most other container systems. The importance of seedling density is discussed in detail in section 5.3. There are no great differences in field performance of plug-type containers. Most of the variations in performance are more of a reflection of cavities per unit area, or seedling density, than container per se. Although plugs are easily planted by hand or conventional planting machines, adaptation to automated planting operations may be difficult.

5.2.3 *Blocks*—Block designs incorporate advantages of both 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.

Although numerous block-type products have been evaluated, only a few have been available for use in large-scale programs. One type of self-contained container consists of acrylonitrile-bonded softwood pulp (Schneider and others 1970, White and Schneider 1972). This product, originally manufactured by American Can Company under the trade name of BR-

Table 5-1.—*Survival and heights of slash pine (*Pinus elliottii*) seedlings grown in various container products 1 + years after outplanting*[1]

Container	Survival			Height		
	4–26–74[2]	6–25–74	8–28–74	4–26–74	6–25–74	8–28–74
	percent			*cm*		
Gro-block	69	57	89	73	49	40
Peat stick	91	94	100	98	55	52
Paperpot (315)	81	76	96	64	46	46
Syroblock-2	89	93	98	76	49	43
Rootrainer (Ferdinand)	83	71	98	82	49	43

[1]Survival and height measurements taken in January 1976.
[2]This row gives planting dates.

8®, was later made by Famco, Inc., and called Gro-block®. Gro-blocks are not now commercially available. Although young seedlings (6 weeks old) grown in these blocks performed well when outplanted (Barnett 1975), older seedlings generally showed poorer survival and growth than seedlings of the same age growing in other containers. This poorer performance probably reflects the small volume of these Gro-blocks when compared to the other products tested. Further developmental work, such as increasing the size and ease of separation, is needed before the system is a viable one.

Probably the most promising block-type container evaluated has been developed by Keyes Fibre Company. The block consists of a blend of sphagnum peat moss, vermiculite, cellulose fibers, and nutrients. An early design of this product was rectangular in cross-section (2.8 by 3.2 cm or 1 1/8 by 1 1/4 in) and 15 cm (6 in) long. This block, termed a "Peat Stick" was used in several studies with good results (table 5-1). Loblolly and slash pine seedlings grown for 10 weeks in this block survived and grew better than those in other containers, particularly when outplanted under conditions of moisture stress (figs. 5-2 and 5-3).

High survival was maintained even following planting in June, July, and August, when survival of seedlings grown in Gro-blocks and Paperpots dropped. Heights of seedlings outplanted in Peat Sticks in June compared favorably to those of bare-root seedlings planted in the previous March.

Because of the success with Peat Sticks, the product was redesigned to provide for easier handling, packaging, and outplanting. The resulting Kys-Tree-Start® has a smaller volume, but has the same properties. The advantages of the Kys-Tree-Start include: (1) simplified greenhouse operations because no filling is required, (2) no root manipulation into undesirable patterns or constraint after outplanting, and (3) adaptability to mechanized planting equipment. After outplanting, root egress occurs from the entire block surface, and no unusual patterns of root development are evident that might cause future problems in seedling growth or stability (fig. 5-4). The blocks are subject to development of a saprophytic mold during the early greenhouse period and some root cross-over occurs along the back of the 10-block strip if seedlings are held for long periods. Some further development could make this an excellent product, but at the present time insufficient demand exists to keep this product commercially available.

5.2.4 *Other Containers*—Numerous container materials other than those described have been evaluated with the southern pines (table 5-2). Some of these have promise but for some reason have not been produced for commercial use. Our experience with a wide range of containers should provide the information necessary to anticipate the performance of other containers not reported here.

5.3 Container Size

There is a wide range of container sizes available; however, most in operational use have volumes of 40 to 165 cm^3 (2.5 to 10 in^3). Optimum size probably varies according to container characteristics, species, soil type, site preparation, and length of the growing period (Barnett 1974d).

A 10- to 12-cm (4- to 5-in) length is generally satisfactory for the southern pines. Diameters of 2.5 to 3.0 cm (1.0 to 1.25 in) seem minimal (Barnett 1974b). Recent studies have shown that container volume is less critical than seedling density (number per unit area). Figure 5-5 indicates some interaction between volume and density. Although Todd Planter Flats® had 25 percent less volume, seedling dry weights at time of outplanting were about twice as heavy in the Todd Planter compared to Japanese Paperpots. This difference in seedling condition resulted primarily from the much smaller number of seedlings grown per unit of area—312/m^2 (29/ft^2) for Todd Planters vs. 1,657/m^2 (154/ft^2) for Japanese Paperpots. The larger seedlings performed better in the field. In fact, seedling development even in the small Todd Planter cavities, both in the greenhouse and field, was better

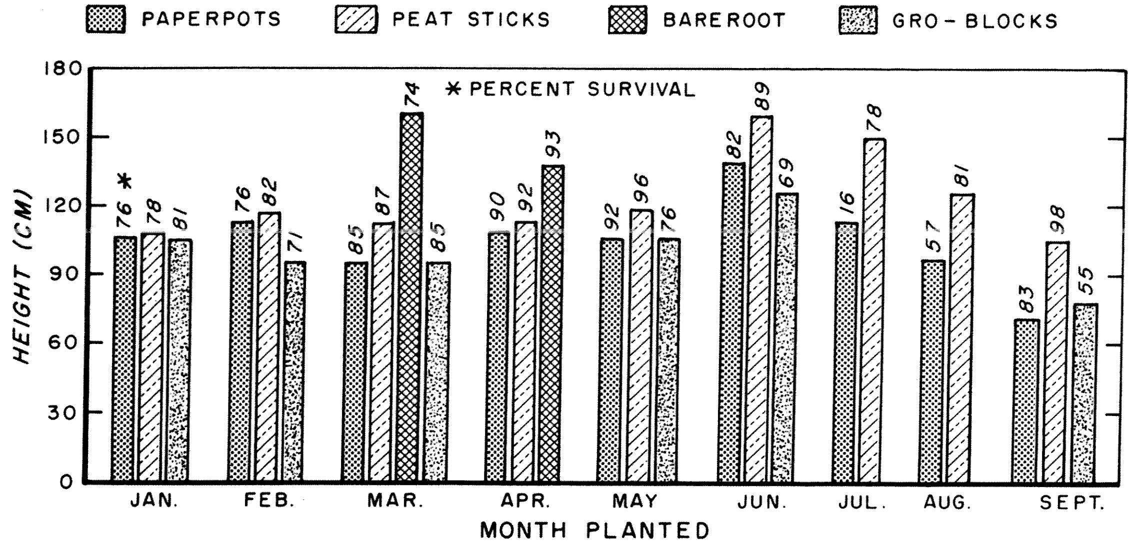

Figure 5-2.—*Heights and survival of loblolly pine seedlings outplanted in 1973; survival and growth measured in January 1976.*

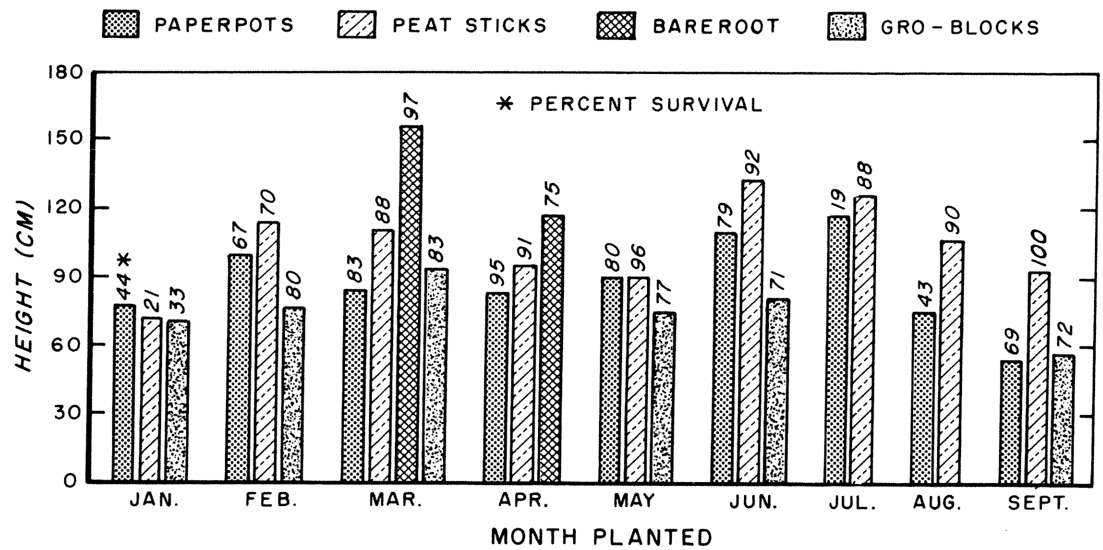

Figure 5-3.—*Heights and survival of slash pine seedlings outplanted in 1973; survival and growth measured in January 1976.*

than in Japanese Paperpots. The volume of the small Todd Planter was only 25 cm^3 (1.5 in^3) compared to 88 cm^3 (5.3 in^3) for the Japanese Paperpots. The initial seedling development is largely due to lower numbers of seedlings per unit of area.

The effects of seedling density during the greenhouse growing period become clearer when container volume remains constant. The period that seedlings are grown in containers also interacts with seedling density (fig. 5-6). If growing periods are limited to 8 to 10 weeks, spacing has less effect on seedling development than if larger seedlings are being grown. Densities exceeding about 1,075/m^2 (100/ft^2) reduce initial development and the resulting field performance of the southern pines. Although lowering seedling densities may continue to improve development and performance, factors such as the cost of greenhouse space will also influence the choice of container size and seedling density.

The species grown can also influence the relationship of container size and seedling density to performance. For example, longleaf pine, which is very intolerant, increases markedly in development when grown in larger-volume containers with lower spac-

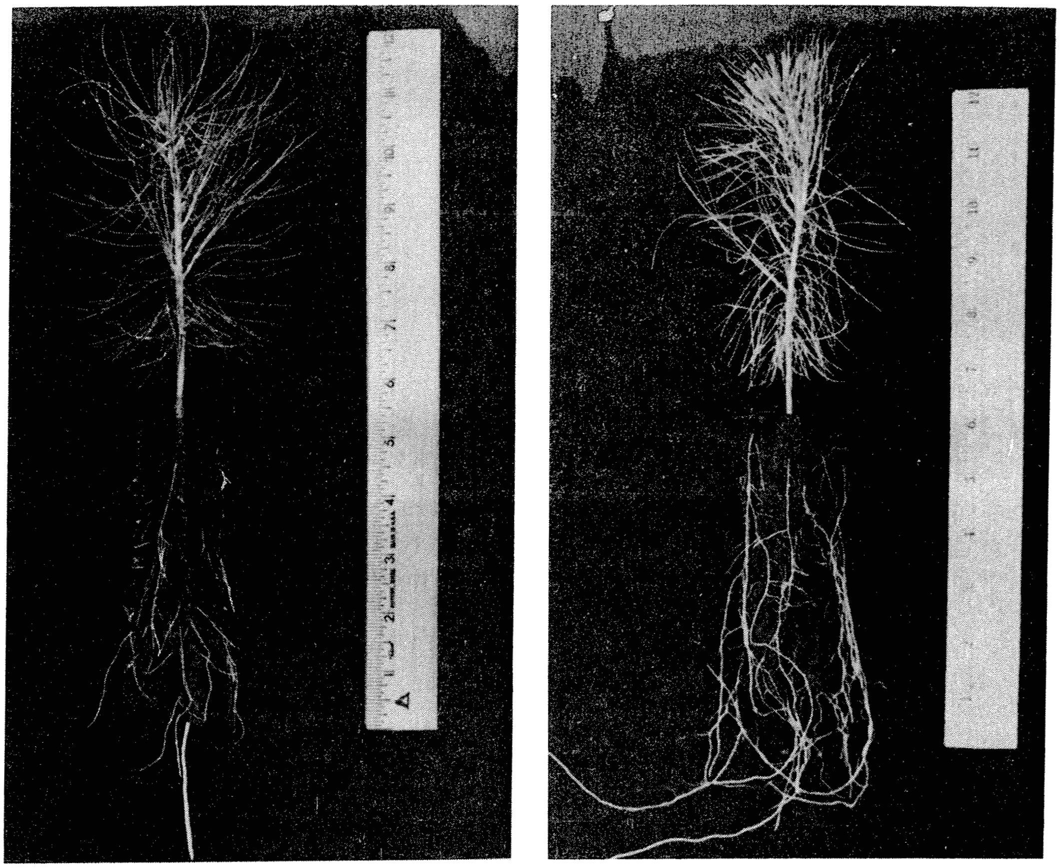

Figure 5-4.—*Development of loblolly pine seedlings in Kys-Tree-Starts 2 weeks (A) and 4 weeks (B) after outplanting into a sawdust bin.*

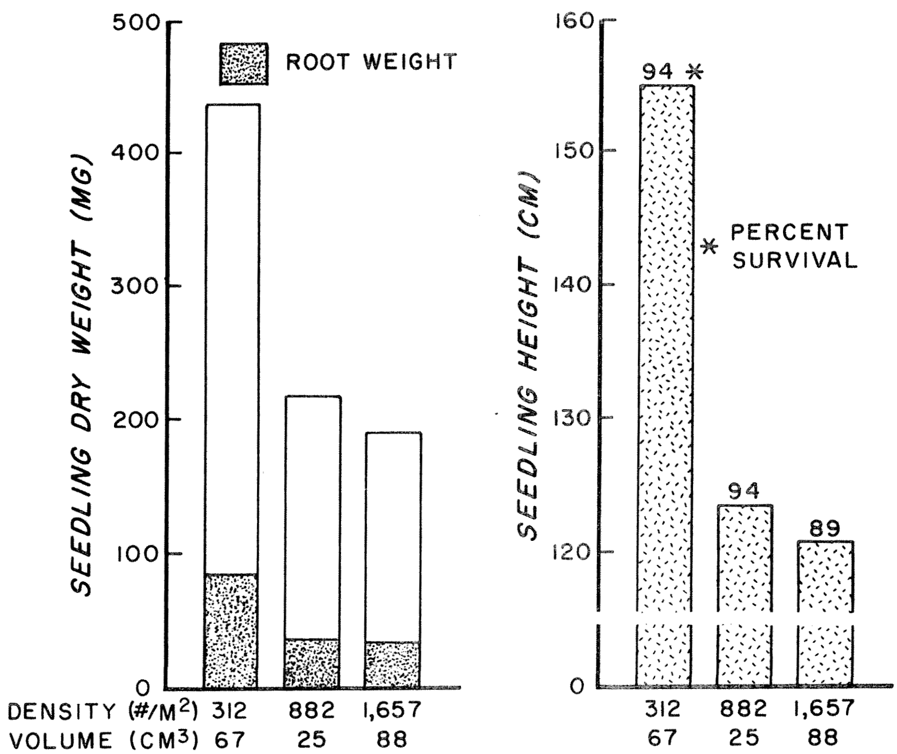

Figure 5-5.—*Effects of container parameters on development and performance of loblolly pine seedlings; height and survival measured after 3 years in the field.*

Table 5-2.—*Major container materials evaluated with southern pines*[1]

Container	Volume[2]		Density[2]		Description
	cm³	*(in³)*	*#/m²*	*(#/ft²)*	
Tubes:					
Kraft paper	94	(5.7)	1,076	(100)	Square tube, 2.5 × 15 cm (1 × 6 in)
Plastic bullet	30	(1.8)	1,345	(125)	High impact polystyrene, 2 × 11.4 cm (.75 × 4.5 in)
Japanese Paperpot 315	90	(5.4)	1,657	(154)	Special paper, 3 × 15 cm (1.2 × 6 in)
Japanese Paperpot 408	70	(4.3)	1,000	(93)	Special paper, 4 × 8 cm (1.6 × 3.2 in)
Conwed	77	(4.7)	1,162	(108)	Plastic mesh, 3 × 15 cm (1.2 × 6 in)
Biodegradable	64	(3.9)	1,807	(168)	Polycaprolactone, 2.5 × 12.5 cm (1 × 5 in)
Plugs:					
Styroblock 2	40	(2.5)	1,064	(98)	Polystyrene foam, 2.5 × 11.4 cm (1 × 4.5 in)
Styroblock 4	65	(4.0)	807	(75)	Polystyrene foam, 3 × 12.5 cm (1.2 × 5 in)
Styroblock 8	130	(8.0)	441	(41)	Polystyrene foam, 4 × 15 cm (1.5 × 6 in)
Rootrainers:					
Ferdinand	40	(2.5)	1,280	(119)	Polystyrene cellulose acetate, 2 × 10 cm (.75 × 4 in)
Fives	62	(3.8)	882	(82)	Polystyrene cellulose acetate, 2.5 × 10 cm (1 × 4 in)
Hillsons	165	(10.5)	398	(37)	Polystyrene cellulose acetate, 3.8 × 12.5 cm (1.5 × 5 in)
RL Single Cell:					
Pine cell	65	(4.0)	1,076	(100)	Polyethylene, high impact, 2.5 × 16 cm (1 × 6.3 in)
Super cell	164	(10.0)	500	(46)	Polyethylene, 3.8 × 20 cm (1.5 × 8 in)
Stubby cell	100	(6.1)	500	(40)	Polyethylene, 3.8 × 12.5 cm (1.5 × 5 in)
Todd Tray:					
100A	25	(1.5)	882	(82)	Polystyrene foam, 2.5 × 7.5 cm (1 × 3 in)
200	75	(4.6)	312	(29)	Polystyrene foam, 5 × 7 cm (2 × 3 in)
150-5	75	(4.6)	550	(50)	Polystyrene foam, 3.8 × 12.5 cm (1.5 × 5 in)
Tree Planter (ITW)	107	(6.5)	1,076	(100)	Molded polystyrene, 2 × 15 cm (1 × 6 in)
Blocks:					
Gro-block	20	(1.2)	1,861	(173)	Modified cellulose fiber, 1.9 × 9 cm (.75 × 3.5 in)
Polyloam	45	(2.8)	2,485	(231)	Nutrient enriched polyurethane foam, 2 × 10 cm (.75 × 4.0 in)
Kys-Peat-Stick	138	(8.4)	1,033	(96)	Organic-inorganic mixture, 3 × 15 cm (1.2 × 6.0 in)
Kys-Tree-Start	65	(4.0)	1,323	(123)	Organic-inorganic mixture

[1]Other containers and container sizes have been evaluated, but these are the ones where most data are available.
[2]The volumes and densities shown are approximate and may vary according to the level of filling and according to the type of tray in which the containers are supported.

ings (table 5-3). Stem caliper of longleaf pine increased 66 percent when grown in Styroblock-8 instead of Styroblock-4 containers. The comparative increase for loblolly stem calipers was only 19 percent.

5.4 Containers and Root Form

When planting any tree, you risk having a root system that is deformed, at least to the extent that it will not have the same root configuration as trees grown from seed in place. Many investigations have focused on root deformation (Hulten 1982, Van Eerden and Kinghorn 1978). Yet, there is still no clear determination of effects of root malformation on seedling performance.

Our results with southern pines indicate that the severe constraint of many of the tube-type containers adversely affects seedling growth. For example, plastic bullets can limit root egress to the extent that growth is stunted (fig. 5-7). Other containers can result in root strangulation (fig. 5-8) or root spiraling (fig. 5-9). If, however, these obvious extremes of deformity are avoided, the configuration imposed by the container may not be harmful. Block-type containers seem to impart less of an "oriented" root system than bare-root planting. Root egress from blocks such as Kys-Tree-Starts occurs from the entire surface of the block in a natural manner (fig. 5-4).

The effect of plug-type containers on root configuration can vary greatly. Round cavities as in the styroblock container can result in root spiraling if vertical ribs are not incorporated to force root growth downward; ribs effectively reduce root spiraling.

Studies have also shown that the amount of root malformation varies with species and soil type. Long-

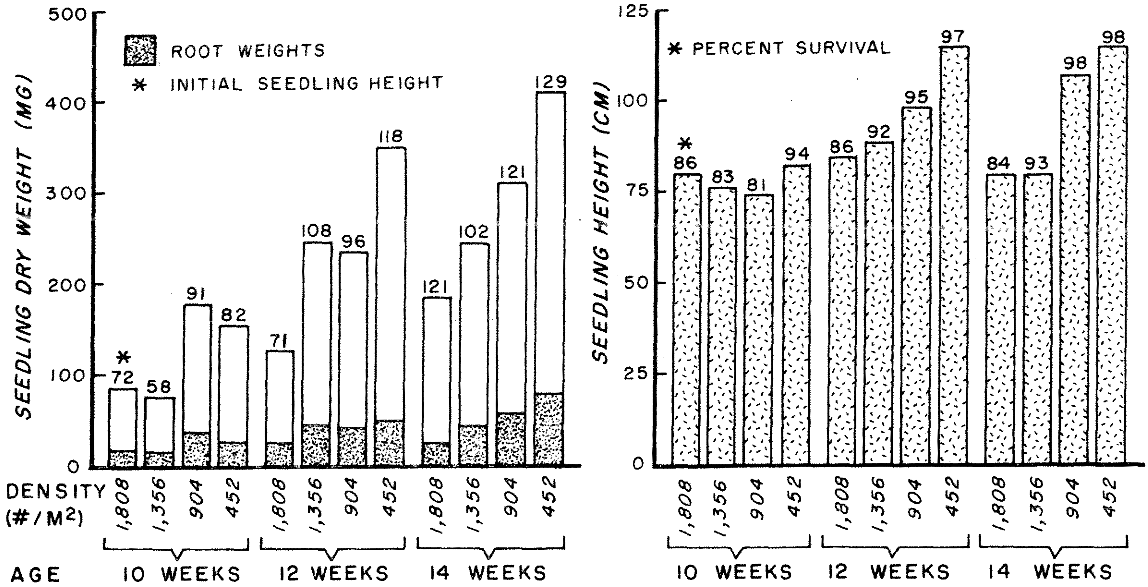

Figure 5-6.—*Effects of seedling density and age on development and field performance of loblolly pine seedlings; measurement taken at 2-1/2 years.*

Table 5-3.—*Development of loblolly and longleaf pine seedlings as related to container size and seedling density*

		Seedling development[1]		
Species	Container	Stem caliper	Top weight	Root weight
		--- *mm* ---	---------- *mg*[2] ----------	
Loblolly	Styroblock-4	2.6	840	162
	Styroblock-8	3.1 (19%)[3]	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 these measurements were made.
[2]Dry weights.
[3]Values in parentheses are proportional increases in seedling development due to the larger container.

leaf pine is more susceptible to root spiraling than loblolly or slash, probably because the lack of early stem growth results in more rapid root elongation. With punched planting holes, heavy soils can increase the amount of root malformation by limiting rapid root egress through the planting hole wall (Barnett 1978a) (see section 12.5). Root spiraling can occur within the planting hole when holes are punched in heavy clay soils. However, with reasonable precautions in selection of containers and planting techniques, root configuration should not adversely affect seedling growth and development. The development of adverse root forms increases rapidly with the length of time seedlings are grown in containers. With 12- to 15-week growing cycles and removal of the seedlings from the container, there should be no problem if you are using properly designed containers.

5.5 Containers for Specific Applications

Certain uses of containerized seedlings make specific types and sizes of containers necessary. A few of these more specific applications are discussed below. Planting of container-grown seedlings is discussed in greater detail in section 12.5.

5.5.1 *Hand-Planting Operations*— Seedlings grown in plug-type containers are generally best adapted to hand planting. The planting rate using punch-type dibbles usually exceeds that of bare-root stock because of the tapered configuration of the root mass (Vyse 1971). The planting hole does not have to be closed with the dibble as in bare-root planting 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 (fig. 5-10). Both tubes and blocks are more difficult to plant by hand. Tube containers shaped like bullets are the exception, but these seriously constrict the root system and inhibit growth (Arnott 1973).

5.5.2 *Mechanized Planting Operations*— Although extractable plugs seem well suited to hand planting, they are not well adapted to an automated tree planter (Edwards 1974). Tube and block-type containers lend themselves more easily to a mechanized planting system because of their rigidity and durability. In many areas, especially in the Southeastern States, an automated planter will work effectively and avoid labor intensive and costly hand planting. Edwards (1982) discusses the development of semi-automatic and automatic planters and the problems involved in their development.

5.5.3 *Forest Genetics Programs*— One of the advantages of container planting listed earlier was to increase efficiency of genetically improved seeds. A more specific application in this regard is to produce seedlings for progeny tests. Use of containers allows complete utilization of limited quantities of seeds and also results in very uniform seedlings. Because of the full utilization of seeds, it may be possible to begin progeny evaluations several years before they could be started if seedlings were grown in forest nurseries. Even if sufficient seeds are available, container-grown seedlings can be in the field one growing season before bare-root plants, if seed extraction is done promptly and the seedlings are grown over the winter months (van Buijtenen and Lowe 1982).

It may be desirable to grow seedlings for progeny tests in containers larger than normally used for operational production. This would allow development of high-quality seedlings in a relatively short time. RL Single-Cell containers are ideal for this use, because individual tree randomization can be accomplished in

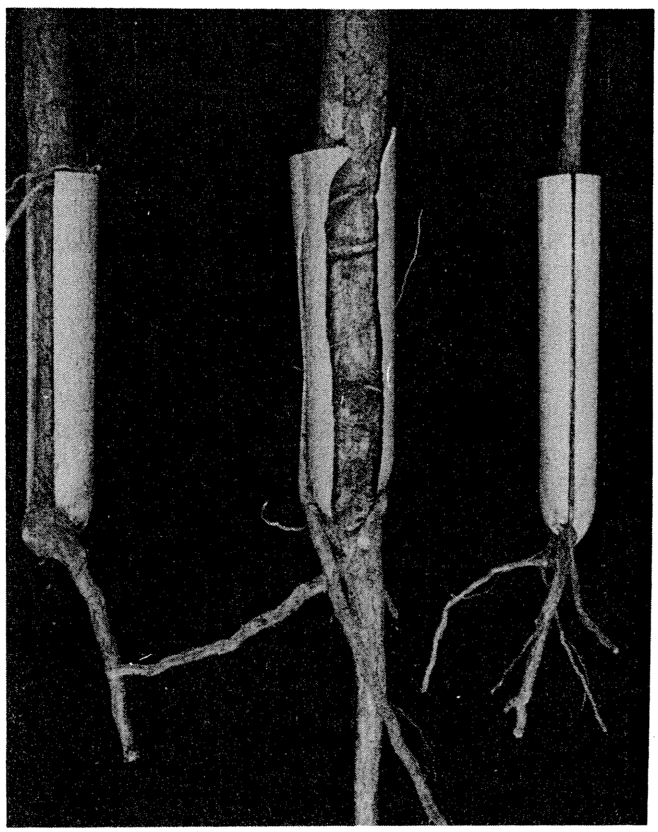

Figure 5-7.—*Loblolly pine seedlings grown in and outplanted with plastic bullets and excavated after 3 years. Various stages of root constraint are shown.*

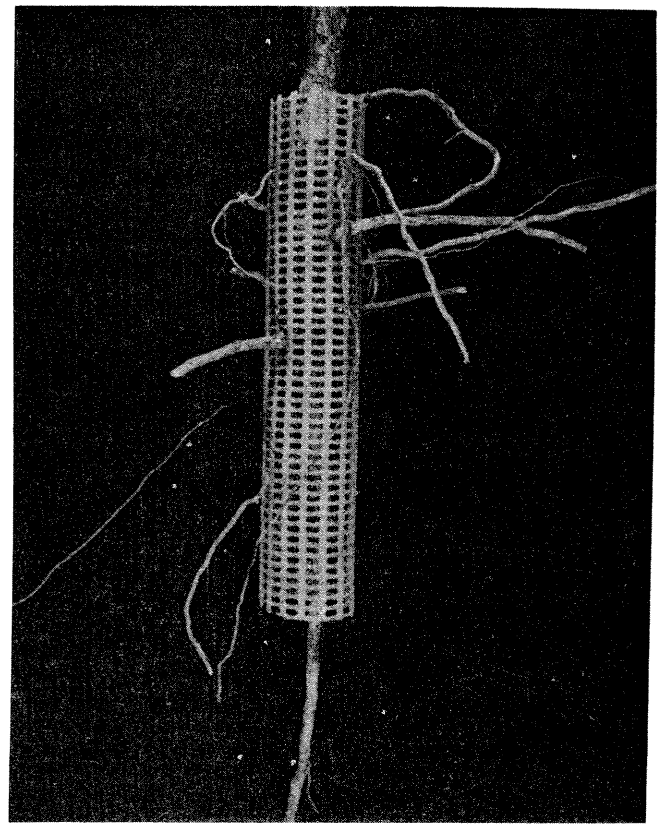

Figure 5-8.—*Conwed mesh-type container showing configuration of loblolly pine roots about 3 years after outplanting.*

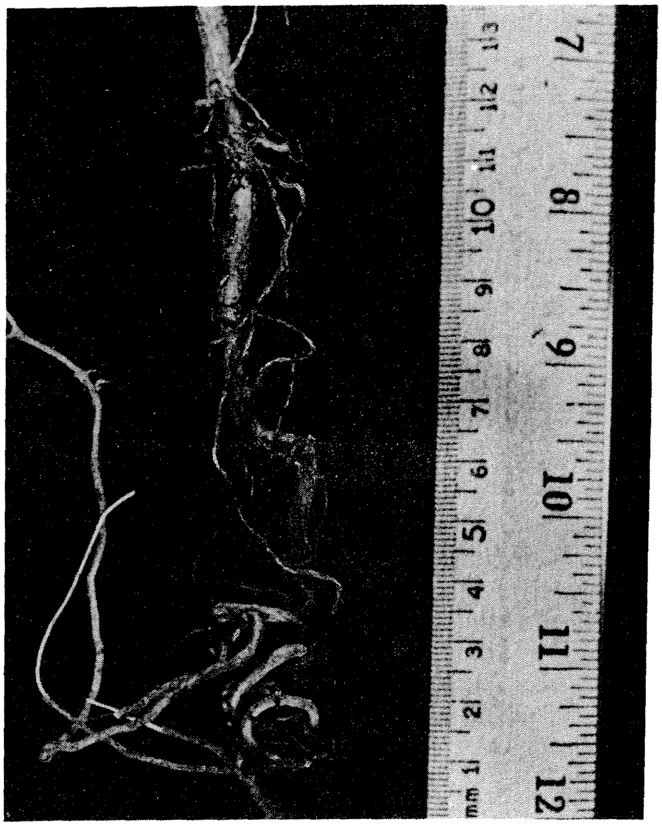

Figure 5-9.—*Root system of loblolly pine seedling showing deformation at the bottom of the styroplug, below the extent of the vertical ribs.*

the greenhouse, blank cavities can be removed, and seedlings per unit area and other factors affecting seedling quality can be easily controlled.

5.5.4 *Problem Species and Sites*—Nursery-grown seedlings of some species are difficult to plant successfully. Longleaf pine and Fraser fir (*Abies fraseri* (Pursh) Poir.) are two species that are difficult to grow in bare-root nurseries. Longleaf pine, because of its dormant epicotyl or "grass stage" characteristic, produces rapid root development. During lifting of nursery-grown seedlings a large proportion of this root system is lost and the resulting field survival is usually lower than for other southern pine species. Fraser fir develops slowly in seedbeds, requiring 3 years to reach transplantable size in bare-root nurseries. Both species seem well adapted to production in containers. The root systems remain intact and cultural conditions hasten development, so that plantable seedlings are obtained in a relatively short period.

Certain sites are typically difficult to plant with success. Examples of problem sites are (1) dry, sandy soils, (2) mine spoil banks, (3) highly erosive soils, and (4) low, poorly drained soils. Many of the dry, sandy soils throughout the southern United States were originally longleaf pine sites, but difficulties in planting this and other species have slowed regeneration of these areas. Amidon and others (1982) showed that container-grown longleaf seedlings did much better than bare-root seedlings on these harsh sites (table 5-4). Mine spoils present very difficult sites to regenerate in parts of the South, and although the total acreage is relatively small, Davidson and Sowa (1974) demonstrated that containerized seedlings may do well on these areas, particularly when seedlings are inoculated with mycorrhizae adapted to these soils (Marx and Bryan 1975). Dickerson (1973) also reported that container-grown seedlings gave promising results on severely eroded forest sites caused by poor agricultural practices. Early summer planting of containerized seedlings is a practical means of regenerating many of the low, poorly drained soils where roads are not accessible in the winter months.

6. GROWING MEDIUM

6.1 Selection of the Medium

Numerous natural and artificial soils have been used alone and in combination as a plant growing medium. Good topsoil is increasingly difficult to find, and its nutrient content, drainage characteristics and disease organism or weed seed content are difficult to determine. Unless topsoil is sterilized, poor crop growth often results from its use (Boodley and Sheldrake 1963). Artificial mixes are readily available, easy to handle, and produce uniform plant growth from one year to another.

A number of workers have evaluated combinations of artificial soil mixes (Edgren 1973, Phipps 1974, Hellum 1975, Matthews 1971, Goodwin 1976, Pawuk 1981). Almost without exception, the combination resulting in best seedling performance involved sphagnum peat moss and vermiculite. Sphagnum moss provides good water holding capacity, a low pH (see section 9.5), good buffering capacity, and a high cation exchange capacity. Vermiculite provides pore space thus ensuring good aeration for root growth. The ratio of peat to vermiculite most often used is 1:1 or sometimes 2:1.

Domestic peat moss is generally unsatisfactory because of the large quantities of nutrients or other materials in unknown amounts and because it is usually too decomposed to provide the necessary structural and water drainage capacities (Phipps 1974). Canadian peat moss is recommended, but because of the transportation costs to the southern United States, alternative materials have been evaluated.

Because it is readily available and relatively inexpensive, pine bark has been suggested as a medium for growing plants (Scarborough 1979). Results to date have indicated that bark has physical properties making it a possible alternative to peat moss

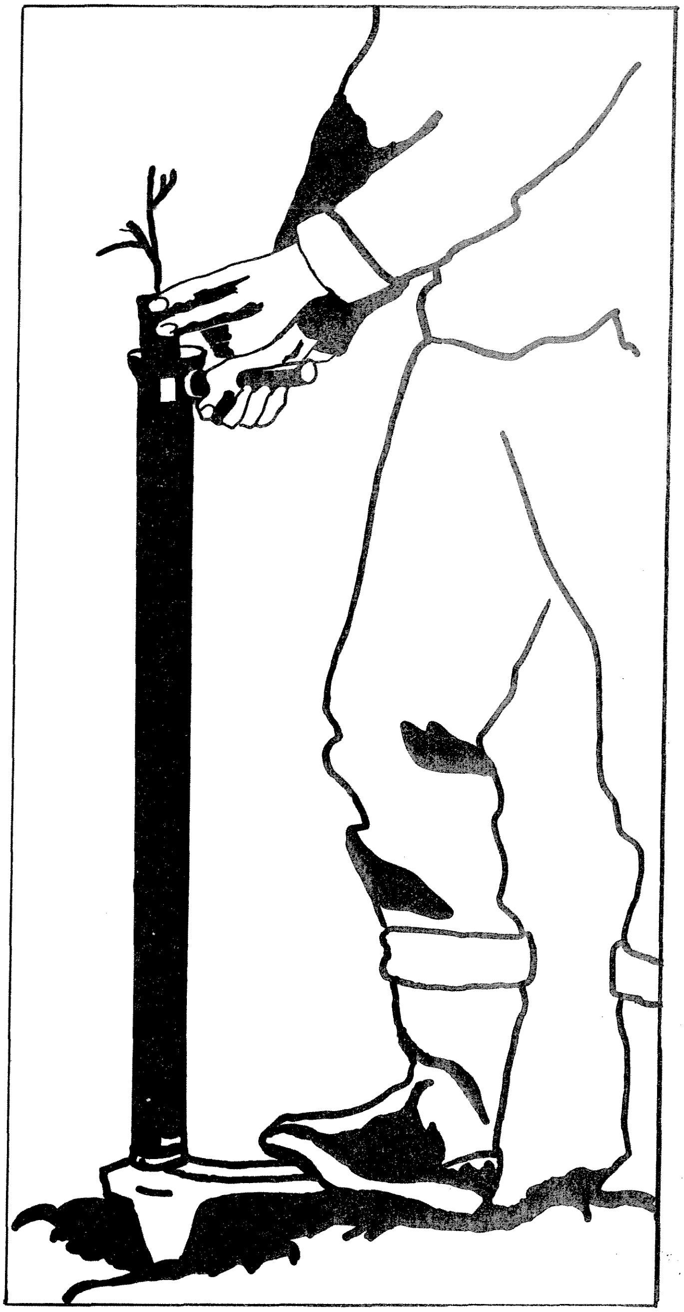

Figure 5-10.—*Using tools for hand planting containerized seedlings can increase the planting rate.*

(Pokorny and Perkins 1967, Brown and Pokorny 1975). Other advantages of bark are excellent mycorrhizal development (Ruehle and Marx 1977) and possible inhibition of disease organisms (Pawuk 1981). Media incorporating pine bark or pine cone chips resulted in significantly less mortality when infested with *Fusarium* and *Phythium* than commercial or locally blended peat and vermiculite mixes (table 6-1). Seedling mortality was related to drainage and pH of the media. Seedling losses were greatest in commercial media with pHs above 6.0 and increased as water-holding capacity of the medium increased. However, pine bark also has certain disadvantages. A nitrogen deficiency problem develops in bark-amended media, which requires special attention. This has caused some researchers to recommend against the use of bark as a medium ingredient (Mitchell and Kay 1973). The use of milled bark in plug-type containers results in difficult extraction and in poor binding by the root system. Another characteristic of bark is poor water retention capacity (Johnson 1968). Although rapid drainage reduced disease problems, it resulted in the need for more frequent watering during the greenhouse growing phase and in rapid depletion of moisture from the medium when outplanted in the field.

Comparisons of composted and milled fresh bark indicate that the aged bark results in fewer growing problems (Mason and Van Arsdel 1978, Gartner 1979). If properly handled, hardwood bark can also be used satisfactorily; however, the pH increases from about 5.2 for fresh bark to 7.5 to 8.0 as it ages (Gartner 1979). Iron sulphate and elemental sulfur must be added to compensate for this decrease in activity.

Until more information is available, bark should be used only as a partial replacement for peat in the growing medium. Our current data indicate that although there is no universal medium, the peat-vermiculite blend is still the most satisfactory (tables 6-1, 6-2).

6.1.1 *Commercial Mixes*—A number of commercial potting mixes are available for container growing. Almost all of these are based on the Cornell mixes, which consist of various ratios of peat moss, vermiculite, and perlite (Boodley and Sheldrake 1963). To these blends are added nutrients and enough dolomitic limestone to buffer the media to a pH of about 6.0. These blends have been developed for horticultural and vegetable use and are unsuitable for conifers unless special precautions are taken to reduce the pH to levels more nearly optimum for conifers. A few producers will custom blend and reduce the amount of limestone so the pH is more satisfactory for growing coniferous species. The advantage of peat-vermiculite mixes with low levels of limestone (or none) is evident when compared to commercially blended peat-vermiculite mixes (Jiffy Mix®) produced for horticultural uses (tables 6-1, 6-2). The nutrients in Cornell-type mixes are sufficient for the first several weeks, but then supplemental fertilizers should be added.

6.1.2 *Other Blends*—Any number of mix combinations are possible if the grower has access to blending equipment. Small quantities suitable for uses such as progeny testing can be mixed by hand. However, when quantities needed exceed a few cubic meters, other arrangements for mixing must be made. Commercial concrete mixers may be rented for occasional

Table 5-4.—*Longleaf pine seedling survival and root-collar diameters on two dry sites following extremely harsh drought conditions in the summer of 1980*[1]. *Adapted from Amidon and others (1982)*

Container	Survival		Root-collar diameter	
	Louisiana	Texas	Louisiana	Texas
	------- *percent* ------		------- *mm* --------	
Late summer planting (August 1979)[2]				
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)				
Bare-root seedlings	7	43 b	10 a	10 a
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]Measurements taken in January 1981.
[2]Container treatment means within columns and site averages within rows followed by the same letter are not significantly different at the 0.05 level for each of the two plantings.

Table 6-1.—*Growth and disease development of 12-week-old longleaf pine seedlings grown in peat, pine cone, and pine bark media (Pawuk 1981)*

Medium[1]	Final pH	Dry Weight	Seedling loss due to[2]	
			Fusarium	*Pythium*
		mg	----- *percent loss* -----	
Peat				
PV-50	5.1 e[3]	798 a	00 a[3]	40 cd
Commercial (PV-50)	6.2 b	755 a	08 bc	94 f
Pine Cone				
CV-50	6.1 bc	636 b	00 a	46 d
CV-70	6.1 bc	619 bc	06 abc	40 cd
C-100	5.9 c	562 cd	00 a	36 bcd
CS-70	5.9 c	628 b	02 ab	26 abcd
Pine Bark				
BV-50	5.2 d	510 de	00 a	24 abc
BV-70	4.9 f	452 ef	00 a	16 ab
B-100	4.6 g	460 ef	02 ab	06 a
BS-70	5.1 e	530 d	00 a	1.6 ab
Jiffy 50-50 (BV-50)	6.4 a	420 f	16 d	68 e
Jiffy 70-30 (BV-70)	6.4 a	410 f	12 cd	88 f

[1]P = peat; V = vermiculite; C = cone chips; B = bark; S = soil: the number following the medium designation indicates the percentage of peat, bark, or cone chips present.
[2]Medium infected with *Fusarium* and *Pythium* at the time of blending.
[3]Means followed by the same letter are not significantly different at the 0.05 level.

Table 6-2.—*Seedling growth of 12-week-old shortleaf pine grown in peat, pine cone, and pine bark media. Adapted from Pawuk (1981)*

Medium[1]	Media final pH	Seedling Weight	Seedling Height
		mg	*cm*
Peat			
PV-50	5.4 c[2]	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; V = vermiculite; C = cone chips; B = bark; S = soil: the number following the medium designation indicates the percentage of peat, bark, or cone chips present.

[2]Means followed by the same letter are not significantly different at the 0.05 level.

use, but large operations are generally best served by purchasing their own blending equipment. Ribbon blenders are available in a number of sizes, but a 0.8 m^3 (28 ft^3) blender is adequate for most operations. This type of blender can thoroughly mix the medium with any additional amendments in 10 to 15 minutes. Addition of water during the blending process reduces dust problems and also prevents the media from falling out of the bottom of the containers during filling and handling. Enough water should be added to thoroughly moisten the mix, but not so wet that water can be wrung from a handful.

6.2 Amendments

6.2.1 *Wetting Agents*—Several types of amendments can be added to the medium as it is blended. The addition of a wetting agent is desirable because it increases the uniformity and rate at which moisture spreads through hydrophobic peat. Most commercial peat mixes contain small amounts of such an additive, but growers blending their own medium must add a wetting agent separately. The amount added must be carefully controlled to avoid phytotoxicity to the germinating seed. In some cases, the manufacturer's recommended concentration may be too high. Burridge and Jorgensen (1971) reported that wetting agents reduced the speed of germination and radicle development of several northern conifer species. Edwards (1973) found that low concentrations had negligible effects on germination.

Aqua-Gro®, a 1:1 mixture of polyoxethylene ether and ester used widely in nursery operations in the United States, was evaluated on southern pine seed germination (Barnett 1977). The recommended rate (0.1 percent) reduced germination of longleaf, slash, loblolly, and shortleaf (*Pinus echinata* Mill.) pine seeds. The application rate should be lowered to 0.02 to 0.04 percent, which provides adequate wetting without reducing germination (fig. 6-1). Applications can also be made through the watering system after the medium is blended and containers are filled.

6.2.2 *Fertilizers and Fungicides*—A balanced fertilizer combination is usually blended into commercial potting mixes. Both the University of California (Baker 1957) and Cornell University (Boodley and Sheldrake 1963) have developed potting mixes in which nutrients are incorporated. Modification of these or other nutrients can be included as the mixes are blended. There may be merit in incorporating slow release fertilizers such as Osmocote® into the media. Specific nutrient formulations are discussed in section 9.6.

Fungicides to control root rot and damping-off diseases may also be incorporated at the time of blending (see section 9.2.1) (Pawuk and Barnett 1974, Walters 1975). Such applications may be more effective than drenches done after disease symptoms appear.

6.2.3 *Hydrophilic Polymers*—The addition of hydrophilic polymers to potting media greatly increases the water-holding capacity and availability of water (Jensen and others 1971). The incorporation of these polymers into the media increases the ability of plants to withstand drought conditions and lessens the amount of watering needed to produce plants.

Two such amendments, Viterra I® and Viterra II®, have been evaluated with forest tree species. Tests of effects on initial seedling development indicate no significant improvement in seedling size. However, trends are indicative of some response (table 6-3). Field results to date are inconclusive because of the lack of moisture stress. Other materials have similar properties, including synthetic- and starch-based superabsorbents such as Tera-Sorb®. The use of such amendments is generally unnecessary in well run container nurseries.

7. SEED

7.1 Seed Lot Selection

Many species have sufficient racial variation to necessitate collection from specific seed collection zones for planting in certain regions. For example, loblolly pine from some geographic areas grows faster and has more disease resistance when planted on other areas

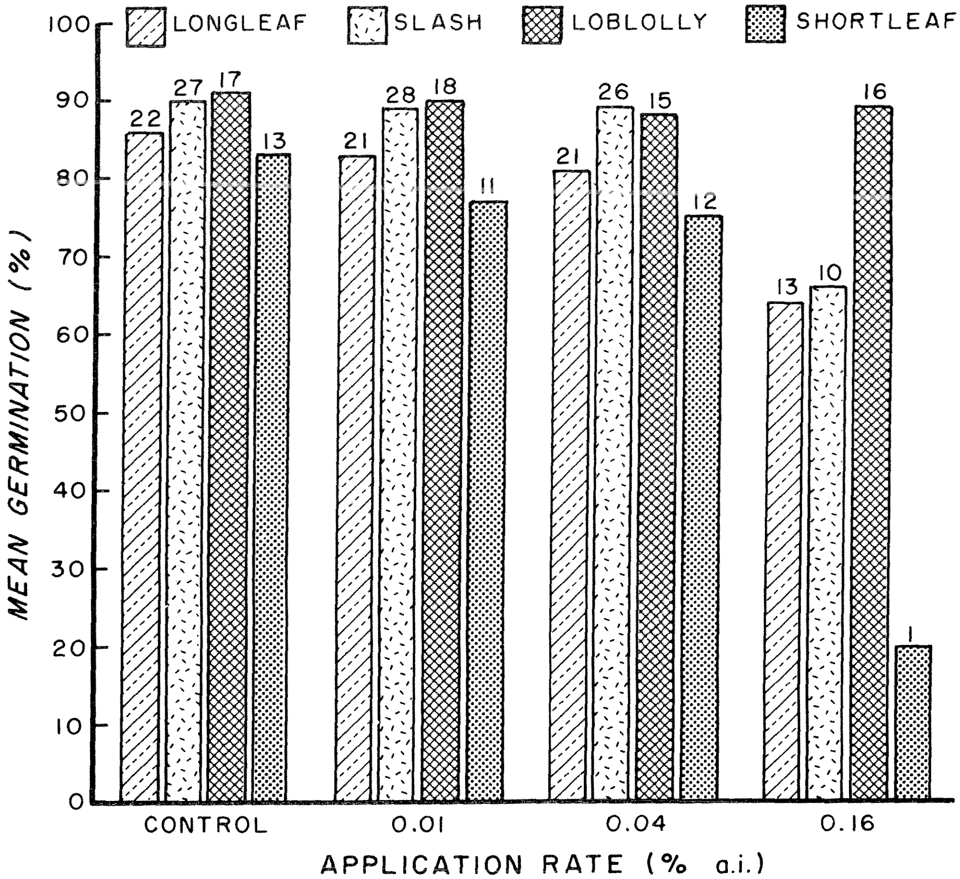

Figure 6-1.—*Germination percentages and germination values of longleaf, slash, loblolly, and shortleaf pine seeds after treatment of the growing medium with a wetting agent. Numbers above bars are mean germination values (peak germination X daily germination at 30 days (from Barnett 1977).*

Table 6-3.—*Seedling development of 12-week-old longleaf pine grown with hydrophilic polymer additives*[1]

Treatments	Root collar diameter	Dry weight of tops	Dry weight of roots
	mm	*mg*	*mg*
Control	1.98	552	85
Viterra I	2.02	583	71
Viterra II	2.38	702	93

[1]Grown in Union Carbide biodegradable tubes filled with peat-vermiculite media.

in the South (Wells and Wakeley 1966). Similar seed source recommendations have been developed for longleaf (Wells and Wakeley 1970a), shortleaf (Wells and Wakeley 1970b), and slash pine (Snyder and others 1967).

Once seeds from an appropriate geographic source have been selected, high seed quality becomes the paramount concern, because maximum utilization of containers is necessary to make the system economically justifiable.

7.2 Collecting and Processing Seed

The high quality seed necessary for use in container-planting facilities results from operations where cone and seed collecting and processing methods are carefully controlled (Barnett 1976a).

Cone maturity at the time of collection can have a major impact on the seed quality of slash and longleaf pine. Loblolly seeds usually have high viability, even when collections begin early. Detailed information on the effects of cone maturity and storage on seed yield and viability are available for these species (Barnett 1976b, McLemore 1961, 1975b).

Seeds are usually extracted from southern pine cones in forced-draft kilns. Temperature and duration of kilning are critical for southern pines, particularly longleaf. Temperatures over 45 °C (115 °F) markedly reduce germination (Rietz 1941). Alternative methods of extracting and drying southern pine seeds are under evaluation and may result in increased seed quality (Barnett 1979a).

After seeds are extracted, they must be dewinged, cleaned, and dried. The wings on seeds of all southern pines, except longleaf, are completely removed by brushing and tumbling in mechanical dewingers where the wings are mechanically removed. The structure of longleaf makes dewinging difficult, so dewingers must be carefully regulated to prevent injury to these thin-coated seeds. Storage of longleaf pine seeds will be adversely affected if wing removal damages the seedcoat (Barnett 1969a, Belcher and King 1968). The dewinging process for the other southern pine species is hastened and improved by moistening dry seeds, but this excess moisture should be removed prior to storage.

Complete removal of unsound seed should be specified when seed lots are purchased. When seed lots are small, it is often convenient to do your own processing. Small laboratory cleaners or aspirators are available that are quite efficient (Bonner 1977). Separation by flotation in water or organic solvents also can be used. When the appropriate liquid is used, sound seed sinks, while unsound seed floats and can easily be skimmed off. For flotation of southern pine seeds, use water for loblolly pine; 95 percent ethyl alcohol for shortleaf, sand (*Pinus clausa* (Chapm. ex Engelm.) Vasey ex Sarg.), and spruce (*P. glabra* Walt.) pines; a water-ethyl alcohol mixture (1:1) for slash pine; and *n*-pentane for longleaf pine (Barnett and McLemore 1970). Flotation in ethyl alcohol should not be done until just prior to use, because viability rapidly declines during storage unless the alcohol is thoroughly removed by drying (Barnett 1971b).

7.3 Seed Storage

Careful control of seed moisture content and storage temperature is essential to maintain viability (Barnett and McLemore 1970, Jones 1966). General recommendations for long-term storage are to dry seeds to 10-percent or less moisture content and hold at subfreezing temperatures (fig. 7-1). Seeds that are damaged or are known to have low vigor can be preserved by lowering storage temperatures to about −18 °C (0 °F) (Kamra 1967), if moisture contents are as low as 8 to 10 percent. Storage at temperatures near −18 °C (0 °F) can reduce viability if moisture levels are 20 percent or more (Barnett 1974c).

Seed moisture content can also affect the amount of undesirable secondary dormancy that develops during storage (fig. 7-2). Seed dormancy is related to germination values (Czabator 1962), which reflect speed as well as completeness of germination, and low values reflect more dormant seeds. Loblolly seeds stored for 1 to 5 years at moisture levels below 10 percent are less dormant than those held at levels between 10 and 18 percent (McLemore and Barnett 1968).

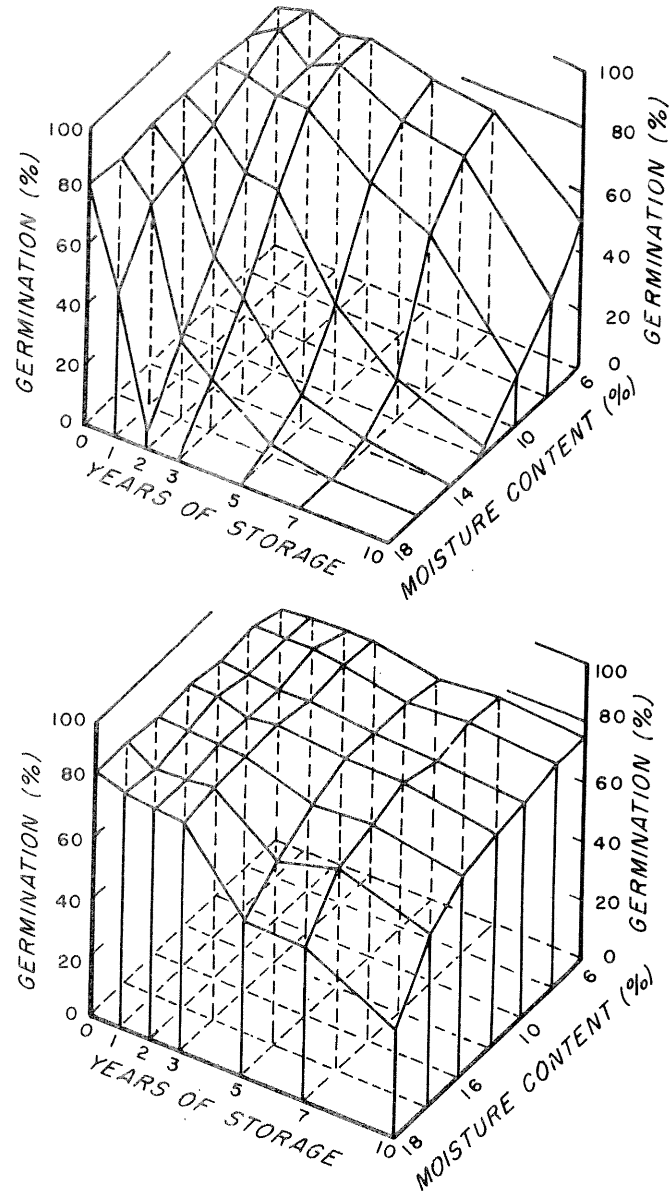

Figure 7-1.—*Germination of longleaf pine seeds as influenced by moisture content and years of storage at 2 °C (top) and −18 °C (bottom).*

7.4 Seed Sizing

The reported effects of seed size on germination and early seedling growth are conflicting. In general, large seeds have been found to germinate faster and more completely than small seeds and to produce seedlings whose initial growth is greater (Shoulders 1961, Fowells 1953, Righter 1945). This growth advantage usually has not been retained after the first few years. However, with the limited information available, many growers of containerized seedlings

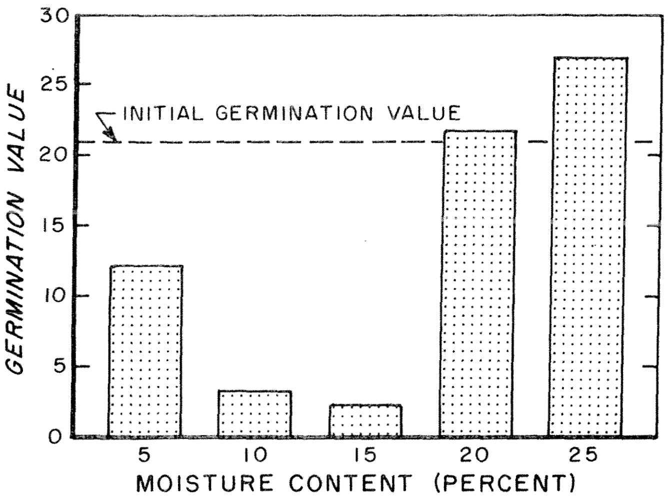

Figure 7-2.—*Germination values of unstratified loblolly pine seed stored for 1 year at moisture contents of 5 to 25 percent (from McLemore and Barnett 1968).*

still recommend seed sizing. The objective is to produce uniform sized crops of seedlings (Owston 1972). Medium to medium-large seeds have been reported to be best (Ghosh and others 1976). Larsen (1963) reported that although seed size can influence seedling size when seedlings are grown under uniform conditions such as greenhouses, the importance of size is minor when compared to the effect of germination date. Uniformity of germination may be, then, the most important consideration in sizing.

Sizing of genetically improved orchard seeds seems to have little effect on seedling performance (table 7-1). Grouping for production of uniform seedlings is probably the only reason to size these seeds (Barnett and Dunlap 1982). Certainly all sizes should be used, or certain clones will be segregated from a mixed seed lot (Silen and Osterhaus 1979). The large seeds listed in table 7-1 were primarily from two clones. Seed size tends to be consistently uniform from year to year within clones (McLemore 1975a), so sizing could easily segregate orchard seed lots.

Seed sizing was examined as a possible method for manipulating the size of containerized seedlings produced from a single half-sib family of loblolly pine (Dunlap and Barnett 1983). Under laboratory conditions of minimal environmental stress, germinant size after 28 days of growth was strongly correlated with seed size. The faster germinating seeds in each size class produced larger germinants after 28 days of incubation (fig. 7-3). The rate of germination was related to seed size. All seeds reached a maximum rate by the sixth day, but smaller seeds were slower to initiate germination (fig. 7-4). In a similar experiment conducted under greenhouse conditions, large seeds produced the largest seedlings.

Seedling size differences in both experiments appeared to result from differences in the rate of germination, which seems to be characteristic of each size class. This supports the findings of Venator (1973), indicating that faster growing Caribbean pine (*P. caribaea* var. *hondurensis* Barrett & Golfari) seedlings tend to develop from early germinating seeds. Consequently, seedling size and possibly uniformity of growth were primarily a function of germination patterns, which were partially determined by seed size. However, germination patterns also can be manipulated by pregermination treatments. For example, long stratification periods tend to eliminate differences in rate of germination.

7.5 Seed Dormancy

The seeds of nearly all 10 species of pines indigenous to the southern United States exhibit some dormancy. There has been little agreement on the cause of this dormancy. It has been attributed to impermeability of the seedcoats to oxygen (Stone 1957, Kozlowski and Gentile 1959, Asakawa 1964), germination inhibitors (Barnett 1970), or to some condition in the embryo (Kramer and Kozlowski 1960). However, recent studies have established that inherent dormancy in the southern pines is most likely a result of mechanical seedcoat constraint (Barnett 1972,

Table 7-1.—*Effect of size of genetically improved loblolly pine seeds on initial seed and seedling performance and field survival and growth (from Barnett and Dunlap 1982)*

Seed size class	Seeds per pound	Proportion of lot per class	Germination		Seedling characteristics				Field performance[1]	
			Unst.	Strat.	Ht.	Diam.	Top Wt.	Root Wt.	Survival	Height
	number	------- *percent* -------			--- *mm* ---		------ *mg* ------		*percent*	*cm*
Unsorted	17,059	....	87 b[2]	89 b	125 a	1.5 a	225 a	52 a	85 a	128 ab
Small	20,100	19.9	86 b	87 ab	146 b	1.6 ab	297 ab	59 a	84 a	131 b
Medium	17,518	36.1	89 b	90 b	130 a	1.6 ab	260 a	44 a	89 a	128 ab
Medium-large	15,406	41.8	88 b	83 a	154 b	1.7 b	328 b	60 a	84 a	101 a
Large	13,089	2.1	79 a	83 a	150 b	1.7 b	316 b	59 a	81 a	122 ab

[1]At 30 months.

[2]Values in columns followed by the same letter are not significantly different at the 0.05 level.

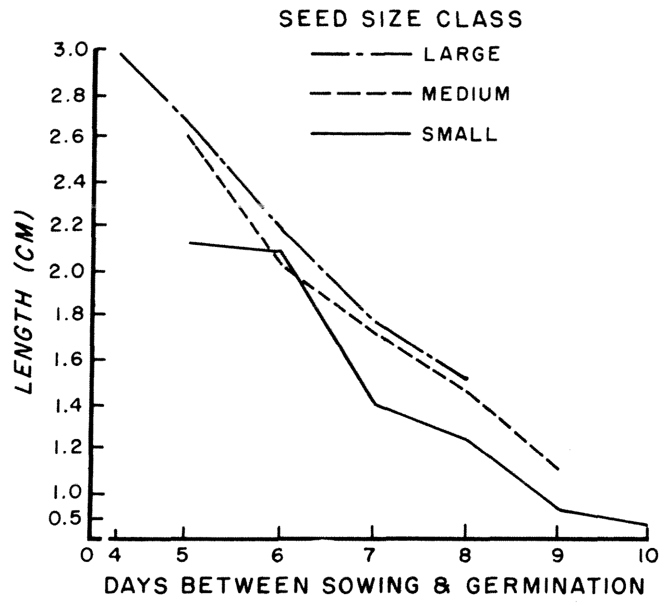

Figure 7-3.—*Mean hypocotyl length of loblolly pine germinants 28 days after germination (from Dunlap and Barnett 1983).*

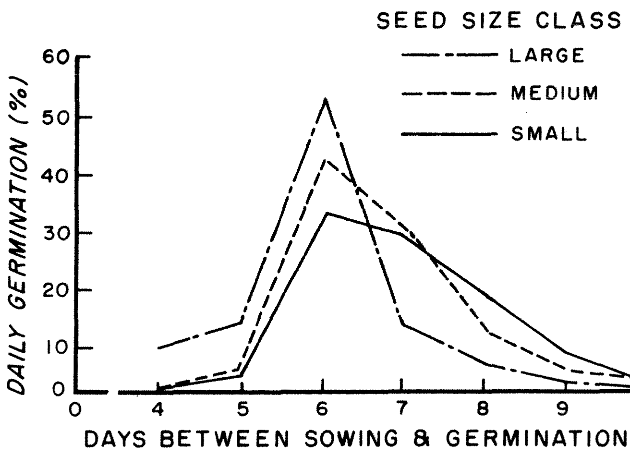

Figure 7-4.—*Mean daily germination of loblolly pine seed from the large, medium, and small classes incubated under standard laboratory conditions (from Dunlap and Barnett 1983).*

1976c). This innate dormancy can be increased by unfavorable conditions during processing and storage (McLemore and Barnett 1966, 1968). For example, dormancy of loblolly pine seeds is markedly increased when stored at moisture contents of 10 to 18 percent (fig. 7-2). Moisture levels below 10 percent during storage minimizes this induced dormancy. Storage at a moisture content of 20 percent or more has a stimulating, prechilling effect.

Seeds of several of the southern pines are routinely treated before use to obtain complete and uniform germination. Pregermination treatments increase the growth potential of the embryo, allowing seeds to germinate more promptly (see section 7.6).

7.6 Presowing Treatments to Speed Germination

7.6.1 *Stratification*—Presowing treatments to speed pine germination are discussed in detail by Bonner and others (1974) in *Seeds of Woody Plants in the United States*. Although the term stratification refers to the layering of seeds in a good moisture-retaining medium such as peat moss, stratification is now used to describe any cold, moist seed treatment. Southern pine seeds are typically prechilled in polyethylene bags. After an 8- to 24-hour period of moisture imbibition, fully imbibed seeds are placed in bags and held at temperatures of 1 to 5 °C (34–41 °F). Temperatures below freezing may injure imbibed seeds (Barnett and Hall 1977) while those above 5 °C (41 °F) may cause germination. The length of stratification depends on the species and time in storage. General recommendations for length of treatment are given in table 7-2. However, 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. Periods of stratification of 45 to 90 days not only hasten germination over that of the 30-day treatment but also result in better germination under adverse conditions (McLemore 1969, Barnett 1979b).

7.6.2 *Aerated Water Soaks*—Cold water soaks have been used to promote germination of some coniferous species (Bonner and others 1974), but soaks longer than a few days tend to reduce germination of southern pines (Barnett and McLemore 1967). However, soaking loblolly, slash, and shortleaf pine seeds in

Table 7-2.—*Recommended cold stratification periods for southern pine seed (adapted from Krugman and Jenkinson 1974)*

Pine species	Recommended length of stratification[1]	
	Fresh seed	Stored seed
	days	
Loblolly	30–60	30–60
Longleaf	0	0
Pitch	0	0
Pond	0	0–30
Sand		
var. Choctowhatchee	0–15	0–21
var. Ocala	0	0
Shortleaf	0–15	15–60
Slash	0	0–30
var. So. Florida	30	30
Spruce	30	30
Table Mountain	0	0
Virginia	0–30	30

[1]Use longer period of stratification if adverse environmental conditions are expected when seeds are sown.

continuously aerated water at 5 °C (41 °F) speeded germination in the laboratory as much as stratification in polyethylene bags (Barnett 1971a). Soaking at 10 °C (60 °F) stimulated germination as much as colder soaks and did so in less time. Although dormant loblolly seeds can be soaked at low temperatures for nearly 5 months without harm, periods of up to 60 days are usually sufficient. With less dormant seeds and higher soaking temperatures, periods as short as 2 or 3 weeks may be necessary to prevent germination in water and induction of secondary dormancy. The water should be aerated continuously to keep the oxygen content near saturation.

An outgrowth of aerated water soaks has been the fluid drilling, or germinant sowing, technique (Currah and others 1974). In fluid drilling, seeds are allowed to begin to germinate to a radicle length of 1 to 2 mm in aerated water. These germinants are then placed in a solution of appropriate specific gravity to separate the germinants from ungerminated seeds (Taylor and others 1977). The germinants are then mixed in a viscous gell to protect the seeds and to provide a means of drilling (sowing) these seeds onto the nursery beds. Research is underway to evaluate the potential of this technique for southern pine seeds. Although firm recommendations have not been developed, if certain criteria are followed, about 85 percent germination of loblolly pine seeds can be obtained in 4 to 5 days (Barnett 1985). This is accomplished without the separation of germinated and ungerminated seeds, which is now impractical for loblolly seeds. Guidelines to use for pregerminating loblolly seeds are:

1. Stratify seeds for 60 days prior to aerated-water germination.
2. Germinate at a temperature of 24 °C (75 °F).
3. Provide about 1600 lux (150 foot-candles) of light with a 16-hour photoperiod during germination.
4. Use high quality seed lots (>90 percent germination) to avoid separation of ungerminated seeds.

Other pine species will require less stratification because they are less dormant than loblolly, and longleaf seeds will require a lower germination temperature.

Fluid drilling offers the potential of having every sown seed result in a seedling and extremely uniform seedling development. However, considerable research is still needed to adequately develop all phases of this technique.

7.6.3 *Chemical Treatments*—Many chemicals have been evaluated in a search for a "trigger compound" that can eliminate, quickly and simply, the delayed germination associated with internal dormancy (Bonner and others 1974). There have been limited successes in the laboratory with inorganic ions, organic acids, and growth regulators, especially the gibberellins (Cotrufo 1962, Hatano and Asakawa 1964, Biswas and others 1972), but nursery response has generally been negative. Stein (1965) reported that a 48-hour soak in 1-percent hydrogen peroxide hastened germination of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in a field test. The same treatment had little positive effect on sugar pine (*Pinus labertiana* Dougl.) and ponderosa pine (*P. ponderosa* Dougl. ex Laws) germination. A combination of citric acid soaks followed by stratification increased nursery germination of baldcypress (*Taxodium distichum* (L.) Rich.) (Jones 1962). New growth regulator formulations now offer potential for increasing rapidity of seed germination, but these must be subjected to further research. At the present time there is no effective chemical substitute for stratification.

7.7 Disease Problems

In the past, seed fungi on southern pine seeds have not been considered a major concern, because most observations indicated they were saprophytic and did not affect germination (Belcher and Waldrip 1972). With the advent of container culture it has become apparent that seedborne fungi can be an important cause of seedling mortality. Pawuk and Barnett (1974) associated *Fusarium* spp. infection of container-grown longleaf pine seedlings with retention of infested seedcoats. Cotyledons become infected, and the disease spreads down the stem, resulting in mortality.

Many seed lots contain infested seeds. For example, 8 to 20 percent of the seeds from five longleaf seed lots tested for *Fusarium* were found to be infested, and all five species of *Fusarium* recovered were pathogenic on longleaf seedlings (Pawuk 1978). *Fusarium* has since been isolated from seedcoats of shortleaf, slash, and loblolly pine seed (Pawuk 1982). Recent studies show that pathogens may also be present inside pine seeds (Miller and Bramlett 1978). Such infected seeds germinate poorly, and damping-off losses are increased. In addition to *Fusarium*, Mason and Van Arsdel (1978) recently have identified *Trichothecium* as a pathogen on loblolly pine seeds.

Microorganisms infesting conifer seedcoats can be controlled by sterilization or by coating the seeds with fungicides. Many fungicides evaluated for forestry use are phytotoxic (Cayford and Waldron 1967, Vaartaja and Wilner 1956), and sterilants inhibit germination of some species (Neal and others 1967), so both methods have been evaluated with southern pine seeds.

7.7.1 *Sterilants*—Hydrogen peroxide sterilizes seedcoats (Trappe 1961) and also increases germination of some pine seeds (Barnett and McLemore 1967, Carter and Jones 1962). Barnett (1976d) found that a 3-percent solution of hydrogen peroxide reduced infesting organisms on loblolly pine seeds but not on slash, shortleaf, or longleaf seeds. A 30-percent solution virtually eliminated infesting organisms from seedcoats of all four species, but germination was reduced by some soaks (table 7-3).

Short soaks in 30-percent hydrogen peroxide best controlled infestations without reducing germination (table 7-3). Germination of some longleaf seed lots, especially those with low viability, can be increased by a 30- to 60-minute soak, but a preliminary test should be done before soaking an entire lot longer than the recommended time period (Campbell 1982).

7.7.2 *Fungicide Coatings*—Fungicides applied as seed coatings provide a chemical barrier between the germinating seed and soil fungi. Stratified shortleaf pine seed germination and postemergence damping-off were reduced by dusting seeds with 50-percent thiram before sowing (Hamilton and Jackson 1951). The amount of fungicide adhering to seeds can be increased with such adhesives as methyl cellulose or latex. But while fungicides may reduce damping-off (Carlson and Belcher 1969), heavy dosages often reduce germination (Peterson 1970).

Because of the high costs of container production, fungicides must control diseases without sacrificing quick, vigorous germination. The four important southern pine species have different tolerances to fungicides (table 7-4). Loblolly and longleaf seeds are the most tolerant, and slash the most sensitive (Pawuk and Barnett 1979). Shortleaf seeds responded intermediately to the other species.

Captan and thiram (Arasan 42-S®) were the least toxic fungicides. Neither reduced germination of any of the four species, even when applied at 454 g ai/45 kg (16 oz ai/100 lb).

Table 7-3.—*Germination of southern pine seeds soaked for different periods of time of hydrogen peroxide (from Barnett 1976d)*

Hydrogen peroxide	Germination			
	Loblolly	Slash	Shortleaf	Longleaf
treatment	*percent*			
None	91	81	76	53
3 percent				
4 hours	87	82	82	36
8 hours	93	79	80	26
24 hours	93	50	67	27
48 hours	84	43	73	3
30 percent				
1/4 hour	88	83	82	49
1/2 hour	89	85	*75*	63
1 hour	*90*[1]	*84*	48	*77*
3 hours	44	75	7	54

[1]Percentages in italics represent germination at the maximum amount of recommended time.

Table 7-4.—*Maximum fungicide dosages for four southern pines (adapted from Pawuk and Barnett 1979)*

Fungicide[1]	Slash	Loblolly	Shortleaf	Longleaf
	grams ai/45 kg of seed			
Captan 50 WP	454	454	454	454
Arasan® 42-S	454	454	454	454
Terraclor® 75 WP	113	454	454	227
Demosan® 65 WP	113	454	454	227
Truban® 30 WP	57	227	454	454
Banrot® 40 WP	57	114	57	114
Dexon® 35 WP	57	114	57	227
Terra-Coat® SD-205, 25 WP	57	227	113	454
Mertect® 42 F	28	227	113	113
Benlate® 50 WP	28	113	57	57
Busan® 72 60 EC	0	113	57	113
Terra-Coat® L-205, 30 L	0	113	57	113

[1]Common names and chemical names for the fungicides can be found in American Phytopathological Society (1977).

7.8 Sowing Techniques

Sowing rates can be adjusted for poor seed lots. The National Tree Seed Laboratory in Dry Branch, Georgia, will test seed lots for a small fee. Germination tests require 600 seeds, but a complete analysis that estimates stratification requirements takes about 2,500 seeds.

7.8.1 *Number Per Container*—When seed lots have low germination, multiple seeding can reduce the number of vacant cavities. Containers with excess seedlings usually must be thinned. Tables prepared by Balmer and Space (1976) that use sowing rates and expected germination to predict the number of vacant and stocked cavities are useful in selecting sowing rates and in estimating how much thinning will be required.

For example, if germination tests show that expected germination is 70 percent, sowing two seeds per cavity can reduce the percentage of vacant cavities from 30 to 9 percent but will increase doubles to 49 percent. Sowing three seeds per cavity will further reduce vacant cavities to 3 percent but will increase double and triple to 78 percent. To help minimize these problems, Pepper and Barnett (1982) suggest consideration of a mixed sowing scheme. For instance, 30 percent of the containers could receive three seeds, 20 percent of the containers could receive two seeds, and the remaining 50 percent could receive one seed. Mixed sowing schemes are generally more cost-efficient than the standard constant number approach, and the vacuum seeders in use could be adjusted to seed approximately the mix desired. For the nursery manager who wishes to use this method, a user-oriented, interactive computer program is available, which determines an optimal sowing strategy based on the users' estimates of costs and overall germination and survival rates (Pepper and Hodge 1982). However, mixed sowing will still require some thinning and transplanting of germinants to approximate one seedling per container.

7.8.2 *Sowing Methods*—Methods of seed sowing vary from hand seeding or use of simple templates to elaborate electrical seeding devices. However, most container operations now use some type of a vacuum seeder. These consist of a seeding head with holes drilled to match the container arrangement. The head is connected to a vacuum cleaner or pump. Even the most efficient seeders occasionally leave blank containers, so it is desirable to visually check the cavities before the containers are moved to the greenhouse.

7.9 Seed Covering

Covering seeds with granite grit, vermiculite, or potting medium is recommended in many containerized seedling operations (Matthews 1971, VanEerden 1974, Wood 1974) to create a favorable environment for germination by keeping seeds moist, to help radicle orientation, and to reduce development of moss and algae on the medium surface.

The effect of covering southern pine seeds varies with the type of watering regime used and, to some extent, with fungicide coatings (Barnett 1978b). The most complete and rapid germination usually occurs when seeds remain uncovered and are watered by a misting system. When seeds are watered less frequently, covering is helpful in obtaining germination. The data in table 7-5 indicate that larger seeds can be covered to a greater depth than small ones. The beneficial effect of covering seeds that are not under a mist system is probably due to the mulching effect that retains moisture near the seeds.

Fungicide applications to slash seeds reduces germination when under the misting system (table 7-5). Untreated longleaf seeds that were hand watered had a lower germination than all other treatments. This tends to confirm Jorgensen's (1968) finding that thiram coating helps improve germination of covered longleaf seeds. Longleaf may react differently from the other species in this respect because its seedcoats are known to carry pathogenic *Fusarium* fungi (Pawuk and Barnett 1974).

7.10 Transplanting and Thinning Germinants

For maximum efficiency in the production of containerized seedlings, empty cavities must be avoided. Seed germination seldom reaches 100 percent, so containers will have empty cavities after germination is completed. Growers must decide on the best method to

Table 7-5.—*Variation in germination due to watering method, depth of cover, and fungicide application (from Barnett 1978b)*

Species	Depth of cover	Fungicide treatment	Watering method[1] Hand	Mist
	mm		----- *percent*[2]	-----
Slash	0	Untreated	60[3]	96
		Arasan®	74	85
		A. + latex	64	81
	6	Untreated	80	69
		Arasan	77	50
		A. + latex	72	44
	12	Untreated	67	26
		Arasan	56	26
		A. + latex	58	26
Longleaf	0	Untreated	38	76
		Arasan	61	77
		A. + latex	60	77
	6	Untreated	66	78
		Arasan	82	80
		A. + latex	73	79
	12	Untreated	80	75
		Arasan	81	73
		A. + latex	83	74

[1]Watering method: hand, about 2 times per day; mist, numerous times daily depending on environmental conditions.
[2]Percent germination at 28 days.
[3]Least Significance Difference (LSD 0.05) for germination percentages are 9.2 for longleaf and 21.2 for slash pine.

increase stocking. Their decision whether to multiple-sow and thin, single-sow and transplant, or to sow and accept initial stocking levels will depend on seed germination, labor costs, and possible long-term effects on field performance. Regardless of the seed sowing regime, there will remain some blank and multiple-sown cavities. Hence, the great interest in operational methods for planting germinated seeds.

7.10.1 *Transplanting*—If the percentage of cavities with ungerminated seeds is between 5 and 15 percent, transplanting of germinants from cavities with multiple germinants or from germination flats is a feasible alternate. Up to 5 percent blank cells 4 weeks into the rotation will have little practical effect on costs. If more than 15 percent of the cells are empty, the short fall should be made up by sowing additional containers.

Pawuk (1982) studied the effect of transplanting on initial seedling growth and development. His evaluations involved transplanting germinants with different lengths of radicle development; 1.5 to 2.0 cm, 3.0 to 3.5 cm, and 4.5 to 5.0 cm (0.6 to 0.8 in, 1.2 to 1.4 in, and 1.8 to 2.0 in). All transplanting was done carefully so as to avoid injury to the tender radicles. Earlier observations had shown that damage to the radicle, such as the tip being broken, would slow root development and seedling growth and should be avoided. Transplanting longleaf pine germinants, regardless of their radicle length, was detrimental to subsequent diameter growth compared to nontransplanted controls (table 7-6). Total dry weight of both longleaf and shortleaf pine seedlings at 15 weeks was directly and significantly related to radicle length when transplanted. Control seedlings were heaviest, with the average weight about double that of transplants with short radicles. Heights of shortleaf pine seedlings at 15 weeks were also directly related to radicle length at the time of transplanting, with control seedlings tallest (table 7-6). After transplanting, only seedlings originating from germinants with the shortest radicles were significantly smaller than those from all other treatments.

The importance of careful timing when replacement seedlings are transplanted into empty cavities is clearly shown. Seedlings established by sowing were 1 to 2 weeks older than seedlings established by transplanting. This age difference accounts for the larger size of the control seedlings. Likewise, seedlings from transplants with long radicles were probably older than those from transplants with short radicles. Transplanting should be done as soon as an empty cavity becomes evident. This determination is possible about 10 to 14 days from sowing. At that time, replacements with short radicles would be easier to transplant without damage than seedlings with long radicles. If transplanting is delayed much beyond that time, germinants with longer radicles should be used because smaller seedlings are quickly suppressed at dense stockings.

7.10.2 *Thinning*—If cavities are multiple-sown, then a decision on whether or not to thin must be made. Thinning should be completed as soon after germination occurs as is feasible to minimize the effects on seedling development.

The short-term effects of leaving multiple seedlings in container cells have been evaluated with longleaf, loblolly, and slash pine (fig. 7-5). The most marked

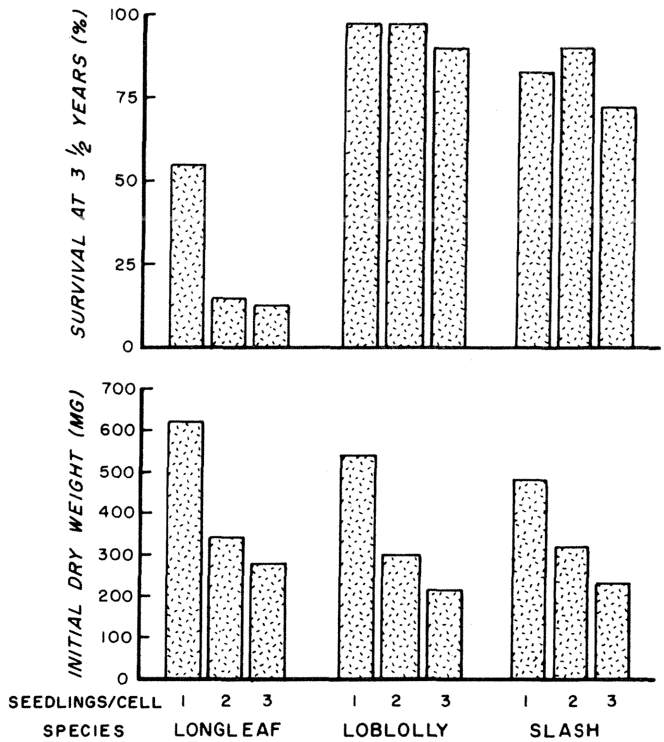

Figure 7-5.—*Initial seedling development 14 weeks after sowing in Styroblock-4 containers and field performance after 3-1/2 years.*

effect was on seedling development, measured as dry weight at the end of the 14-week greenhouse growing period, where multiple seeding reduced seedling dry weights by one-half or more. The smaller, multiple-grown seedlings had poorer survival compared to those grown with only one seedling per cavity.

Longleaf pine seedlings were more seriously affected by multiple seeding than loblolly or slash seedlings. The effects of multiple sowing were less drastic with slash and loblolly pine. But even with these species, initial seedling development was reduced by multiple seeding if no thinning occurred. Although there are no significant size differences among treatments after 3 years in the field, differ-

Table 7-6.—*Effect of radicle length at time of transplanting on growth of longleaf pine and shortleaf pine seedlings after 15 weeks (adapted from Pawuk 1982)*

	Longleaf pine		Shortleaf pine	
Radicle length	Root-collar diameter	Dry weight	Height	Dry weight
cm	*mm*	*mg*	*cm*	*mg*
1.5 - 2.0	1.12 a	168 a[1]	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
Seeded (control)	1.48 b	342 d	9.93 b	280 c

[1]Means in vertical columns followed by the same letter are not significantly different.

ences become greater each year, i.e., slash seedlings in the one-per-cavity treatment were 3 percent taller than in the three-per-cavity treatment after 1 year but 8 percent taller after 3 years in the field.

No long-term data are available on the effects of planting containers with multiple seedlings; however, results from 15-year-old multiple-seeded spots in direct seeding tests give an indication of the effects (Campbell 1983). Leaving two or more seedlings per spot caused a significant reduction in height and diameter. The effects on container plantings will be even more adverse, because with multiple seedlings per container, each seedling is smaller when outplanted than where there is a single seedling per container.

As a general recommendation, the grower should (1) use only the best quality seed 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.

8. GREENHOUSE ENVIRONMENTAL CONTROLS

Detailed descriptions of greenhouse equipment and facilities to maintain specified environmental conditions for germination and seedling growth will not be given here. Tinus and McDonald (1979) have provided this information. However, the environmental conditions resulting in best germination and seedling performance will be reviewed for the southern pine species.

8.1 Germination Period

Germination depends on adequate light, moisture, and favorable temperatures. The lack of optimum conditions for germination 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.

8.1.1 *Light*—It has been well documented that southern pine seeds require light for germination (Nelson 1940, Toole and others 1962, McLemore 1971). However, the intensity of light is relatively unimportant. Slash and loblolly pine seeds germinate as well at 1600 lux (150 footcandles) as at 3200 lux (300 footcandles)(Jones 1961). It is the length of the light period that is important. When the photoperiod is increased from 8 to 16 hours, germination of loblolly pine seeds increases (fig. 8-1), but slash pine germinates about the same under 8-, 12-, and 16-hour light exposures. The adverse effect mentioned in section 7.9 of deep covering on germination is probably largely due to the lack of sufficient light penetration of the medium (Barnett 1978b).

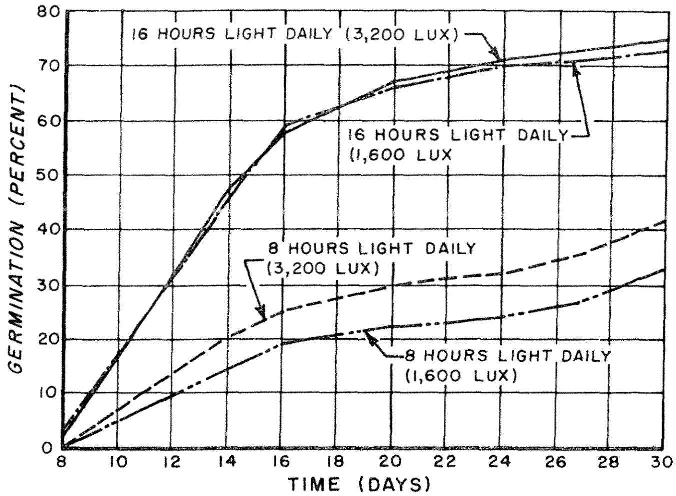

Figure 8-1.—*Germination of loblolly pine seed under 8-hour and 16-hour light regimes and two light intensities (from Jones 1961).*

The quality of light can be an important consideration. Wave lengths in the red spectrum (660 nm) are known to promote germination of southern pine seeds, while those of the far-red (730 nm) length inhibit germination (Toole and others 1962, McLemore 1971, McLemore and Hansbrough 1970). The red wave lengths are in sufficient quantity in sunlight, incandescent, and fluorescent light, so artificial lighting has no detrimental effect on germination.

8.1.2 *Moisture*—Containers must be watered frequently during the germination period. The watering system must keep the seeds in contact with a moist medium. When using a misting system, the mist should not be so light as to allow the potting mixture to dry at the bottom of the container. The condition of the sky, outdoor temperatures, and location in the greenhouse will affect the frequency required to maintain an ideal condition for germination. For these reasons, controls for watering systems that reflect environmental changes, such as the Mist-A-Matic® control (Geiger 1960), are more desirable than time clocks that water on a predetermined schedule regardless of need. If there are considerable minerals in the water, controllers must be cleaned frequently with acid to avoid calibration changes.

During the germination period, it is important that the moisture content of the potting mixture remains near field capacity. Any moisture stress beyond −2.5 bars (−250 kPa) reduces germination of southern pines (Barnett 1969b). Germination of longleaf pine is better than slash pine seeds at moisture stresses of −8 to −14 bars (−800 to −1400 kPa).

8.1.3 *Temperature*—Even though Wakeley (1954) suggests some limits for germination of the major southern pines, definite temperature effects are not known. McCulley (1945) did note that temperatures above 27 °C (80 °F) were detrimental to germination of longleaf pine seeds. Knowledge of the maximum temperatures for germination of pine seeds becomes a necessity because of the need to germinate seeds under greenhouse conditions where temperatures may be quite high.

Germination responses of southern pine seeds to temperature vary by species, seedlot, and the use and length of stratification (Barnett 1979b). Longleaf pine seeds have no stratification requirement, but unstratified seeds germinated well only at 18 °C (65 °F) and 24 °C (75 °F), (fig. 8-2). The responses of loblolly, slash, and shortleaf seeds to temperature are similar (fig. 8-2). The temperature at which unstratified seeds of the three species reached peak germination was 24 °C (75 °F). Unstratified slash pine seeds were less affected by temperature extremes than loblolly or shortleaf seeds. Slash pine seeds have a wide range, 18 to 29 °C (65 to 85 °F), at which germination was greater than 70 percent, the generally accepted minimum.

For loblolly, slash, and shortleaf seeds, stratification for either 28 or 56 days widened the range of temperatures at which a fairly uniform plateau of satisfactory germination occurred.

Because the above data were obtained under standard laboratory conditions with constant temperatures, these results cannot be applied directly to greenhouse conditions where temperatures fluctuate from day to day and during a 24-hour period. Additional evaluations were made with fluctuating temperatures that were more representative of greenhouse conditions. Longleaf pine was the only one of the four species that was adversely affected by temperatures alternating between 24 °C (75 °F) and 35 °C (95 °F) (table 8-1). These tests indicate that daily short periods of high temperatures may not reduce seed germination. Dunlap and Barnett (1982) found that exposures of loblolly and shortleaf seeds to periods of 35 °C (95 °F) up to 12 hours per day speeded germination without adversely affecting total germination. However, longleaf germination was reduced by this high temperature exposure.

8.2 Postgermination Period

8.2.1 *Light*—Photoperiod can either be lengthened or shortened, depending on the type of facilities available. Extending the photoperiod by the use of low-intensity light at intermittent intervals generally produces larger seedlings during the winter months when natural photoperiods are relatively short. Early bud set is prevented and longer internodes, increased size of foliage, and early change from primary to secondary needles can result from extending the photoperiod.

Limited data are available on the amount of response with southern pines from extended photoperiods. However, ponderosa pine seed sources from a latitude of 33° N, which is about the latitude of Dallas, Texas; Jackson, Mississippi; and Savannah, Georgia; are quite photosensitive (Tinus 1977). Both height growth and seedling dry weights were increased by treatments where the photoperiod was extended by incandescent lighting for 1 minute out of every 30

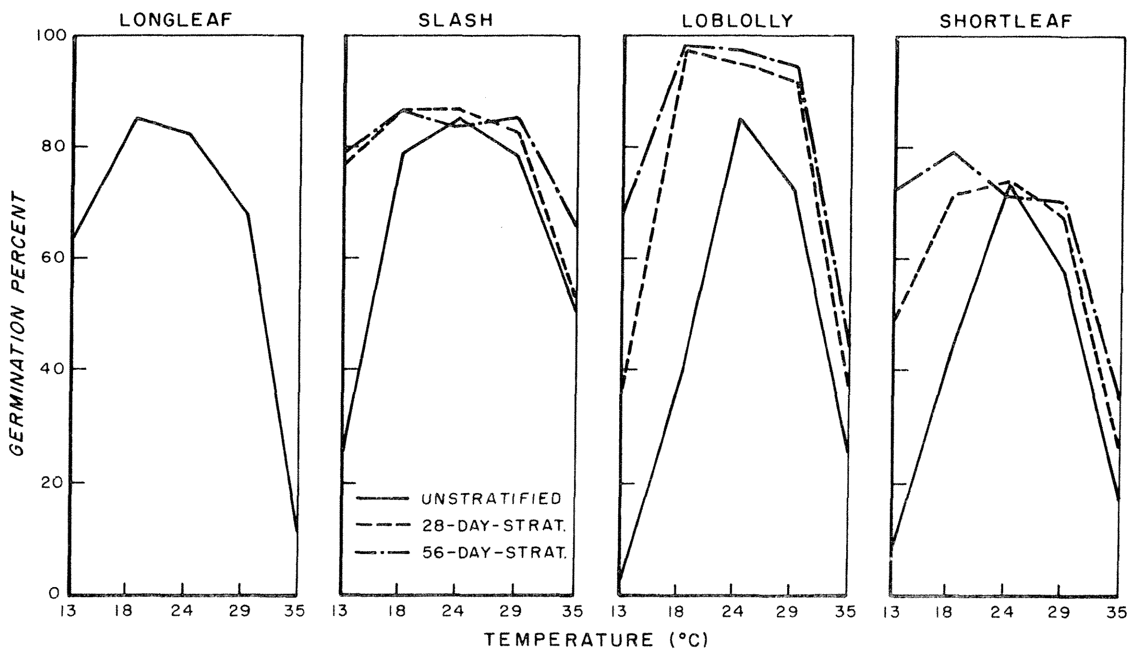

Figure 8-2.—*Germination of southern pine seeds at five temperatures following pregermination treatments (adapted from Barnett 1979b).*

Table 8-1.—*Germination of southern pine seeds at various temperature regimes*

Species	Seed stratified	Germination at Constant 24 °C	24–35[1]	Constant 35 °C
		------- *percent* -------		
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 and 6 hours at 35 °C.
[2]Means within species stratification treatments (across rows) followed by the same letter are not significantly different at the 0.05 level.

during the night at intensities of 270 lux (25 footcandles). One minute out of every 30 at 270 lux was as efficient at maintaining growth as continuous light at 1,200 lux (112 footcandles) (fig. 8-3). Height growth and dry weight of this southern source of ponderosa pine were found to be less dependent on long days than more northern sources of the same species (fig. 8-3, 8-4).

It is not necessary to have continuous light for extending the photoperiod. Having lights on for as little as 3 percent of the time during the night is effective provided that no dark period is longer than 30 minutes. Although photosensitivity varies somewhat by species, light intensities of 430 lux (40 footcandles) are generally sufficient (Tinus 1977).

Although lengthened days are important in preventing bud set and in maintaining seedling growth during the short photoperiods of winter, short days are important in developing cold hardiness. Some growers shorten the photoperiod by covering seedlings with black cloth part of each day during late summer or early fall. This technique stimulates early bud set and frost hardiness, but is difficult to do on a large scale. Reductions in both irrigation and fertilization are the most common techniques used for inducing seedling dormancy (see section 9.10). Frost hardiness can also be promoted by exposing seedlings to cool temperatures after buds develop.

The use of high-intensity light to increase photosynthesis for better growth in the short-photoperiod winter months is biologically feasible, but it has become impractical from an energy standpoint. Minimum light intensity necessary to produce good growth from increased photosynthetic activity is about 5,400 to 10,800 lux (500 to 1,000 footcandles) (Tinus and McDonald 1979).

Several types of lighting are now available for greenhouse operations. A combination of cool-white fluorescent and incandescent lamps has been considered the best to supplement sunlight in greenhouses. Recent work has shown that high intensity discharge lamps such as the sodium type are more effective for starting plants (Anon. 1977b). However, this type of lighting is advantageous only when the purpose of the supplemental light is to increase growth by maintaining high light intensities. They are not suitable for cyclic lighting because they require 5 minutes to start and cannot be conveniently used in short-duty cycles (Tinus and McDonald 1979). For extending the photoperiod, incandescent lamps provide the desired spectral qualities, are inexpensive to install, and can be turned on and off frequently without loss of bulb life. Incandescent lamps are not as economical to operate as some other types of lamps, but their other characteristics make them advantageous.

8.2.2 *Moisture*—Overhead spray systems are the most frequently used watering system for commercial growth of tree seedlings. Fixed overhead sprinklers

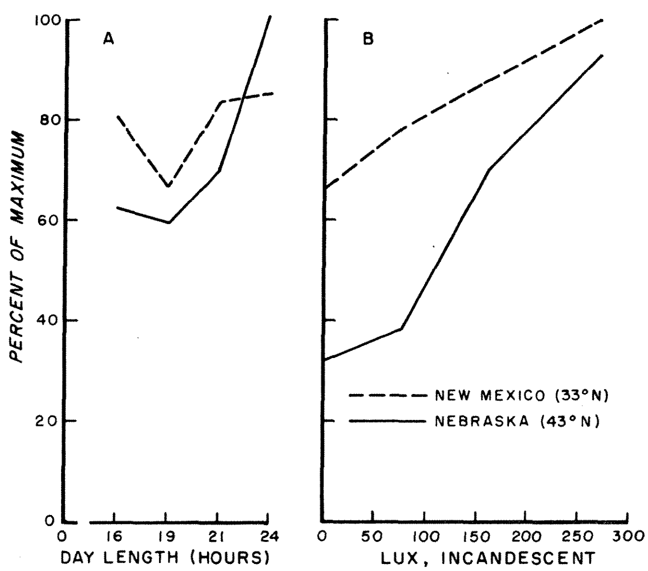

Figure 8-3.—*Height growth response of ponderosa pine from Valentine, Nebraska, and Ruidoso, New Mexico, to different durations of continuous incandescent light at night at 1,200 lux (A) and different intensities of incandescent light given 1 minute out of every 30 throughout the night (B) (adapted from Tinus 1977).*

are the most common and consist of four types—fixed overhead, rotating, oscillating, and spray stake. The main problem of the fixed systems is lack of uniform coverage. Traveling boom units generally result in more uniform coverage. They are also much more expensive. Because of the lack of uniform drying conditions, some supplemental hand watering will be necessary with almost any watering system.

An important part of the watering system is a feeder mechanism for applying nutrients, fungicides, and other chemicals. Several types are available and the size of operation and type of watering system influences selection of the feeder. Proportional feeders with water-to-chemical ratios of 100:1 to 200:1 are commonly recommended.

The method of watering during the postgermination period differs from that used during germination. Heavy, infrequent waterings should characterize the postgermination period (see section 9.1.1). This allows the surface of the medium to dry between waterings and reduces the chance of damping-off. Less frequent waterings also reduce the water content of the medium, which increases the amount of aeration, absorption of minerals, and root growth.

8.2.3 *Temperature*—Extremes in temperature are not much of a problem once the seedlings become several weeks old. Because greater fluctuations in temperature can be tolerated once seedlings begin rapid growth, less environmental control of the greenhouse facilities is required. During the frost-free period of the year (see section 4.1.3), southern pine seedlings 4 to 5 weeks old can be moved into nonenvironmentally controlled facilities for the remaining period of growth. Generally these facilities should be covered with transparent fiberglass or something similar so that the amount of water the seedlings receive can be controlled.

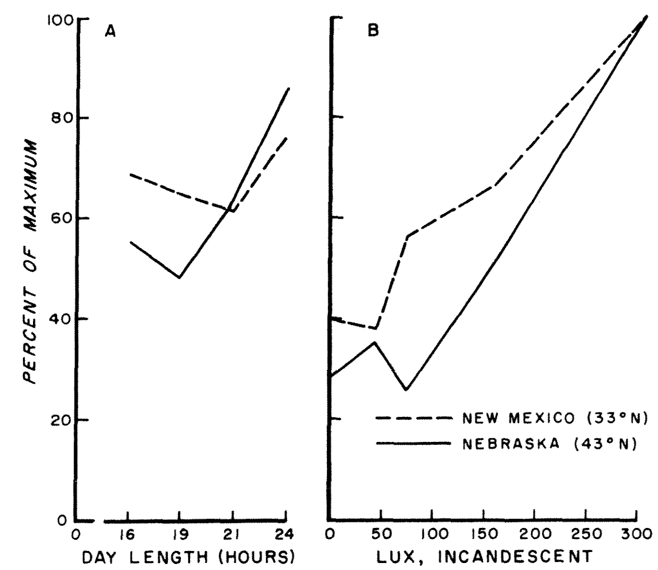

Figure 8-4.—*Dry-weight growth response of ponderosa pine from Valentine, Nebraska, and Ruidoso, New Mexico, to different durations of continuous incandescent light at night at 1,200 lux (A) and different intensities of incandescent light given 1 minute out of every 30 throughout the night (B) (adapted from Tinus 1977).*

If seedlings are to be produced during the winter, a heated greenhouse will be required. Heat can be provided either overhead or under the seedling benches. Greenhouses must also be cooled during warm weather to provide optimum growing temperatures. The evaporative cooling that is most often used in greenhouses utilizes exhaust fans and wetted pads or lava rock; shading can also be used to help maintain cooler temperatures. Tinus and McDonald (1979) provide a thorough discussion of various sytems of greenhouse heating and cooling. The cultural and economic aspects of various greenhouse energy conservation measures are discussed by Cameron (1982).

8.2.4 *Carbon Dioxide*—Carbon dioxide (CO_2) is necessary for plant growth. The ambient level of CO_2 in the atmosphere is about 325 ppm. Tinus (1972) has shown that CO_2 enrichment up to about 1,500 ppm can result in increased plant growth. Raising the CO_2 level above the ambient level can be accomplished in a greenhouse by burning natural gas or propane, and small CO_2 generators are readily available from nursery supply houses. However, it is practical and efficient to raise the CO_2 concentration only during daylight hours and only when the greenhouse vents are closed (Tinus and McDonald 1979). This limits CO_2 generation to periods during the winter months when greenhouse venting systems remain closed due to cold weather. Fortunately this is when growth is normally the slowest and thus the need for growth stimulation is the greatest. The usefulness of increasing CO_2 levels has not been demonstrated in the southern latitudes, probably because climatic conditions limit the amount of time the technique is practical. However, CO_2 generation is fairly inexpensive and it may be practical for a few morning hours each winter day. Tinus and McDonald (1979) describe several ways to generate CO_2. The most practical is an inexpensive gas generator (fig. 8-5). For a greenhouse of average tightness, 245 joules of gas burned per square meter (2.5 Btu/ft^2) of greenhouse space yields about 1,000 ppm CO_2.

9. CULTURAL TECHNIQUES

Many of the cultural techniques necessary to optimize growth of the southern pines remain to be refined. However, sufficient information is available to produce high quality seedlings in a reasonable length of time.

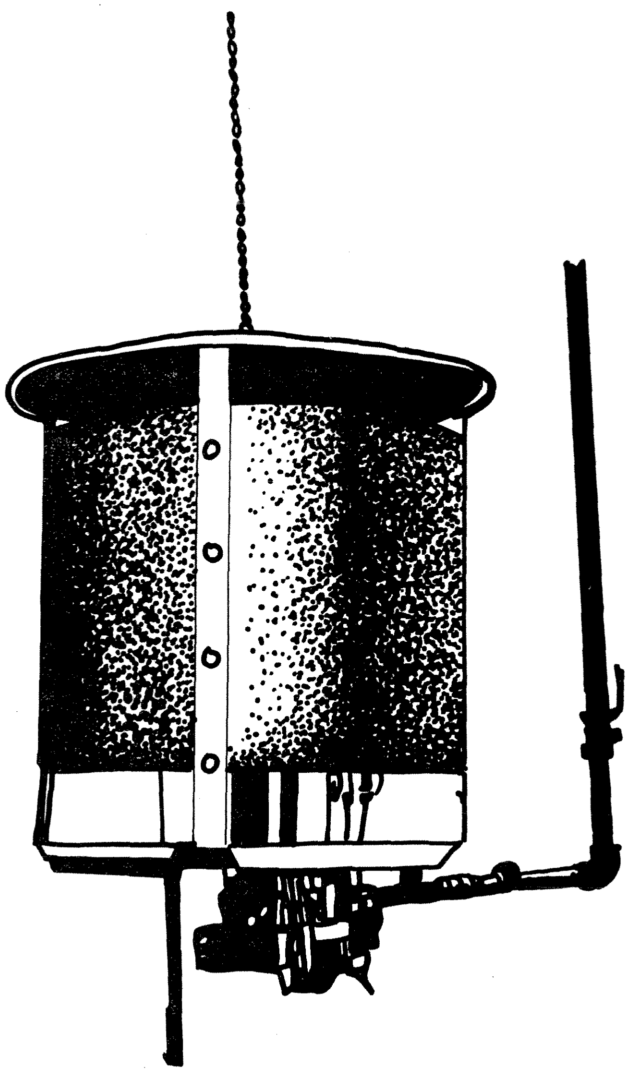

Figure 8-5.—*Inside ceiling-mounted gas CO_2 generator (from Ekblad 1973).*

9.1 Maintaining Proper Moisture and Temperature

One of the most critical factors in the day-to-day growing operation is maintaining proper moisture of the potting medium.

9.1.1 *Moisture Content for Optimum Growth*—The watering schedule should keep the moisture contents of the potting medium near field capacity at all times during the active growing phase. This will result in optimum growth if other factors such as nutrients or temperatures are not limiting. An important consideration in watering is aeration of the medium. The mix texture itself determines how much oxygen is available for root respiration at a particular watering level—larger sized particles increase porosity.

The symptoms of poor aeration, which is caused primarily by overwatering, include needle chlorosis, inhibition of shoot and root growth, and even death when overwatering is severe and prolonged (Kozlowski 1975).

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. 9-1). The seedlings were grown in 6-inch plastic pots filled with a 1:1 peat-vermiculite medium. Different moisture levels were maintained by weighing the pots and adding sufficient water twice weekly to keep the media near the prescribed moisture levels. Moisture contents between 300 and 500 percent (dry-weight basis) resulted in the best seedling development. Moisture contents higher or lower than this adversely affected seedling growth. Generally, shoot-root ratios increased as the moisture content of the potting medium increased. Such gravimetic measurements are too time consuming for everyday use, but they are very helpful when calibrating other methods.

Medium moisture content can readily be evaluated using the weighing method (McDonald and Running 1979). Weighing seedling containers is a useful irrigation monitoring practice. When the weight of a filled container declines to some predetermined percentage of the saturated weight, the crop is watered. This percentage is often around 75 to 80 percent of the saturated weight, depending on the type of container.

Once the seedlings become large, the pressure chamber is the quickest, most foolproof method of measuring water stress in seedlings (Scholander and others 1965). A sample seedling is cut at the root collar and placed in a steel chamber with the cut end protruding from the top (fig. 9-2). By slowly applying pressure to the seedling in the chamber, water will be forced back to the cut surface by a pressure equal to the tension originally in the plant.

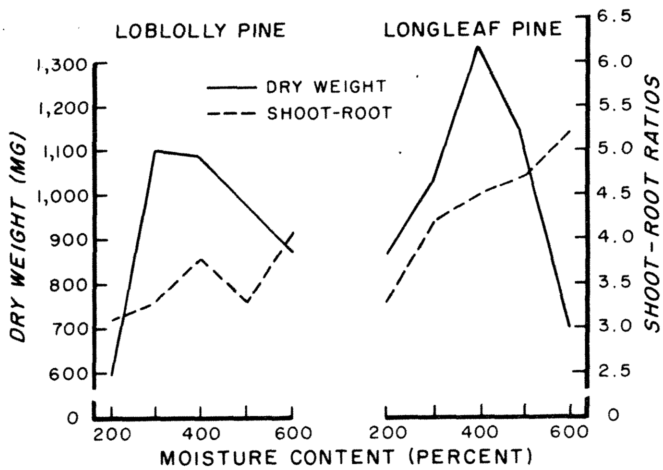

Figure 9-1.—*Oven-dry weights and shoot-root ratios of loblolly and longleaf pine seedlings grown at various moisture levels of the potting medium (1:1 peat vermiculite).*

Certain precautions are important when using the pressure chamber (McDonald and Running 1979). First, the sample should be measured within 1 minute or wrapped in a wet paper towel and sealed in a plastic bag until measured. Second, the pressure should be increased slowly at about 1 bar (15 lbs/in^2) per 5 seconds. Third, it is best if the size of the cut sample is consistent. Fourth, the cut end should not protrude more than 1 cm (0.39 in) from the gasket. See section 9.10.1 for further details on water stress relationships.

9.1.2 *Temperatures*—Many studies have involved a search for specific optimum temperatures for growth. The complex relationships between temperature and growth makes the determination of optimum temperatures difficult to pinpoint. Heat energy is not used directly by plants for growth, but controls the rate at which chemical energy is made available for growth (Went 1957). The relationship is further complicated, because growth is a result of a multitude of processes that are undoubtedly affected somewhat differently by particular temperatures. Various phases of a temperature regime have been found to affect growth, such as day and night temperatures and the differences between them. Information available on how the relationships affect growth of southern pines is limited. Kramer (1957) subjected 1-year-old loblolly seedlings to various day and night temperature combinations. He reported that growth of shoots increased with increasing day temperature and decreased with increasing night temperatures. 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 between day and night temperatures.

Perry (1962) also reported a general increase in height growth of loblolly seedlings with increasing day temperature. Growth with a day temperature of 23 °C (74 °F) was lowest when the night temperatures were in the range of 20 to 26 °C (68 to 79 °F) and highest for nights in the 10 to 17 °C (50 to 63 °F) range. In one of the most extensive studies of temperature effects on loblolly seedling growth, Greenwald (1972) took data at 6 and 9 months of age on height and shoot and root dry weights. His results indicate maximums in height, shoot dry weight, and total dry weight when the day temperature ranged from 17 to 26 °C (63 to 79 °F) and night temperature ranged from 17 to 23 °C (63 to 73 °F). The 23/17 °C (73/63 °F) day/night degree combination produced maximum height growth and shoot dry weights, with a rapid decrease through 26/20 °C (79/68 °F) to a low value at the 29/23 °C (84/73 °F) combination.

Results by Mulroy (1972) and Bates (1976) with younger seedlings of loblolly pine indicate that the temperature relationships may differ with seedling

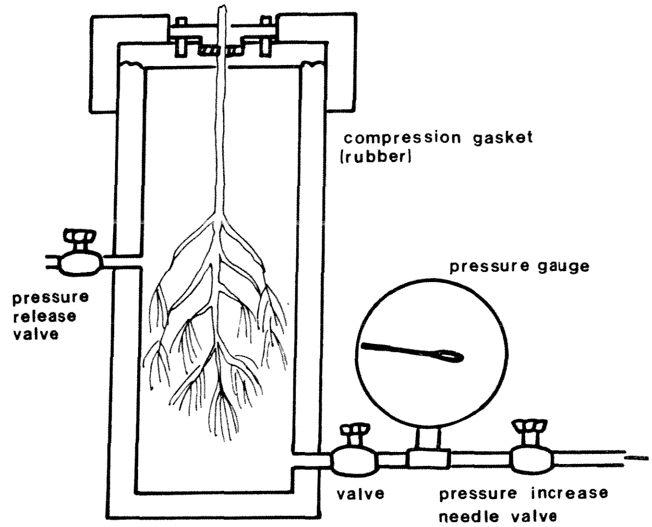

Figure 9-2.—*Diagram of a pressure chamber (modified from McDonald and Running 1979).*

age. Young plants in warmer greenhouses grew more rapidly, elongated earlier, and had longer stems. Bates (1976) suggests that containerized loblolly seedlings grown for periods of about 12 weeks should be grown for 4 to 6 weeks at the warmest combination (29/23 °C or 84/73 °F day/night temperatures), followed by 26/20 °C (79/68 °F) or 26/17 °C (79/63 °F) regimes for the remainder of the greenhouse period. This would take advantage of the fast start, but would reduce shoot growth while maintaining high total weight production. However, none of the day/night temperatures were clearly superior in producing containerized loblolly seedlings.

Bates (1976) has reported the effects of varying day/night temperature combinations on development of container-grown longleaf pine seedlings. He evaluated the effects of the temperature combinations at 30 and 60 days. Results from the 30-day evaluations indicated that shoot growth and total dry weight increased with both day and night temperature, especially when the temperature difference was 6 degrees (fig. 9-3 and 9-4). The 26/20 °C (79/68 °F) and 29/23 °C (84/73 °F) regimes produces the tallest shoots. The 23/17 °C (73/63 °F) combination resulted in high dry weights.

The results of Bates' (1976) evaluations of 60-day longleaf seedlings followed the same trends, except there was a tendency to shift away from the highest day temperatures and toward the 23 °C (73 °F) days for greatest shoot growth (fig. 9-5). The 23/17 °C (73/63 °F) regime produced the greatest total dry weight (fig. 9-6) and appeared to be the best combination for growing containerized longleaf seedlings. This temperature regime favored development of all the desired characteristics for successful handling and

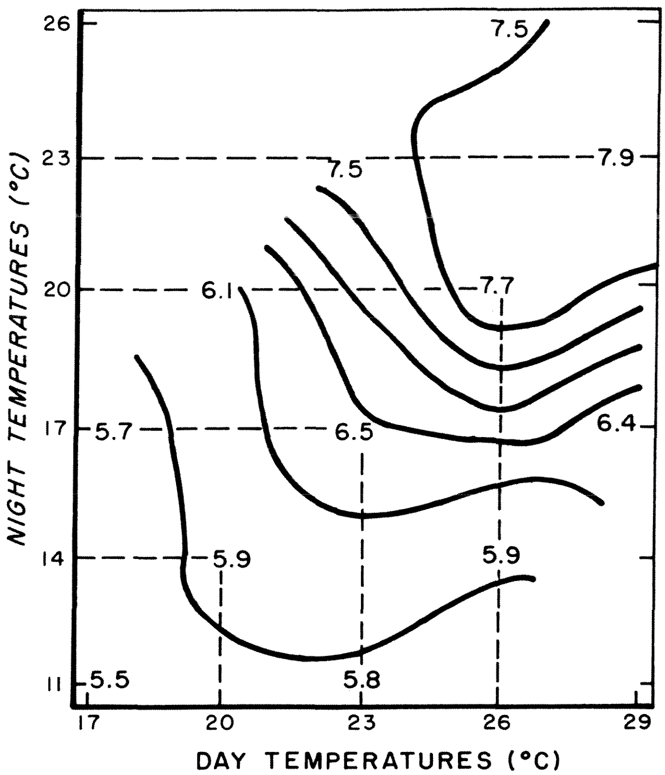

Figure 9-3.—*Computer generated contours of longleaf seedling heights in cm for each discrete temperature combination (sampled at 30 days); the range within each contour is 0.336 cm.*

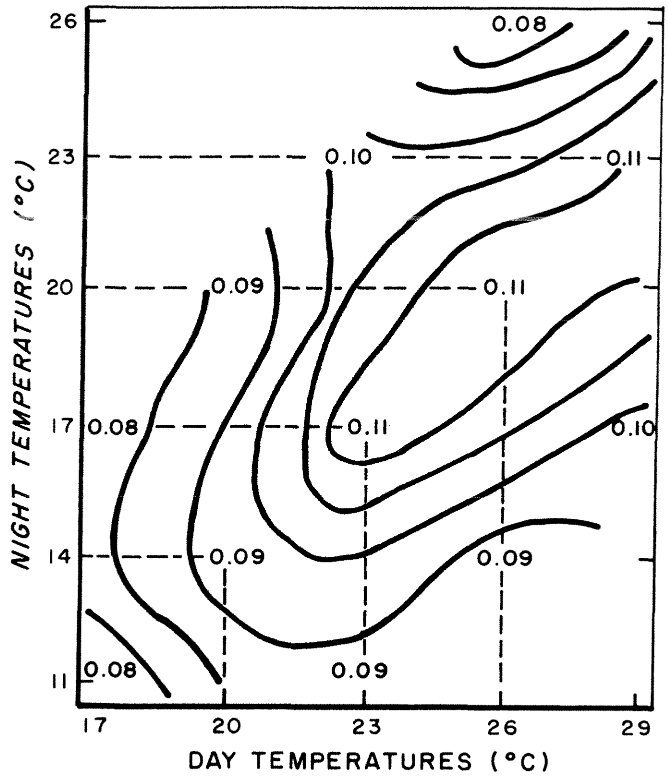

Figure 9-4.—*Computer generated contours of longleaf seedling total dry weights in grams for each discrete temperature combination (sampled at 30 days); the range within each contour is 0.0052 g.*

planting. While warmer temperatures resulted in better top appearance, weaker and finer roots were produced.

Between 6 and 10 weeks of age, optimum day temperatures for longleaf seedlings shifted from 29 °C (84 °F) to 23 °C (73 °F). The 23/17 °C (73/63 °F) regime was the best overall combination.

The optimum temperatures for containerized loblolly seedlings according to Bates' (1976) work is a 29/23 °C (84/73 °F) day/night regime. This is quite different from the data of Greenwald (1972), who measured seedlings more than 6 months old. The differences between these results may be due to changes in environmental responses during seedling development. Apparently, as seedlings develop there is a shift in the temperatures that are optimum for growth.

9.2 Disease Control

Pathogens that cause diseases of southern pine seedlings in bare-root nurseries can cause similar diseases when seedlings are container-grown. Fortunately, not all diseases found in bare-root nurseries have been problems in container seedling culture. The greenhouse environment in which most container seedlings are grown differs greatly from the bare-root nursery, and disease development in container nurseries may be more rapid and intensive. Also, the relatively high cost of carrying blank cells makes disease loss more serious on a seedling basis than in bare-root nurseries, where some seedling losses are accepted.

While the greenhouse environment can create problems, the nursery manager is able to control the environment much more than when seedlings are grown outside. He can regulate temperature, humidity, soil moisture, and soil fertility to a great extent. Pesticides can be applied effectively to control diseases and insects.

To control disease losses, a thorough understanding of the pathogens and the conditions necessary for infection is essential. The problems of seedborne diseases are probably greater in greenhouse operations than in nursery beds. These diseases and their control were discussed in chapter 7. The discussion here includes diseases commonly referred to as damping-off or root rot, caused by fungi present in the growing media. It includes those that may in a strict sense be water-borne, being introduced into the soil by contaminated irrigation water.

9.2.1 *Soilborne Diseases*—Species of *Fusarium,* especially *F. moniliforme,* are the fungi most commonly cultured from diseased seedlings and growing media

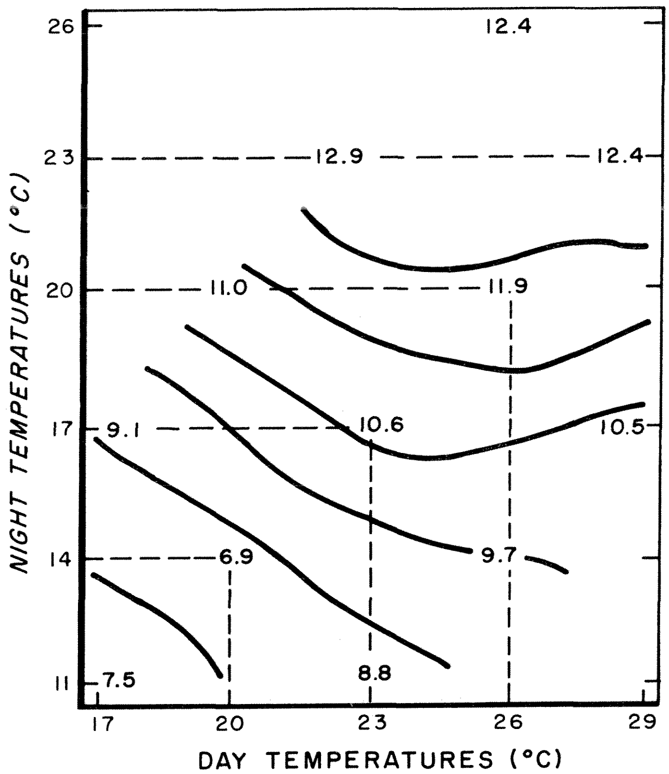

Figure 9-5.—*Computer generated contours of longleaf seedling height in cm for each discrete temperature combination (sampled at 65 days); the range within each contour is 0.77 cm.*

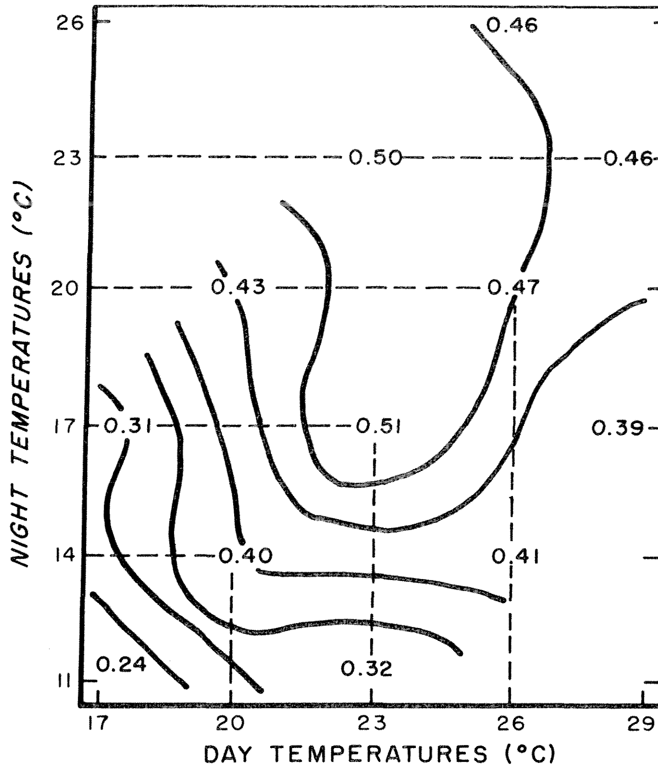

Figure 9-6.—*Computer generated contours of longleaf seedling total dry weights in grams for each discrete temperature combination (sampled at 65 days); the range within each contour is 0.038 g.*

(Pawuk 1982). Attempts to culture *Fusarium* from potting mixes prior to sowing have been unsuccessful. This indicates that it becomes established and develops after containers are placed in the greenhouse.

Pawuk (1982) cultured *Fusarium* from air and water samples in and around greenhouses, but always at low levels. While these sources cannot be ruled out, spread from infected seedlings during watering is probably the most important source. *Fusarium* can often be seen producing abundant spores on infected seedlings. It spreads to the soil where there is a buildup of *Fusarium* with time. Fortunately, seedlings become more resistant to infection as they mature.

Rhizoctonia has been observed on container-grown longleaf pine seedlings. In all cases it developed during periods when seedling foliage was wet for extended periods. Its spread is from seedling to seedling, and the mycelium is clearly visible. The source of *Rhizoctonia* is not known. It is a common soil fungus that spreads in nature by movement of infected soil or plant debris from one area to another. It could easily be brought into greenhouses, as could other soil fungi, by workers or on tools and equipment. *Rhizoctonia* has been observed attacking seedlings in germination trays in the seed testing lab (Pawuk 1982).

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 can be reduced.

Some cultural practices can go a long way toward preventing disease loss. Media should be pathogen free from the start. It should be well drained and seedlings should not be overwatered. Equal parts of peat and vermiculite can be mixed to make a growing medium that combines high cation exchange capability, good moisture retention, and low pH (Phipps 1974). Commercial media are available but most of these were developed for other crops and have a high pH. Growth may be acceptable, but disease development is favored.

Inoculation studies on longleaf seedlings by Pawuk (1981) using *Pythium* and *Fusarium* compared disease development using several media. The best growth of seedlings was with equal parts of peat and vermiculite (table 6-1). Less growth but better disease control was achieved using pine bark, pine bark-vermiculite, or pine bark-soil (see section 6.1). Commercial peat-vermiculite, or pine bark-vermiculite mixes that have higher pH's, had the greater disease incidence.

9.2.2 *Fungicide Treatments*—Several fungicides are available that will control damping-off and root rot if applied correctly. There is no one fungicide cure-all that gives protection against all pathogens.

Pawuk (1982) tested several fungicides for control of *Fusarium* and *Pythium*. The best results were with Benlate® for *Fusarium* and Truban® for *Pythium* at rates recommended on the labels. When applied correctly, they give good disease control without phytoxicity.

During studies with Benlate, applications were made immediately following sowing, with no loss in germination. Truban was not tested this way because it had been found to reduce early seedling development in previous studies (Pawuk and Barnett 1974).

Fungicides affect mycorrhizal development. Responses vary with fungicides and mycorrhizal symbionts. Not much work has been done with southern pines, but some data are available. Pawuk and others (1980) tested the effect of several fungicides on the development of ectomycorrhizae on longleaf seedlings grown in pine bark media. The mycorrhizal fungus, *Pisolithus tinctorius* (Pers.) Coker and Couch was completely inhibited by Terraclor®, reduced by Captan® and Dexon®, not affected by Mertect® and Truban, and stimulated by Benlate and Banrot®. *Thelephora terrestris* (Ehrh.) Fr. was greater on seedlings drenched with Banlate, Mertect, and Dexon than on the control. Terraclor and Truban reduce *T. terrestris*. Seedlings drenched with Terraclor had poor lateral root development suggesting that repeated use of this fungicide should be avoided in container nurseries.

Additional tests found that shortleaf pine seedlings grown in peat-vermiculite and drenched with Benlate formed more mycorrhizal roots than undrenched seedlings (Pawuk and Barnett 1981). *Pisolithus* formed best at the highest level tested, 10 mg of Benlate per seedling every 2 weeks, which also produced the largest seedlings.

Marx and Rowan (1981) reported that drenches of Benlate and Captan increased mycorrhizal development by *P. tinctorius* and *T. terrestris* on loblolly pine seedlings in a bare-root nursery. Terraclor had no effect on either symbiont, but Benodanil® decreased infection by *P. tinctorius*. In this study, two drenches were made in early spring, so the effect of repetitive dosages was not tested.

9.2.3 *Foliage Diseases and Rusts*—Foliage diseases have not been a problem on container-grown southern pine seedlings. This is probably due to the short period necessary to grow plantable seedlings and to the absence of prolonged periods when foliage is wet. The same can be said for the rusts, although, even if seedlings were infected with *Cronartium* rusts, the symptoms would probably not be observed before they were shipped.

It is a good idea to take certain precautions that should keep the probability of rust infections to a minimum. Spraying with fungicides to prevent rust infection is not necessary in closed greenhouses. However, during the spring, seedlings should be watered early in the day so foliage is dry by night. This is especially true during wet weather when rust spores are released. Pawuk (1982) 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 during the night to favor rust infection. Infection was only 3 percent compared to 65 percent for seedlings similarly treated and grown in an adjacent open shade house. 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 the 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.

The systemic fungicide Bayleton® (triadimefon) is effective for control of fusiform rust caused by *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme* (Cumm.) Burds. & Snow in pine tree nurseries. Bayleton has been tested as foliar sprays and seed soaks on pine for both protective and curative control of fusiform rust (Mexal and Snow 1978, Snow 1978, Snow and others 1979).

Normally, seedlings are susceptible to fusiform rust during the rust hazard season from early March until the first week in July. However, foliar sprays of Bayleton effectively control fusiform rust whether applied 2 weeks before or 2 weeks after inoculation (Rowan 1982).

9.3 Algae Control

Many blue-green and green alga species form on soil in containers used for growing containerized southern pine seedlings (Barnett 1978c). Ross and Purtich (1981) determined that most of such contaminants are not in the medium or water, but are airborne. When algae develops and dries, a crust develops, creating a barrier that interferes with irrigation, fertilization, and pesticide applications (Tinus and McDonald 1979). One effective algae control is a perlite or grit covering on the surface of the growing medium. However, this may affect seed germination (section 7.9), and chemical control of algae may be desirable.

Chemicals that control algae in water or on the surface of the potting soil are not labeled for soil treatments, so the greenhouse manager has no guidelines for selecting appropriate chemicals to treat the soil. A greenhouse screening study evaluated 11 substances for controlling algae on soil in styrofoam containers used to grow shortleaf pine (table 9-1) (Pawuk 1983).

Algae formed a thick mat on soil in control plots and many treatment plots. Simazine® gave the best control but was toxic to shortleaf pine seedlings at all levels tested (table 9-1). Bordeaux mixture, Dichlone®, and Maneb® gave good control at one or more concentrations and were not phytotoxic. Dichlone and Maneb were more effective than Bordeaux mixture at low concentrations and were selected for further testing.

Pawuk (1983) reported that both Maneb and Dichlone reduced alga development (table 9-2). Alga control was better when fungicides were applied at both 3 and 8 weeks or once at 5 weeks than once at 3 weeks. There was an interaction between drench rate and fungicide. Maneb was better than Dichlone at 0.8 or 1.0 mg/cm^2 but not at 0.4 or 0.6 mg/cm^2. At each drench schedule, alga development decreased as Maneb concentration increased. This trend was not present in the Dichlone treatments.

Drenching increased height growth over the control treatment. Seedlings drenched with Maneb were significantly taller than those drenched with Dichlone, but they differed by only 0.7 cm. Height growth was unaffected by drench schedule but was affected by drench rate. Seedlings from the 0.4 mg/cm^2 treatment were smaller than those from the 0.8 or 1.0 mg/cm^2 treatment. None of the other treatments differed from each other.

Drench schedule or rate did not affect seedling dry weight, although all treatments resulted in heavier seedlings than the control. Seedlings drenched with Maneb were larger than seedlings drenched with Dichlone.

Neither Maneb nor Dichlone inhibited the growth of shortleaf pine seedlings, and growth was greater in many treatments, especially Maneb, than in the control. Maneb and Dichlone may have protected the seedlings from pathogenic soil fungi.

9.4 Pest Control

The location of the greenhouse facility may affect the type and severity of pest problems. For example, infestations of pales weevils may occur when the facility is near a mill complex.

9.4.1 *Weeds*—Where sterile growing media are used and tree seed is weed free, weeds in the containers are not a problem. Weed seeds can be drawn into the greenhouse through the ventilation system or carried in on workers' feet. This can be minimized by controlling weeds close to the greenhouse and through proper sanitation. The weed seeds introduced into the

Table 9-1.—*Alga control on potting soil[1] treated with 11 chemical substances (adapted from Pawuk (1983)*

Treatment	Alga control[2]			
	0.02[3]	**0.03**	**0.04**	**0.05**
Simazine®	0.8	0.0	0.0	0.0
	0.1	**0.2**	**0.3**	**0.4**
Dichlone®	1.8	1.2	0.8	0.5
Maneb®	2.8	1.2	0.8	0.2
Bordeaux mixture	4.0	3.0	2.0	0.8
Captan®	2.5	3.2	3.2	2.8
Sulfur	3.0	3.2	3.5	3.8
Zineb®	3.5	4.0	3.8	3.8
Copper sulfate	4.0	4.0	3.8	3.8
Kocide 101®	4.0	4.0	4.0	4.0
	0.5	**1.0**	**1.5**	**2.0**
Cutrine®	2.5	3.5	2.0	1.8
Clorox®	3.2	3.0	2.5	3.2
Untreated control		3.9		

[1]Potting medium consisted of peat/vermiculite (1:1) in Styroblock-2® containers.

[2]Alga control categories (measured at 10 weeks): 0 = no algae present, 1 = algae present but barely detectable, 2 = algae forming a pale thin film, 3 = algae forming a thin mat less than 0.5 mm thick, 4 = algae forming a thick mat greater than 0.5 mm.

[3]Numerals in bold type face are amount of chemical applied per surface area (mg/cm^2).

Table 9-2.—*Alga development and shortleaf pine seedling growth in containers drenched with Maneb and Dichlone (adapted from Pawuk 1983)*

Variables	Alga[1] rating	Seedling Height	Seedling Dry weight
		cm	*mg*
Material			
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[3]	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
Drench rate (mg/cm^2)[2]			
0.4	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]Alga control 0 = no algae present, 1 = algae present but barely detectable, 2 = algae forming a pale green film, 3 = algae forming a thin mat less than 0.5 mm thick, and 4 = algae forming a thick mat greater than 0.5 mm thick.

[2]An interaction among drench rates and materials occurred in the alga development data. Maneb was better than Dichlone at the 0.8 or 1.0 mg rates but not at the others.

[3]Mean separation in columns for treatment variable groupings by Duncan's Multiple Range Test, 0.05 level.

greenhouse will germinate in the containers or on the floor. Those that germinate and grow in the containers can be removed by hand. Greenhouses with gravel floors can develop a considerable growth of weeds on the floor. This is not only unsightly but also unsanitary. These weeds may harbor other pests. Because the weeds develop between and under benches, they may be hard to control manually. The gravel floors of greenhouses can be treated with non-volatile broad spectrum herbicides such as simazine. Apply them so that the tree seedlings are not contaminated.

9.4.2 *Rodents*—Exclusion of rodents from the greenhouse is important. The principal pests are mice, which can eat or cache large numbers of seeds from containers in a short time. They will also clip young succulent seedlings. The main defenses are construction of physical barriers, minimizing rodent cover near the greenhouse, and trapping or baiting. Areas around the greenhouse should be clean and free of debris or plants that will shelter or provide food for rodents. The greenhouse should be tightly constructed 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 (Tinus and McDonald 1979).

9.4.3 *Insects*—Most common insect pests, such as ants and caterpillars, are not serious pests in seedling culture. They can usually be controlled by sanitation, barriers, and baiting. Serious insect pests usually enter the greenhouse through the ventilation system. Under greenhouse conditions, these insects can reproduce rapidly and cause extensive damage. The most bothersome are aphids, whiteflies, scales, thrips, and mites. Large insects occur less frequently. They are more obvious, and are easier to identify and control.

If harmful insects are present, eradicate them with approved insecticides. In most cases, some limited use of chemical controls is needed despite the most careful avoidance measures. If management is alert and observant, the see-and-treat program should be best. The mode of application and chemical used should be designed for the target insect. Timing the application is also very important to achieve optimum effectiveness. Some approved insecticides are listed for the common insect problems in table 9-3.

9.5 Control of pH and Salts

The availability of minerals to the plant is affected by many factors. Two important ones are hydrogen ion concentration (expressed as pH level) and the cation exchange capacity of the medium. The effect of pH on nutrient element availability is shown in fig. 9-7. The optimum growth for most conifer seedlings occurs in the range of 5.0 to 6.0 (Kramer and Kozlowski 1960). In predominantly organic media, optimum pH may be somewhat more acid than with less organic soils (Lucas and Davis 1961). At increasing pH levels above 5.5, availability of phosphorus and manganese drop rapidly (fig. 9-7).

Limited data indicate that pH ranges within those normally encountered have little adverse effect on germination (table 9-4). Only at an extremely high pH is germination reduced, and then only on an inert medium. The peat medium buffered the high alkaline effects, and germination was less affected.

9.5.1 *Measurement of pH*—The pH is conveniently measured at two places: in the water applied and in

Table 9-3.—*Insecticides for greenhouse pests (adapted from Tinus and McDonald 1979)*

Type of insect	Chemicals for control	Remarks
Thrips	malathion, dieldrin, lindane, parathion, Sulfotepp®	Apply malathion and lindane frequently
White flies	pyrethrum, rotenone, nicotine sulphate, malathion	pyrethrum, rotenone and nicotine sulphate control nymphal stage
Scales	malathion, nicotine sulphate and soap	
Aphids	nicotine sulphate and soap, lindane, malathion, Sulfotepp, parathion, Thiodan	nicotine sulphate on warm days only; do not apply parathion before or after sulfur
Mites	sulfur, Aramite®, Dimite®, Kelthane®, Ovex®, malathion	

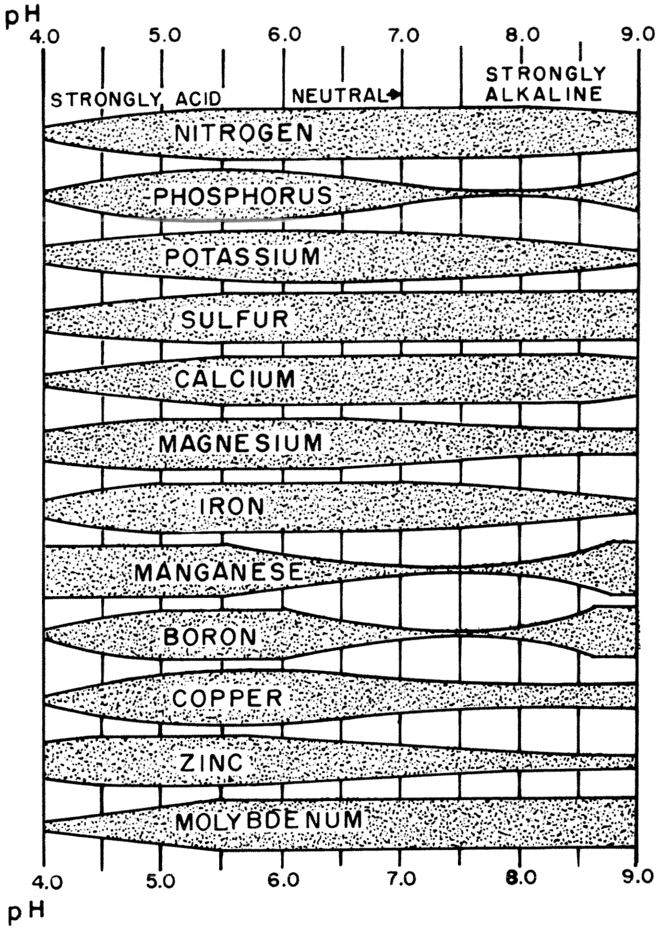

Figure 9-7.—*Influence of pH on availability of plant nutrients in organic soils—widest part of bar indicates maximum availability (adapted from Lucas and Davis 1961).*

the leachate from the bottom of the container. To provide an adequate supply of water to the trees and prevent salt accumulation in the containers, container tree seedlings should be watered enough to insure that water flows through the container during each irrigation. The method for monitoring pH suggested by Tinus and McDonald (1979) consists of:

1. Measuring pH of the nutrient solution applied.
2. Measuring pH of the "leachate" (water that runs through the growing medium and out the bottom of the container).
3. Comparing the two readings to make inferences about the pH of the soil solution in the growing medium at time of reading and as a trend over time.

This method avoids the usual method of soil pH determination, where dry soil is mixed with water in some standard proportion, allowing the mixture to stand for about one-half hour; then, while the mixture is stirred, potentiometer electrodes are inserted, and the pH is measured on the soil suspension (Jackson 1958). The standard procedure is difficult to use in tree seedling operations because of the small container volumes.

The difficulty of catching leachate from containers varies with the type of container. It is essential that the fluid caught has passed through the medium in the container. Several container systems are designed so that irrigation water can reach the bottom of the bench, via cracks, dividers, holes, etc., without going through the container. This "bypass" water must not enter the sample being collected for pH measurement. In most cases a minimum of 3 to 5 ml of leachate is required to take a pH reading; it is better if you can obtain more than this amount. The sample size should be standardized. The pH of the first leachate coming from the container will be different from that coming later, since it may contain more salts. This is not important as long as the same volume of fluid is caught at each collection.

9.5.2 *Adjusting pH with Irrigation Water*—The pH of the media is best controlled by the ingredients used and how they are blended. The potting mix should initially be acidic. Depending upon the nature of the potting mix (see section 6.2), it may be desirable to irrigate with acidified water to maintain low pH. Matkin and Peterson (1971) describe the techniques necessary to lower the pH with acid. Phosphoric acid is the least dangerous acid to use for this purpose. Considering the high value of the crop and the crucial nature of pH control to plant nutrition and disease control, nurserymen should monitor the pH of the growing medium and make adjustments as needed.

9.5.3 *Measurement of Salt Concentrations*—Some water sources have high levels of dissolved salts; these can cause injury to plants in four ways (Fuller and Halderman 1975): (1) reduce moisture availability, (2) decrease soil permeability, (3) cause direct toxicity, and (4) alter nutrient availability. The best control for saline water problems is to avoid them in the first place by a comprehensive examination of water quality. However, because of the large amount of irrigation water used in most greenhouses, there is a real potential for salt accumulation in the potting media, not only from salts in the water source but also in the fertilizers.

Table 9-4.—*Average germination of slash pine seeds as affected by pH*

	Germination media	
pH	Peat-vermiculite	Kimpak® cellulose
	percent	
4	93	90
7	90	89
10	91	90
13	90	75
Mean	91	86

Salt concentrations are measured by use of an electrical conductivity (EC) meter to monitor the irrigation solution and the leachate. Very pure irrigation water may have EC's as low as 100 to 200 µmhos. Water, carrying a complete nutrient solution and buffered for conifer growth, will range from 500 to 1,000 µmhos higher than the untreated water, normally in the 1,500 to 2,000 µmhos range (Tinus and McDonald 1979).

High salt concentrations generally result in stunting, although seedlings may also be chlorotic. If the leachate EC exceeds the nutrient solution EC by 1,000 µmhos or more, the nursery should immediately take steps to rectify the problem. Normally, the two should be within 100 to 200 µmhos. If the EC of the leachate is 3,000 µmhos or more, the trees are probably dead or dying. Normally, total nutrient solutions should not be used if the EC of the irrigation formulation exceeds 2,200 to 2,400 µmhos. This should be a problem only in the western extremes of the southern pine range.

A rise in the normal EC of the leachate without a similar rise in the EC of the irrigation solution applied indicates there is not enough leaching of the growing medium (i.e., not enough water being applied per irrigation cycle). The best solution to excess salt buildup is to ensure that the excess salt is leached from the potting mix during each irrigation by watering until leachate drains from the bottom of the container.

9.6 Seedling Nutrition

Information about the nutritional needs of southern pine seedlings is very limited. Fortunately the range of nutrient concentrations that will provide good growth is quite broad, and most coniferous tree species are similar in their requirements. Nutrients needed in relatively large amounts are termed macronutrients. Not only are the total amounts of macronutrients important, but the relative proportions of each element are important for proper nutrition. Micronutrients are also important but are only needed in trace amounts for seedling growth.

The six macronutrients—nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur—have been studied in some detail, and recommendations are available. The recommended nutrient levels for bareroot southern pine nursery soils are: phosphorus, 25 to 38 ppm; potassium, 75 to 100 ppm; and calcium, 300 to 600 ppm (Stienbeck and others 1966). In another study the best growth of slash pine in sand culture was obtained when nitrogen and potassium were both greater than 125 ppm but less than 625 ppm (McGee 1963). From literature on other conifers, magnesium should be in the range of 15 to 73 ppm, and sulfur in the range of 20 to 150 ppm (Tinus and McDonald 1979).

Although micronutrients are needed in very small quantities, they are critical, and if they are not present in sufficient amounts they can limit growth. The micronutrients include: iron, boron, manganese, chlorine, zinc, copper and molybdenum. Work with these elements has been extremely limited. Recommendations for Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst) are: iron, 0.93 ppm; boron, 0.17 ppm; manganese 0.17 ppm; zinc, 0.02 ppm; copper, 0.02 ppm; and molybdenum, 0.003 ppm (Ingestad 1962). The recommendations for macronutrients and micronutrients are summarized in table 9-5.

Ratios among the macronutrients are also important if the nutrients are to be readily available for plant growth. For the first several weeks, the nitrogen to phosphorus ratio should be greater than or equal to 1, and the phosphorus to potassium ratio should be less than 1 (Brix and van den Driessche 1974). Late in the growing season the proportion of nitrogen can be reduced.

Deficiencies or imbalances of nutrients will result in slow growth and poor seedling quality. Mineral deficiencies are often expressed as patterns of unusual leaf coloration. A summary of deficiencies is listed in table 9-6. A dichotomous key to mineral deficiency symptoms in loblolly pine seedlings using Munsell color charts has been developed by Lyle (1969).

However, if mineral nutrient deficiency symptoms appear, the crop is already affected. Production time will be lost while the crop recovers and field performance may be permanently impaired. For a successful and profitable crop, deficiencies must be avoided.

9.6.1 *Incorporation with Growing Medium*—Incorporating slow release fertilizers into the growing medium or adding granular fertilizer as a "top dressing" to the containers is a common practice in horticulture. The use of these techniques in seedling oper-

Table 9-5.—*Recommended nutrient concentrations for southern pines*[1]

Nutrient	Concentration
	ppm
Nitrogen	125–625
Phosphorous	25–38
Potassium	75–625
Calcium	300–600
Magnesium	15–73
Sulfur	20–150
Iron	0.93
Boron	0.17
Manganese	0.17
Zinc	0.02
Copper	0.02
Molybdenum	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.

Table 9-6.—*Visual deficiency symptoms in conifers (adapted from Morrison 1974)*

Deficient nutrient	Symptoms
Nitrogen	General chlorosis and stunting of needles increasing with severity of deficiency; in most severe cases needles short, stiff, yellow-green to yellow; in some cases purple tipping followed by necrosis of needles at end of growing season.
Phosphorus	Youngest needles green or yellow green; older needles distinctly purple-tinged; purple deepens with severity of deficiency; all needles purple in very severe cases in seedlings.
Potassium	Symptoms vary; usually needles short, chlorotic, with some green near base and, in some severe cases, purpling and necrosis with top dieback or little or no chlorosis; purpling, browning or necrosis of needles evident wherever they are found on the tree.
Calcium	General chlorosis followed by necrosis of needles, especially at branch tips; in severe cases, death of terminal bud and top dieback; resin exudation.
Magnesium	Yellow tipping of current needles followed in severe cases by tip necrosis.
Sulfur	General chlorosis of foliage followed in severe cases by necrosis.
Iron	More or less diffuse chlorosis confined in milder cases to new needles; in more severe cases bright yellow discoloration with no bud development.
Manganese	Needles slightly chlorotic; in severe cases some necrosis of needles.
Boron	Tip dieback late in growing season with associated chlorotic-to-necrotic foliage, intergrading to dieback of leading shoot with characteristic crooking.
Zinc	Extreme stunting of trees with shortening of branches; needles yellow, short, crowded together on twig, sometimes bronze tipped; older needles shed early, with resultant tufting of foliage; in severe cases trees rosetted with top dieback.
Copper	Needles twisted spirally, yellowed or bronzed; "tipburn" or necrosis of needle tips evident; in severe cases young shoots twisted or bent.
Molybdenum	Chlorosis of leaves followed by necrosis of tissue, beginning at tip and eventually covering whole leaf.

ations has been limited. The most prevalent method has been the incorporation of Osmocote® formulations. Although good growth may result when using the Osmocote 18-6-12 formulation with southern pines, such incorporation may result in overfertilization and limit the ability of the grower to stop height growth and harden the seedlings when desired. An exception may be when a spring outplanting is anticipated and the need for hardening is not as great. However, the incorporation of nutrients still limits the options of the grower, both in nutritional balances available and manipulation of seedling quality.

9.6.2 *Soluble Commercial Mixes*—Most tree seedling growing operations use soluble commercial fertilizers. These are dissolved in water and injected into the irrigation system of the greenhouse or sprayed over the trees by hand equipment. These fertilizers are formulated by a number of manufacturers and are available in numerous types, formulations, and proportions of macronutrients and micronutrients.

Experiences using soluble fertilizer compounds for growing different species of trees in different locations, containers, and potting mixes has increased in the last few years. Nurserymen considering the use of commercially prepared soluble formulations should consult with other nurserymen to determine which materials to use and the best times of applications. Peters® Peat-lite Special formulations work well with southern pine grown in peat-vermiculite media. However, it is not wise to assume that what works well in one situation will necessarily work well in another. This is because the fertilizer interacts with the water composition of a specific site, the potting media, the species grown, and the growing conditions peculiar to each greenhouse (Tinus and McDonald 1979). Some fertilization manufacturers offer custom fertilizer formulation based on their analysis of water samples and crop needs.

Although commercially formulated soluble chemical fertilizers are convenient to buy and use, they have some drawbacks (Tinus and McDonald 1979):

1. The manufacturer controls the precision of the formulation.
2. The user is limited to the proportions of the nutrients available in mixes.
3. The user often has limited information on what chemical compounds are used to supply the nutrient ions and therefore the cause of any problem may be hard to identify.
4. The nurseryman cannot adjust the nutrient mix to take advantage of nutrients in the water supply or to adjust the pH of the solution by varying the salts used in the formulation.

However, soluble commercially prepared fertilizers are used very successfully in container operations. They are also very convenient and easy to use when applied through the irrigation water.

9.6.3 *Local Nutrient Formulations*—Another method of fertilizing tree seedlings is with locally mixed nutrient stock solutions. These are formulated by adding various amount of technical grade chemical components to water according to the optimum nutrient regime for the species, the potting mix, and water composition. Tinus and McDonald (1979) give an excellent format for determining the chemical composition best suited to an individual nursery situation.

Local mixed formulations are more difficult to handle than commercial mixes, and optimum nutrient concentrations are not clearly specified for most species. In such cases, the local formulation may do no better than a commercial mix.

9.6.4 *Timing of Initial Application*—During germination, the seed megagametophyte (endosperm) supplies sufficient phosphorus and other essential nutrients, so that additional fertilization is unnecessary. The newly germinated seedling reportedly takes up few elements other than carbon, hydrogen, and oxygen until 10 to 14 days after germination (Carlson 1979). Brix and van den Driessche (1974) have reported, however, that growth of container seedlings could be helped with the incorporation of slow-release nutrients into the potting media during the first few weeks of germination. Generally, the addition of mineral nutrients during germination is not recommended, because they are supplied by the seed and they may increase losses due to damping-off fungi (Tinus and McDonald 1979). Fertilization is usually scheduled to begin after the seed coats have been shed from the cotyledons. This delay can have considerable effect on seedling development. Delaying initial application of nutrients until drop of the seed coats (about 3 weeks) can reduce loblolly pine seedling development by nearly 20 percent (fig. 9-8). If the crop is on a short rotation, fertilization at the time of seeding may be desirable. It may be that, although the germinants can not effectively utilize the nutrients at this early stage of development, availability at the earliest possible time will hasten growth. If a short growing period is not critical, delay until germination occurs may be beneficial from a disease management viewpoint.

9.7 Mycorrhizal Inoculation

Mycorrhizae are the structures resulting from the colonization of a tree host root by a suitable fungus. The value of mycorrhizae to tree growth has been known to foresters for decades. They increase availability and absorption of nutrients, especially phosphorus, the most limiting nutrient on most pine sites in the South. Ectomycorrhizae also protect fine absorbing roots from pathogen attack (Marx 1972).

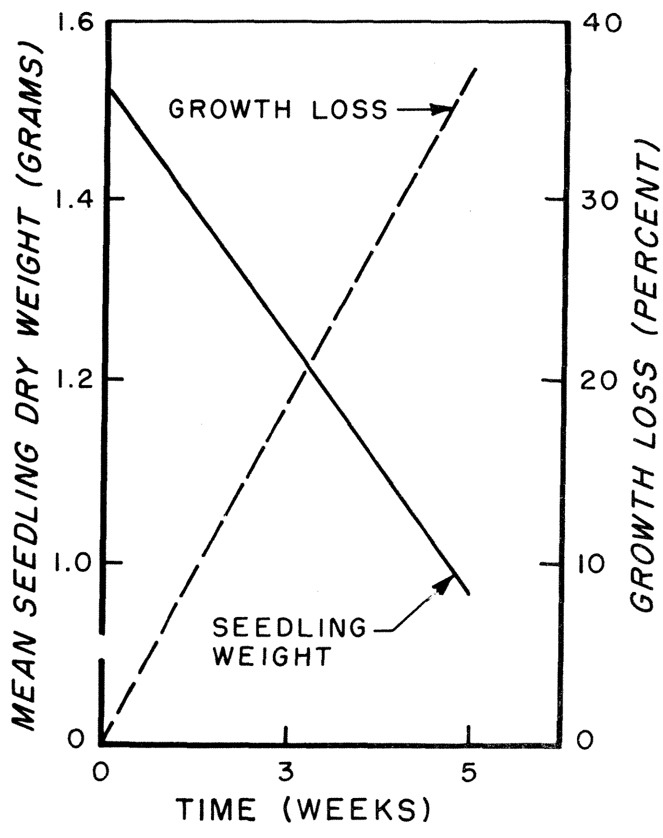

Figure 9-8.—*Effects of timing of initial fertilizer applications on dry weights of loblolly pine seedlings grown for 20 weeks. Time is the delay in application of fertilizer.*

Under natural conditions, pines will not survive or grow well without mycorrhizae. Ample evidence exists to document the benefits of having visible mycorrhizae on the root systems of nursery-grown seedlings when they are outplanted in the field (Marx and Artman 1979).

Seedlings can, however, be grown quite satisfactorily without mycorrhizae if adequate nutrients are provided and pathogens are controlled. Normally, containerized seedlings are grown under conditions that tend to optimize growth, i.e., high levels of fertility. These conditions normally limit the development of mycorrhizae (Marx and Barnett 1974, Marx and others 1977), and lower fertility regimes may be necessary to allow development of mycorrhizal inoculum.

When greenhouses are located near forested areas where airborne mycorrhizal spores are abundant, inoculation may not be necessary. Barnett (1982) found that *Thelephora* developed on seedling root systems in containers from airborne spores in amounts negatively related to the amount of inoculated *Pisolithus* present. High fertility did not seem to inhibit this *Thelephora* development. Further evaluations of the relationships among mycorrhizal presence and seedling size with field performance of shortleaf and longleaf seedlings indicated that initial seedling size was more related to growth than amounts of mycorrhizae on the root systems (Barnett 1982). This relationship makes it very important to consider the effect of differences in seedling size at the time of outplanting on field performance.

Under the humid conditions typical of the Southeast, seedlings grown in greenhouses normally become inoculated with mycorrhizae by windborne inoculation. If so, the effort and cost to inoculate them is probably not necessary for seedling regeneration throughout much of the region. Even if the seedlings lack mycorrhizae when they are outplanted in the field, they usually become inoculated quickly because of the presence of the fungi at the site. However, there is considerable evidence that inoculation with mycorrhizae improves seedling performance on difficult sites such as arid soils, reclamation areas, and shelterbelt plantings in the Great Plains where inoculum may be scarce or lacking.

If inoculation with mycorrhizae is thought desirable or necessary, one method available is to incorporate 2 to 3 percent by volume of forest duff into the potting mix (Tinus and McDonald 1979). The duff should be collected from under a stand of trees of the same or closely related species. Rake aside the undecomposed litter and scoop the humus with a flat shovel. Screen out particles too large to mix well with the rest of the medium. Keep the inoculum moist until used.

Although duff inoculum will work well (Goodwin 1976), it may add harmful organisms. Some research has indicated that it may actually lower survival and growth (table 9-7). McGilvray[1] reported that the addition of duff reduced initial seedling survival by 7 percentage points. The risk of using duff can be assessed by collecting some inoculum well in advance and filling a few containers. Then grow seedlings for several months and evaluate detrimental effects before it is used on a large scale (Tinus and McDonald 1979). Use a pure culture of the desired mycorrhizal fungus if possible.

9.7.1 *Vegetative Mycelia*—Marx and his coworkers (Marx and Bryan 1975, Marx and Rowan 1981) have developed techniques to produce mycelial inocula of *Pisolithus tinctorius* (Pt) and *Thelephora terrestris* (Tt) in a peatmoss-vermiculite culture. These techniques have made it feasible to propagate and manipulate these fungal symbionts for research purposes. In order for mycorrhizal manipulation to become common practice, larger quantities of high-quality inoculum must be available.

9.7.2 *Basidiospores*—A simple and less expensive means of inoculation with Pt is through the use of basidiospores. Basidiospores are the primary agents for disseminating many ectomycorrhizal fungi. Several workers have used spores of specific fungi as inoculum for synthesis of mycorrhizae on pine (Marx and Ross 1970, Theodorou 1971). *Pisolithus tinctorius* produces large basidiocarps or puff balls that contain many spores. Marx and Bryan (1975) collected over 1,300 grams of spores of this fungus under mature pine in less than 3 hours on a strip-mined coal spoil in northwest Alabama. One gram contained approximately 1.1 billion spores. Unfortunately, viability of the spores is difficult to determine (Lamb and Richards 1974). It appears that the best way to determine spore viability is in actual mycorrhizal synthesis tests or operational use.

The most successful method of inoculating media with spores of Pt has been by mixing dry spores with the peat-vermiculite medium before containers are filled. The addition of spores suspended in water to the medium is less effective (Marx 1976). The use of about 3 grams of spores per cubic foot of potting mix has been effective.

Another technique that shows promise is to coat or "pelletize" pine seeds with spores of Pt. Theodorou (1971) found that coating seeds of Monterrey pine (*P. radiata* D. Don) with freshly harvested basidiospores was an easy and effective way to introduce mycor-

[1]McGilvray, J.M. 1973. Evaluation of mycorrhizal formation and its importance in the survival and growth of containerized loblolly pine seedlings. U.S. Forest Serv., Southern Forest Exp. Sta. Establishment and Final Report SO-1102-9.17, 11 p., Pineville, LA 71360 (unpublished).

Table 9-7.—*Percent survival and height of loblolly pine seedlings grown with and without mycorrhizal duff in two growing media*

Media	Treatment	Survival At 3 months	Survival At 8 months	Average height at 8 months
		percent	*percent*	*cm*
Peat-vermiculite mix	Decomposed litter	86 a[1]	85 a	12.5 c
	Control	90 b	89 a	11.0 b
Sand-soil-peat mix	Decomposed litter	84 a	83 a	8.5 a
	Control	94 b	88 a	8.8 a

[1]Averages followed by the same letter do not differ significantly at the 0.05 level.

rhizal fungi into soils. International Forest Seed Company of Birmingham, Alabama, has a commercial process to pellet southern pine seeds with Pt spores. After seeding with pelletized seeds, the container should be drenched with water to insure the pellet is washed from the seed coat. Otherwise, the pellet may inhibit germination. Perhaps the greatest problem in the use of spores as a method of mycorrhizal inoculation is the lack of a technique to evaluate spore viability.

9.7.3 *Cultural Modifications*—Inoculation of the container growing media with mycorrhizal inoculum necessitates some modification of the normal cultural regime if development on the pine root system is expected. The high fertility levels that are usually used to optmize seedling growth should be reduced by about one-half, or development of mycorrhizae will be limited (Marx and Barnett 1974, Marx and others 1977).

Other cultural techniques may also affect mycorrhizae. The use of fungicides can have either a deleterious or a beneficial effect on mycorrhizal development. Pawuk and others (1980) evaluated the effects of seven fungicidal drenches on Pt and Tt mycorrhizal development of longleaf pine grown in containers (see section 9.2.2.). The degree of mycorrhizal development differed significantly among fungicide treatments (table 9-8). Only seedlings drenched with Banrot and Benlate had greater development than the control.

Since Benlate is one of the most effective fungicides for controlling *Fusarium*, an additional study was initiated to test the effect of Benlate in stimulating mycorrhizal development on shortleaf pine in a peat-vermiculite medium and to identify effective drench rates and schedules (Pawuk and Barnett 1981). Seedlings were drenched (2.5, 5, and 10 mg in 15 ml of water per individual) prior to sowing and at either 2-, 4-, or 8-week intervals over an 18-week period. Seedlings drenched with high rates of Benlate and seedlings receiving frequent drenchings generally formed the most mycorrhizae (table 9-9). However, a dosage rate frequency interaction was present (table 9-10).

During the study, seedlings received 5, 10, 20, 40, or 80 mg benomyl, depending on drench schedule and dosage rate. With one exception, mycorrhizal development increased with increased amounts of Benlate.

Benlate application also increased seedling diameter, height, and weight (table 9-9). Highest Benlate dosages produced the largest seedlings. The growth response is probably due to control of soil fungi that reduce seedling growth or to effect of increased mycorrhizal development on Benlate-treated seedlings.

9.8 Control of Root Morphology

Growing seedlings in containers dictates that root morphology will be different than when grown in the wild. Early results with containerized seedlings showed the desirability of restricting root egress from the container during the greenhouse culture period. Copper paint (Saul 1968) or screening (Barnett and McGilvray 1974) was found to inhibit root growth from the bottom of containers and resulted in increased survival of seedlings. However, air pruning was found to be a more efficient means of eliminating root growth from containers. The key to effective air pruning of roots is to provide for easy air access around the container openings.

There is considerable concern about the relationship of the root pattern caused by the container and subsequent field performance and stability of seedlings and young trees (see section 5.4). The type of container used will, of course, have considerable impact on root configuration. Containers are now designed with vertical ribs, rounded horizontal corners, and egress holes with adequate ventilation beneath them for air pruning. These features keep the roots within the container and produce a more or less parallel vertical root system with little root spiraling (Hiatt and Tinus 1974).

Table 9-8.—*Effect of fungicide treatment on development of ectomycorrhizae on longleaf pine seedlings grown in* Pisolithus tinctorius *infested and noninfested media (from Pawuk and others 1980)*

	Pisolithus infection		Airborne symbiont infection	
Fungicide	Infested	Noninfested	Infested	Noninfested
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]Values are expressed as a percentage of short roots forming ectomycorrhizae.
[2]Means followed by similar letters are not significantly different at the 0.05 level.

Table 9-9.—*Mycorrhizal development by* Pisolithus tinctorius *and growth of shortleaf pine seedlings drenched with Benlate (main effects table) (from Pawuk and Barnett 1981)*

		Shortleaf pine		
Benomyl[1]		Diameter	Height	Dry weight
Dosage mg/seedling	*Percent infection*	*mm*	*cm*	*mg*
2.5	17.67[2]	2.06a[3]	13.54a	462b
5.0	24.00	2.04a	13.26a	478b
10.0	36.67	2.12a	13.80a	508a
Frequency				
every 2 wks	34.33[4]	2.19a	14.44a	531a
every 4 wks	27.00	2.06b	13.92a	482b
every 8 wks	17.00	1.96b	12.24b	435c
Control	8.00	1.94	11.90	408

[1]The dosage X frequency interaction was significant. See table 9-10 for mean separation.
[2]Values represent the mean of the three frequencies of application.
[3]Means with dosage rates and frequencies followed by the same letter within columns are not significantly different at the 0.05 level.
[4]Values represent the mean of the three dosages of benomyl.

Table 9-10.—*Mycorrhizal development by* Pisolithus tinctorius *as affected by Benlate dosage and drench frequency (interaction table) (from Pawuk and Barnett 1981)*

	Benlate dosage (mg/seedling)		
Drench frequency[1]	2.5	5.0	10.0
	-------- *percent infection* --------		
Every 2 weeks	25 c[2]	24 c	54 a
Every 4 weeks	16 c	31 b	34 b
Every 8 weeks	12 e	17 d	22 c

[1]For an 18-week period.
[2]Means followed by the same letter are not significantly different at the 0.05 level.

Root spiraling has been the most prevalent problem of root configuration imposed upon southern pines by containers, and proper container selection will largely eliminate this problem. 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 results in improved seedling survival and growth on adverse sites (Barnett 1982). However, the early development of roots from the bottom of the plugs may result in less rapid mycorrhizal development. The microenvironment and soil associates of these more vertically egressed roots are not as favorable as on lateral root development closer to the soil surface (Ruehle 1983).

There are techniques that may be used to change or control the pattern of root morphogensis in plug-type container systems. Burdett (1978) has reported that copper carbonate in acrylic latex paint applied to container walls will stop root growth at that wall. This was done by mixing a small amount of copper carbonate (30 to 100 g/l or 25 to 83 lb/100 gal) with acrylic latex paint and painting the inside of the container with the mixture before filling it with medium. When their tips reached the wall of the containers, many of the lateral roots of the seedlings stopped growing instead of turning and continuing to grow down the walls to the root egress hole. The laterals that stopped often developed a series of adventitious roots. These roots also stopped growth at wall contact. The result was a series of root tips at the container wall. Upon removal from the container, these root tips resumed growth outward from the sides of the root "plug." This lateral root growth promises better lateral anchorage and access to water and nutrients and suggests such root morphogenetic control could be a feasible operational procedure. McDonald and others (1981) also evaluated some synthetic auxin compounds that gave results similar to copper carbonate.

Although some research with these techniques is underway with southern pines, the results are still preliminary. It has been observed, however, that extraction from plugs becomes more difficult, since there are less roots on the plug surface to bind the medium together.

9.9 Carbon Dioxide Enrichment

There are about 325 ppm carbon dioxide (CO_2) in the atmosphere; this is the source of carbon for all green plants. When plants are exposed to conditions of good light and water, growth may be limited by atmospheric carbon dioxide (Kramer and Kozlowski 1960). Since CO_2 can be especially limiting in a closed greenhouse, many growers routinely add it to their greenhouse atmospheres (see section 8.2.4). Increases in seedling growth and dry weight of 50 to 100 percent can result from concentrations of 1,000 ppm CO_2 during daylight hours (Tinus 1972, Yeatman 1970); however, some species are not as responsive as others (Canham and McCavish 1981), and we do not know the effects of CO_2 enrichment on southern pines.

9.10 Acclimating Seedlings

When growing conditions are optimized for rapid height growth, succulent seedlings with a high shoot-to-root ratios generally result. For outplanting under highly favorable conditions, these may survive and grow well, but usually at least some control of top growth is needed. Excessively tall seedlings can be top pruned (see section 9.11), but cultural control of top growth is better.

Most seedlings will cease height growth and set bud when exposed to water stress and short photoperiods. Reducing the nitrogen provided to the seedlings also helps to slow growth. The ease at which growth is stopped depends on the season, but it can be stopped regardless of time of the year. The length of time allowed for the initial hardening stage depends on the environmental conditions expected at time of outplanting. Cessation of growth, followed by stem lignification and bud set, is the normal sequence during initial hardening.

9.10.1 *Managing Moisture Stress*—Total water potential is composed of soil water potential and plant water potential and refers to the status of water with relation to the soil, plant, and air. Soil water potential depends on moisture content and soil texture. Plant water potential depends on soil water potential and atmospheric evaporative demand. Evaporative demand rises with increasing air temperature and decreasing humidity. Radiation intensity and wind speed also contribute, but less directly. Water potential is measured in bars, and optimum soil or plant water potential is usually near 0 bars.

Plant moisture stress is the inverse of plant water potential; as moisture stress increases plant water potential decreases, becoming more negative. Likewise, soil tension is the inverse of soil water potential. Before dawn, soil water potential and plant water potential are in equilibrium, but not necessarily equivalent. While soil water potential declines as the soil dries, plant water potential fluctuates diurnally (fig. 9-9). As the day progresses, plant water potential drops until it stabilizes near midday, then slowly climbs during the afternoon and evening. At midday, the water potential of seedlings may be 7 to 10 bars below soil water potential. The wilting point of plants is defined as -15 bars, although mature trees are often well below that level at midday.

As discussed in section 9.1.1, water potential should be kept high while the seedlings are rapidly elongating. As seedlings approach the desired size, water potentials should be allowed to drop; this will bring about low-level moisture stress and begin the harden-

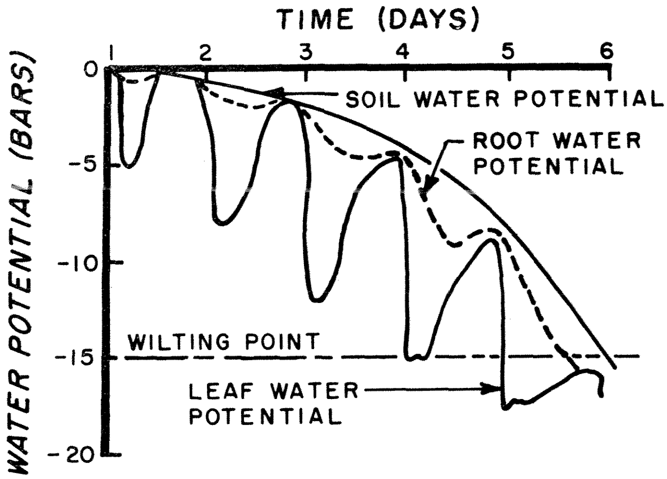

Figure 9-9.—*The influence of decreasing soil water potential on development of plant water stress (adapted from McDonald and Running 1979).*

ing process. In container nurseries, water potential can be evaluated indirectly by weighing the containers to determine moisture content, or by directly measuring plant water potential with a pressure chamber. Weighing is appropriate while the seedlings are small and water content is a major portion of the total weight. As the seedlings become larger, a pressure chamber is recommended to accurately assess plant water potential. When trying to optimize growth, the media should be kept at or near field capacity, or less than −0.3 bars (Tinus and McDonald 1979). Using the weighing method, this means the crop should be irrigated when sample containers dry to about 75 to 80 percent of their saturated weight (McDonald and Running 1979).

During the conditioning phase, midday plant water potential should be allowed to drop to between −12 and −15 bars to impair height growth and help initiate dormancy. The time required for plant water potential to drop to the desired level depends on moisture content of the media and evaporative demand. To maintain plant moisture stress at safe levels, careful monitoring of water potential is important. To aid in interpreting water potential readings obtained with a pressure chamber, McDonald and Running (1979) suggest graphing midday readings over a period of time and at different temperatures and humidities. The resulting curves relate available soil water to midday plant water potential for various levels of evaporative demand (fig. 9-10). Note that the curves are divided into segments by degree of moisture stress. Seedlings stressed beyond the wilting point (−15 bars) are in danger. In the range of −12 to −15 bars, seedlings undergo a conditioning stress. Above −12 bars, water potential does not limit seedling growth. Problems occur when interpreting midday water potentials along lines A-B and B-C. From A to B soil moisture is the same although plant water potential varies with different evaporative demands. From B to C plant water potential is constant despite different soil water contents, again because of different evaporative demands. The development of such curves will help to manage or to maintain water potentials at optimum or desired stress levels without endangering the crop.

9.10.2 *Nutritional Changes and Hardening*—In addition to stress, manipulation of nutrients is another means of increasing seedling hardiness. Once the seedlings have reached about 80 percent of the desired height (about 13 cm or 5.5 inches), reduce the application of nitrogen along with that of water. This aids in the reduction of stem growth. An increase in rates of phosphorus and potassium may help root growth and stem diameter growth to continue (Tinus and McDonald 1979). However, Timmis (1974) found that a rather extreme nitrogen-potassium imbalance strongly reduced the ability of containerized Douglas-fir seedlings to achieve cold hardiness. He found that the potassium-to-nitrogen ratio must be less than 1.0 to permit maximum cold hardening after an 11.5-week hardening regime. The frequency of nutrient applications should also be reduced.

9.10.3 *Cold Hardening*—Additional hardening beyond cessation of growth and stem lignification is needed if a late fall or winter outplanting is planned. This is done by gradually exposing seedlings to more severe conditions, primarily low temperatures, that will bring about physiological changes to enable the trees to tolerate the new conditions. Temperatures of 1 to 5 °C (34 to 41 °F) will generate considerable cold hardiness.

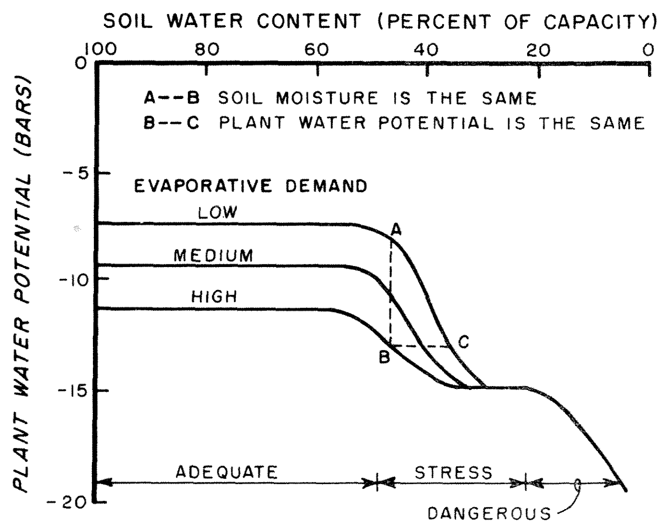

Figure 9-10.—*The change in midday plant water potential produced by changing soil water content and different levels of evaporated demand (adapted from McDonald and Running 1979).*

Mexal and others (1979) found that approximately 42 days of hardening are required to induce sufficient cold hardiness to enable loblolly pine seedlings to survive late fall and early winter outplanting. To ensure sufficient hardening, the hardening process should be initiated by mid-September so that outplanting may occur in November. When soil moisture is adequate, partially hardened stock may be planted successfully in September or October. Hardening can be accomplished by either exposure to low temperatures or to short photoperiods, but the exposure to low ambient temperatures is the most feasible technique.

Loblolly pine has a chilling requirement that must be satisfied before normal bud break and shoot elongation can occur. Garber and Mexal (1980) report that about 7 weeks of exposure to natural conditions during November and December are needed to satisfy the chilling requirement of nursery-grown loblolly pine seedlings. It is not known if small containerized seedlings that have not formed a terminal bud have a chilling requirement (Mexal and Carlson 1982). There are also probably seed source differences in the amount of chilling required. More northern sources are likely to have longer chilling requirements than more southern sources. There is insufficient information available now to evaluate the importance of chilling requirements in the culture of containerized southern pines.

9.10.4 *Cold Injury*—There is considerable variation among species in their susceptibility to cold injury. Loblolly and shortleaf pines extend into the northern portions of the southern states and are adapted to colder temperatures than slash and longleaf pine. Seeds of loblolly and shortleaf are stratified naturally as they overwinter on the soil surface; the seeds then germinate in the spring. The small seedlings are not well adapted to cold temperatures and are susceptible to subfreezing conditions. In constrast, longleaf pine is a more southern species and its seeds normally germinate in the fall soon after release from the cones. Recently germinated longleaf seedlings are then more resistant to cold injury than loblolly or shortleaf pine. Normally, longleaf seedlings survive the ambient temperatures that occur in their range during the fall and winter.

Slash pine is intermediate between longleaf and loblolly in susceptibility to cold. A portion of slash seeds normally germinate in the fall, while another portion overwinters and germinates in the spring. Tests indicate that slash seedlings are more cold resistant than loblolly pine (Barnett and McGilvray 1981).

9.11 Top Pruning

Top pruning of bare-root conifer nursery seedlings is used to retard excessive top growth and keep the seedlings in a better shoot-to-root balance. Normally, the tops are pruned while new growth is expanding and sufficient time is available for subsequent bud formation and normal development (Stoeckler and Jones 1957).

Clipping the needles of longleaf seedlings has been recommended for planting on adverse sites (Allen 1955). However, Derr (1963) reported some growth retardation resulting from clipping longleaf, and Langdon (1955) found no advantage to clipping South Florida slash pine needles (*Pinus elliottii* var. *densa* Little and Dorman).

The purpose of most of the pruning and clipping of conifers has been to reduce transpiration and thus improve seedling survival under adverse conditions. Results from a number of studies show no conclusive advantage for this technique. Photosynthetic production, which is necessary for root development, may be sufficiently reduced by pruning and clipping to account for variation in the results.

Top pruning of container-grown seedlings is normally not necessary. However, there are instances when seedling development has not been adequately controlled by cultural regimes, and then it may be desirable to prune in order to obtain a better seedling balance. It may be beneficial to clip the needles of longleaf pine because even at a low density, needle development in containers can be so great as to cause shading problems in these very intolerant seedlings. Clipping could be used, then, to allow uniform light exposure to all seedlings.

Evaluations of needle clipping or top pruning showed a reduction in initial seedling size and weight (table 9-11). No improvement in field performance resulted from clipping longleaf needles, but if clipped, those that were clipped early performed best. Loblolly and slash pine seedlings should be pruned early, if pruned at all. There was no marked improvement in field survival or growth that resulted from pruning. In fact, field growth was closely correlated with seedling size at time of outplanting. Correlation coefficients of 0.967, 0.956, and 0.923 resulted from comparisons of initial size and growth in the field after 2 years for longleaf, loblolly, and slash pine, respectively (Barnett 1985). Hence, the larger seedlings performed as good or better than those pruned.

10. DEVELOPMENT OF GROWING SCHEDULES

A plan should be developed to insure maximum utilization of greenhouse and shadehouse space consistent with the overall objectives of the greenhouse manager. It is useful to keep a written record of the planned crop rotation, conditions maintained, and growth progress, so that if errors are made, they will not be repeated.

A "growing schedule" should be developed to aid in planning the greenhouse crop rotation and in making

Table 9-11.—*Effect of top pruning and needle clipping on initial development and field performance of southern pine seedlings*

Pruning treatments	Initial seedling characteristics				Field performance[2]	
	height	diameter	top wt.	root wt.	survival	size
	mm		*mg*		*percent*	*cm*
Longleaf pine[1]						
Control	.....	3.4	1,100	158	51	1.52
10 cm, 15 cm	.....	2.9	393	122	48	1.17
10 cm, 20 cm	.....	3.3	668	148	44	1.40
10 cm, 15 cm, 20 cm	.....	3.3	526	144	54	1.50
Loblolly pine						
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 pine						
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 seedlings needles were clipped to 10 cm at about 8 weeks; other treatments were clipped to 15 or 20 cm at 2-week intervals. Loblolly and slash seedlings were pruned to 12.5 cm at 10, 12, and 14 weeks.

[2]Field performance was measured 2 years after outplanting; root collar diameter of longleaf and total height of loblolly and slash pines.

maximum use of space and equipment. The growing schedule is a chart of the conditions to be maintained and operations to be done as a function of calendar date, from seed preparation to shipment from the nursery (Tinus and McDonald 1979). It should incorporate much of what is known about the growing of a particular crop and having it in proper physiological condition on the required shipping date. Consideration must also be given to the growing schedule when designing the facility to ensure that the greenhouse will be able to maintain the required conditions. The growth cycle for the species must be considered, including dormancy and hardening-off needs.

10.1 Features of a Growing Schedule

Figure 10-1 is an example of a growing schedule developed for producing three crops of southern pines per year. Time is on the horizontal axis at the top and the factors to be controlled and operations to be performed are listed on the vertical axis at the left. A growing schedule shows the environmental conditions surrounding the growing plant at any given time. By reading the time season line and estimating the time needed for each of the indicated management activities beneath it, the length of time in the different growth stages can be determined.

Tinus and McDonald (1979) list several common features that all growing schedules should have:

1. They should define the dates between which the crop will be in the greenhouse, the crop conditions at any time during the growth cycle, targets for height, caliper, and other indicators of growth stage, and the condition of the environment in the greenhouse at any given time during the growth cycle.
2. The environmental control designated in the growing schedule should be based on the best biological information available for that particular species. The full capability of the greenhouse environmental modification system should be used to meet these growth optimization guides.
3. The growing schedule should show the complete cycle from seed to crop maturity, even if the crop is moved to a shadehouse partway through its schedule.
4. The length of each segment of the growing schedule and the calendar dates it covers should be defined. This is valuable not only for reference while the crop is being reared, but also to record the true length of time needed to produce a satisfactory crop. Records of the length of time and cultural modifications necessary to rear good crops of trees are valuable for more precise growing schedule formulation for future crops.

10.2 Relating the Schedule to Condition and Rate of Crop Development

The species and required size for outplanting determine the container size, seedling density, and the time required to grow it. The site on which the seedling is planted and the time of year you plant determine the required physiological condition of the tree when it leaves the nursery.

Species Slash, Loblolly, Longleaf pine Container 4 cubic inches Outplanting Spring/Summer/Fall Location Central Louisiana Cycle 3 crops, 1 year

Source James P. Barnett, Research Forester, Southern Forest Experiment Station Pineville, La.

Season: Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept.

Growth stage	Germination Crop #1	Juvenile growth	Exponential growth	Greenhouse hardening	Germination Crop #2	Juvenile growth	Exponential growth	Germination Crop #3	Juvenile growth	Exponential growth
Day temp. (°F) Optimum	72	75	70	65	72	75	78	72	75	78
Day temp. (°F) Permissible	65 – 80	65 – 85	72 – 85	55 – 70	65 – 80	65 – 85	72 – 85	65 – 80	65 – 85	72 – 85
Night temp. (°F) Optimum	72	72	75	55	72	72	75	72	72	75
Night temp. (°F) Permissible	65 – 80	65 – 80	72 – 85	50 – 65	65 – 80	65 – 80	72 – 85	65 – 80	65 – 80	72 – 85
Rel. Hum. (%) Optimum	80		60		80	60		80	60	
Rel. Hum. (%) Permissible	60 – 90		50 – 80		60 – 90	50 – 80		60 – 90	50 – 80	
Daylight	50 % Sunlight		55-70 % Sunlight		50 % Sunlight	55-70 % Sunlight		50 % Sunlight	55-70 % Sunlight	
Supplemental light	None	8 watts/ft² incandescent or equivalent at least 3 % of the time. No dark period over 30 minutes.		None		8 watts/ft² incandescent or equivalent at least 3 % of the time. No dark period over 30 minutes.		None	8 watts/ft² incandescent or equivalent at least 3 % of the time. No dark period over 30 minutes.	
Water	Frequent, light, surface kept well	As needed, surface should dry. Water in excess. Keep rootball near field capacity.		As needed. Dry to wilting	Frequent, light, surface kept wet	As needed, surface should dry. Water in excess. Keep rootball near field capacity.	Stress	Frequent, light, surface wet	As needed, surface should dry. Water in excess. Keep rootball near field capacity.	
Fertilizer	None	Complete, high N, pH 5.0 - 5.5		Low N, high P	None	Complete, high N, pH 5.0 - 5.5		None	Complete, high N, pH 5.0 - 5.5	
CO_2 level	Normal atmos.	1,000 - 1,500 ppm whenever vents are closed in daylight hours.		Normal atmos.	Normal atmos.	1,000 - 1,500 ppm whenever vents are closed in daylight hours.		Normal atmos.	Normal atmos., CO_2 at higher levels not usually feasible because of venting needs.	
Operations	Leach Crop #1; Apply fungicide	Thin		Move to lathhouse. Load Crop #2; Harden Crop #1 in lathhouse	Fungicide; Ship Crop #1 for outplanting	Thin	Move Crop #2 to lathhouse; Load Crop #3	Fungicide; Harden Crop #2 in lathhouse	Thin; Ship Crop #2 for outplanting	Move Crop #3 to lathhouse; Temperatures usually too high for greenhouse production; Harden or ship for outplanting

Figure 10-1.—*A growing schedule for producing three crops of southern pine per year; vertical lines refer to time of the month (adapted from Tinus and McDonald 1979).*

To determine the sowing date, start with the date the end product must be ready to ship, and work back in time. After the seedlings have reached the desired size, they may need hardening. The amount of hardening needed depends on the season of outplanting and the size and condition of the seedlings.

10.2.1 *Stages of Hardening*—There are several different stages of hardening, and the stage required at shipping depends upon which season the seedlings are to be outplanted.

Succulent seedlings have had no hardening. Their top growth is very active, and the upper part of the stem is not lignified. They are tender and can be used only in the most favorable weather on the best sites. When used judiciously, these seedlings will continue growth without interruption, and no time for hardening needs to be allotted in the growing schedule.

Resting seedlings have arrested shoot growth, and stem tissue may be lignified. These are normally succulent seedlings that have been moisture and/or temperature stressed prior to shipping. They can be planted under more adverse conditions than the succulent seedlings and will resume top growth if outplanted in the late spring or summer when favorable growing conditions occur.

Dormant seedlings have set bud, and all of the stem tissue has lignified, but they are not cold hardy. This degree of hardening takes 3 to 5 weeks to produce and is sufficient for planting in summer or early fall when frosts are not expected. Normally, there will be no top flush until the following year.

Fully hardened seedlings are dormant, with well developed winter buds. They have reached a high degree of cold hardiness, and the chilling requirements for bud break have either been met or will be by the time warm weather arrives at the planting site. This condition requires 6 weeks to achieve and is generally needed for late fall or winter planting. The seedlings can be expected to put on a large flush of top growth the first season in the field.

10.2.2 *Stages of Growth*—By the date the seedlings must be at their full height and ready for hardening or shipment, they will have passed through three growth stages.

Germination begins when the seed is placed in warm, moist potting mix and it should be complete in 10 to 14 days. If not, either the seed has not been properly prepared, or the seed is poor. Prompt and complete germination in the greenhouse nursery is important. Any delay is costly.

Juvenile growth begins when the seed is exhausted and the tree becomes autotrophic. There frequently appears to be a pause in growth as the seedling forms a rosette above the cotyledons. The first green leaves are frequently different in shape, size, and ontogeny from the ones on a mature plant. No buds are visible. The seedling grows continuously. The length of this stage varies from a few days to several weeks, depending on the species and seed source.

Exponential growth occurs after the seedling has fully taken hold. Frequently the seedlings will begin to resemble a mature tree. The length of this stage is determined by how close growing conditions are to optimum, how large a tree is desired, and how soon one or more growth factors becomes limiting.

The time required for each growing stage can be easily determined if the nurseryman has growth curves and a table of optimum conditions for the species he is growing. Moving backward in time through these three growth stages establishes when to set the seeding date to fit the schedule.

You must also allow time for seed preparation. Does it require stratification, water soaking, or other time consuming treatment? Finally, consider seed collection and proper storage, which brings us to the beginning of the growing cycle.

10.2.3 *Timing Overlapping Schedules*—Given the date at which the product is needed, once it is known how rapidly the seedlings will grow and how rapidly they will complete all of the required stages, it is easy to establish the dates at which each stage must begin. These dates may need to be adjusted to allow one crop to mesh with the next, and to coordinate the use of space and manpower. If the trees will remain in the greenhouse from sowing until shipment, the only requirement is that they be shipped in time to start the next crop. If shipment is delayed, the seedlings may need to be moved to a temporary holding area. If the trees are to be moved to a shadehouse for part of their stay at the nursery, they must be able to tolerate conditions there. If the trees are fully hardened, they can be moved to the shadehouse at any time.

10.2.4 *Necessary Growing Data*—The optimum conditions for each stage of growth are not generally known for the southern pine species. Certain pertinent information is known, of course, but the grower is well advised to develop specific information for the species, environment, and growing regime at each facility. This information can be used to refine the growing schedule to meet each specific situation.

The growth record from Tinus and McDonald (1979) is a useful tool to use in developing growth response data (fig. 10-2). In addition to information recorded on this form, it is very useful to supplement this with xerographic copies of seedling development (fig. 10-3). information about seed source, size, and growth history can be put on the same sheet with the seedling image. This provides a useful record of development over time and under various environmental and cultural conditions.

GROWTH RECORD

Greenhouse No.___________________ Species____________________________

Seed lot___________________________

Date	Height	Caliper	Weight	Comments

Figure 10-2.—*Form for recording growth data.*

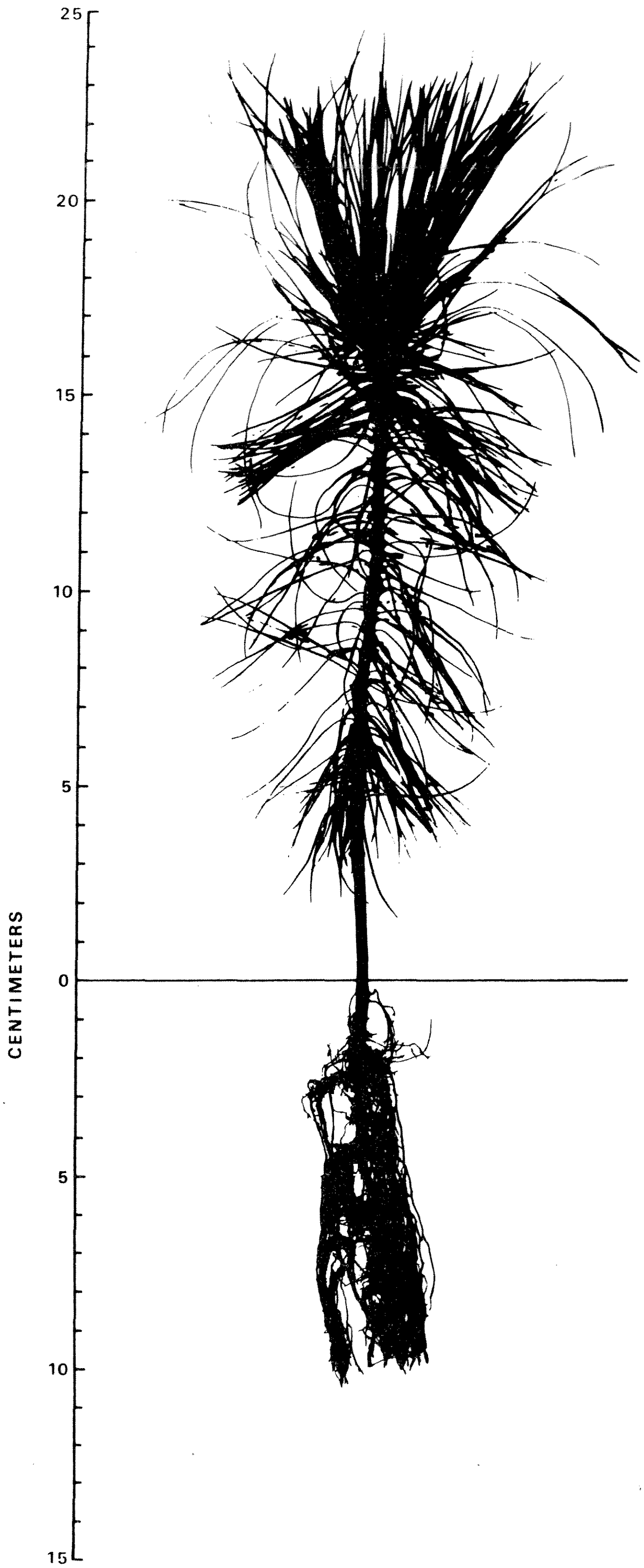

Figure 10-3.—*Loblolly pine seedling development.*

11. DESIRED SEEDLING CHARACTERISTICS

Containerized seedlings of low vigor or poor quality can survive if soil moisture and other planting site conditions are near optimal. However, when less favorable conditions are met soon after outplanting, the morphological and physiological conditions of the outplanted seedlings are closely related to their ability to survive. A number of workers have noted that large and woody seedlings survive and grow better than smaller seedlings on difficult sites or where competition is severe (Iverson and Newton 1980, Davidson and Sowa 1974, Walker and Johnson 1980, Barnett 1974d). Southern pine seedlings are usually large enough at 12 to 14 weeks to perform well in the field. A few more weeks of growth may be desired when planting more difficult sites. Age alone, however, is not a reliable criterion of when to plant, because seedling development varies greatly by season, facility, and cultural treatment.

Almost 30 years ago, Wakeley (1954) established a grading system based on morphology for bare-root southern pine seedlings. This grading system, based primarily on height, diameter, and nature of the stem, is still the best available. However, because there are basic differences in age, development, and cultural regimes between bare-root and container-grown seedlings, grades established for bare-root stock may not be the same as for those grown in containers. Over the past several years we have tried to determine which morphological characteristics of containerized seedlings relate directly to field performance.

11.1 Characteristics to Consider

A variety of seedling characteristics have been directly related to field performance at one time or another. These include: shoot-to-root ratio, height, stem diameter, dry weight, chlorophyll content, secondary needles, and mycorrhizal development. The value of these measurements as indicators of performance for container-grown seedlings varies greatly.

11.1.1 *Shoot-to-Root Ratios*—Seedlings usually have been reared with the view that the ideal seedling shoot-to-root ratio should be between 1 and 2 (Ferdinand 1972, Wakeley 1954). Recent work by Walker and Johnson (1980) with northern species of spruce and pine shows that much higher shoot-to-root ratios may be desirable for container-grown seedlings. Regression analyses of their data indicate that the weight obtained 1 year after planting is proportional to initial seedling weight and shoot-to-root ratio; larger seedlings with shoot-to-root ratios of up to 7.4 had significantly greater weight increases than smaller seedlings with ratios of 2.0. A similar relationship was found with the southern pines when shoot-to-root ratios were related to seedling height (fig. 11-1).

It is apparent from the data shown in figure 11-1 that a so-called "balanced" seedling is not necessary or even desirable with container-grown plants. Studies by McGilvray and Barnett (1982) with container-grown southern pines indicate that higher shoot-to-root ratios are more a function of larger shoots than variations in root size. They concluded that the shoot-to-root ratio is generally not a meaningful criterion when evaluating containerized southern pine seedlings.

11.1.2 *Chlorophyll Content*—Chlorophyll content in seedling needles has been shown to give an estimate of stock quality (Linder 1980). McGilvray and Barnett (1982) found the chlorophyll content of the needles at planting was correlated to the height of the pine seedlings 1, 2, and 3 years later (table 11-1). In this particular study, high chlorophyll content related well to seedling vigor. However, different nutritional regimes were practiced during the greenhouse growing period, and thus differences in seedling quality may have been due to a close relationship between chlorophyll and nitrogen contents. Chlorophyll is generally a nonspecific indicator that is influenced by many factors. When seedlings are grown with abundant nutrients, chlorophyll content may not be closely related to field performance.

11.1.3 *Mycorrhizae*—The visible presence of mycorrhizae on slash and loblolly pine seedlings indicates increased survival of nursery stock (Jorgensen and Shoulders 1967, Shoulders and Jorgensen 1969). The amount of mycorrhizae can have a significant effect on survival and growth of southern pine nursery stock.

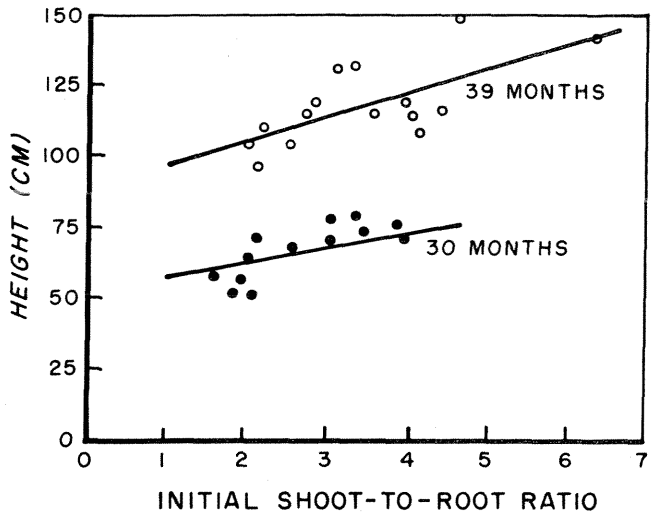

Figure 11-1.—*Initial shoot-to-root ratio and seedling height relationships 30 and 39 months after outplanting of loblolly pine.*

The need for mycorrhizal development on container-grown seedlings is probably not as great as with bare-root plants because the root system remains intact when planted, and initial stress conditions are less severe. Shortleaf pine seedlings grown in contain-

Table 11-1.—*Summary of correlation coefficients relating initial seedling development to field performance (from McGilvray and Barnett 1982)*

Seedling characteristic[1]	Survival 1977	Survival 1978	Survival 1979	Height 1977	Height 1978	Height 1979
Loblolly pine						
Height	0.021	0.238	0.324	0.972*[2]	0.743*	0.738*
Diameter	.168	.361	.455	.913*	.819	.833
Root weight	−.345	−.259	−.339	−.078	−.225	−.259
Stem weight	.049	.294	.315	.870*	.646*	.655*
Chlorophyll	.235	.418	.595*	.771	.915*	.899*
Longleaf pine[3]						
Diameter	.079	.046	.020	−.106	−.112	−.162
Root weight	.534*	.522*	.479	−.396	−.435	−.431
Stem weight	−.252	.296	.176	.548*	.590*	.555*
Chlorophyll	−.418	−.566*	.443	.866*	.810*	.798*
Shortleaf pine						
Height	.052	.147	.283	.929*	.829*	.784*
Diameter	−.142	−.058	.099	.761*	.760*	.687*
Root weight	.170	.157	.182	−.061	−.021	−.057
Stem weight	.030	.128	.249	.773*	.743*	.666*
Chlorophyll	.281	.193	.302	.913*	.861*	.832*

[1]Seedlings outplanted June 22, 1976; all measurements taken during the month of February.

[2]An asterisk represents statistical significance at the 0.05 level.

[3]Longleaf growth was evaluated by measuring root-collar diameter rather than height.

ers and inoculated with *Pisolithus tinctorius* and *Thelephora terrestris* mycorrhizae did not survive or grow better than those that were not inoculated when outplanted on dry sites in the Ouachita Mountains of Arkansas (Ruehle and others 1981). In fact, performance of inoculated seedlings with over 50 percent root infection was no better than for seedlings grown under a high fertility regime where only 16 percent of the roots showed mycorrhizae. The presence of mycorrhizae on root systems becomes more important as the planting sites become more difficult. Goodwin (1980) reported that inoculation with *Pisolithus* increased field performance of container-grown loblolly and Virginia pine on an adverse borrow site.

11.1.4 *Secondary Needles*—The development of fascicle or secondary needles is one criteria used by Wakeley (1954) in his seedling grading system for nursery stock. Tests with container-grown southern pines show that the presence of secondary needles is an important indicator of seedling development (Barnett 1980a). Secondary needles develop when the stem becomes woody and stiff. This condition represents a stage when the seedlings become more hardy and less susceptible to cold and drought damage. Thus, seedlings that have secondary needles are more vigorous than those that have not yet reached this stage of development.

11.1.5 *Stem diameter*—Stem diameter was shown to be a characteristic closely related to seedling development of loblolly and shortleaf pine (table 11-1). Other tests (McGilvray and Barnett 1982) confirmed the relationship of loblolly pine stem diameter to seedling growth after outplanting. Although stem diameter was not consistently related to field survival, when combined with other easily measured characteristics, predictions of field performance should improve.

11.1.6 *Seedling Heights*—The height of a seedling when outplanted is generally a good indicator of subsequent field performance (Walker and Johnson 1980, Iverson and Newton 1980). Studies with container-grown southern pines confirm this observation (table 11-1). Not only is height at the time of outplanting closely related to subsequent heights, it is also correlated to incremental growth for a number of years (table 11-2). How long this relationship will

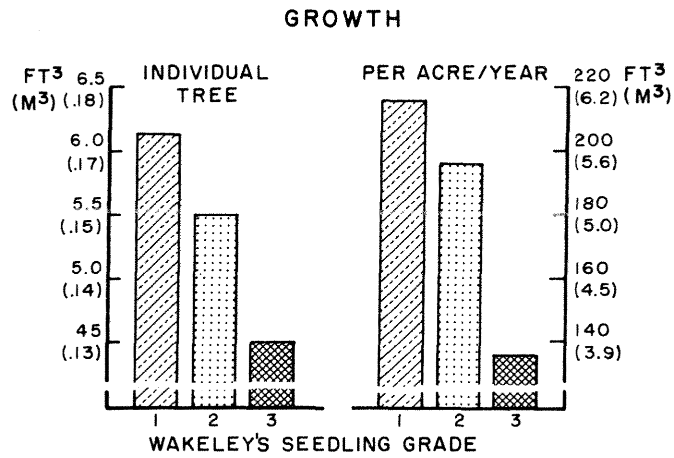

Figure 11-2.—*Volume performance of graded slash pine seedlings after 13 growing seasons (Blair and Cech 1974).*

hold is open to question. Blair and Cech's (1974) work with slash pine nursery stock has shown that Wakeley's Grade 1 and 2 seedlings produced significantly more volume after 13 years than Grade 3 seedlings (fig. 11-2). In Wakeley's morphological grades, height is a major criterion, with the lower grades exhibiting greater seedling height. Similar results have been published for loblolly pine after 30 years (Wakeley 1969).

Heights and diameters should both be considered when developing predictions of field performance. If containerized seedlings are grown at high seedling densities, heights may be about the same as when grown at lower densities, but stem diameters of the seedlings grown at the lower densities will be larger, and seedlings with larger stem diameters perform better in the field (Barnett 1980b).

11.1.7 *Dry Weights*—Dry weights of seedling stems at the time of outplanting were proportional to heights in the field over several years (tables 11-1, 11-2), but were not closely related to survival. Positive correlations of dry weights of roots at outplanting to survival did not occur consistently. Correlations of both height and growth to total seedling dry weight did occur with loblolly pine in another study (table 11-2). Differences in response among studies seem related to environmental conditions at or shortly after planting.

Table 11-2.—*Correlation coefficients of morphological characteristics of loblolly pine seedlings at time of outplanting with heights and growth in the field*

Seedlings characteristic[1]	Height			Growth/year		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Height	0.864[2]	0.814	0.829	0.490	0.770	0.840
Stem diameter	0.899	0.864	0.832	0.579	0.826	0.842
Root weight	0.700	0.641	0.628	0.386	0.594	0.582
Stem weight	0.890	0.837	0.847	0.536	0.790	0.846

[1]Outplanted February 1976.
[2]All values shown are statistically significant at the 0.05 level.

11.2 Suggested Characteristics for Loblolly Pine

There is an insufficient amount of data available to specify which characteristics of containerized southern pine seedlings are necessary to obtain maximum survival and growth when outplanted. Our best information is for loblolly pine, but these data are from studies not designed to provide predictive equations relating initial seedling quality to field performance. However, these data are probably the best available for the southern pines and will give some feel for the relationship between morphology and growth.

There is considerable difference in measurement ease and reliability of the various seedling characteristics that relate to field performance. Characteristics such as chlorophyll content, dry weights, and shoot-to-root ratios are not as easy to determine as are seedling heights or diameters. Results indicate that simplification of measurements may be feasible. For example, seedling stem diameter at the time of outplanting is closely related to initial height (fig. 11-3). This initial stem diameter is also related to seedling heights in the field 2 and 3 years after planting (fig. 11-4). Correlations of stem dry weight with height after outplanting are also significant (fig. 11-5), and these correlations are similar to those that relate initial height to field heights 1, 2, or 3 years later (fig. 11-6).

As long as the type of container and cultural treatment remain constant and provide for 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 taken into consideration.

The correlations of seedling diameters, stem weights, and heights at the time of outplanting all indicate that, within the range of the data, field performance improves as size at the time of outplanting increases. Not only are seedling heights greater in the field after several years, but yearly growth several years after outplanting is affected (fig. 11-7).

This indicates that larger seedlings perform better in the field. However, these results reflect a limited range of initial seedling sizes—from about 7.6 to less than 23 cm (3-9 in) in height. Also, it is expected that a point exists after which larger seedlings do not result in greater field growth.

Additional data with larger initial seedling sizes (18-33 cm; 7-13 in), show that in this larger size range, no correlation occurs with field heights (fig. 11-8). Thus, biologically as well as economically, there are practical limitations as to how large seedlings should be at outplanting.

11.3 Summary of Minimum Specifications

A number of seedling characteristics were closely related to growth in the field. Of these, height was directly related to field performance and is the most easily measured. A combination of heights and other characteristics is probably desirable when seedlings are evaluated after being grown under varying container, cultural, and environmental conditions. For loblolly pine seedlings, heights of 15 to 20 cm (6-8 in), presence of secondary needles and woody tissue, and diameters of 1.5 to 2.5 mm (0.06-0.10 in) at the time of outplanting should result in excellent survival and growth.

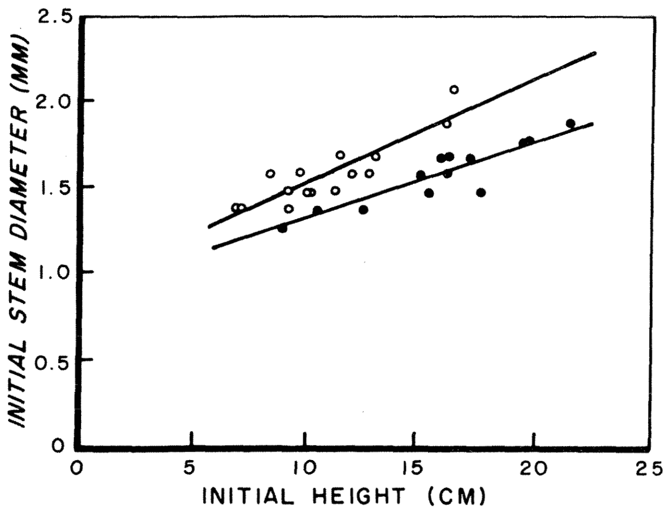

Figure 11-3.—*Relationship of initial height and initial stem diameter for loblolly pine seedlings, based on two separate outplantings.*

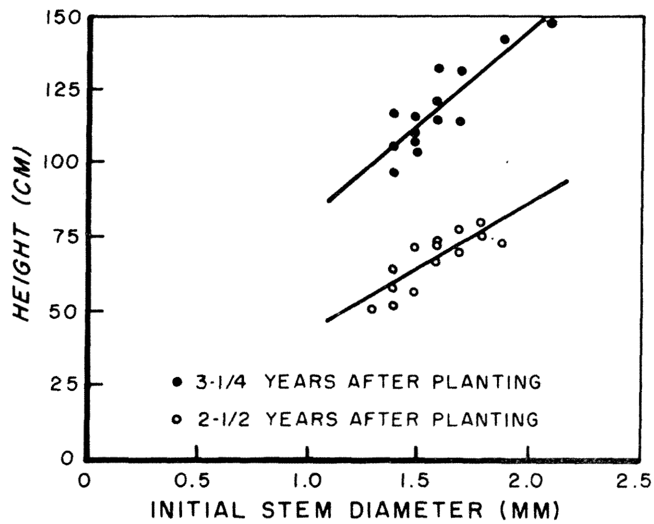

Figure 11-4.—*Relationship of initial stem diameter and height 2-1/2 and 3-1/4 years after outplanting for loblolly pine seedlings.*

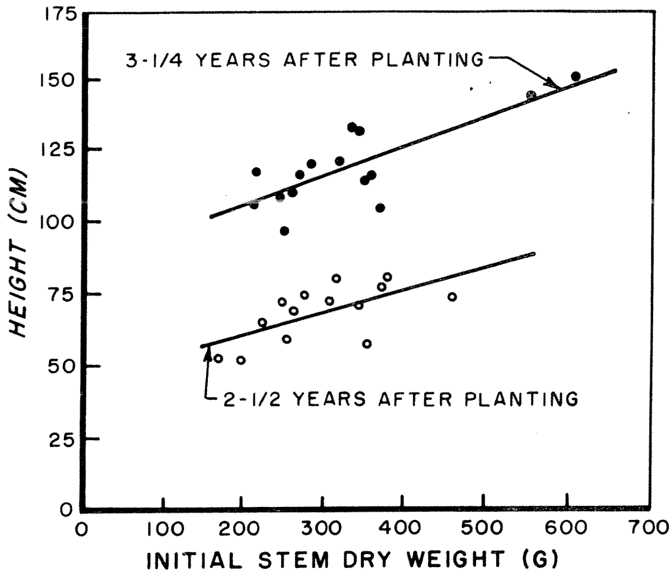

Figure 11-5.—*Relationship of initial dry weight and seedling height 2-1/2 and 3-1/4 years after outplanting for loblolly pine seedlings.*

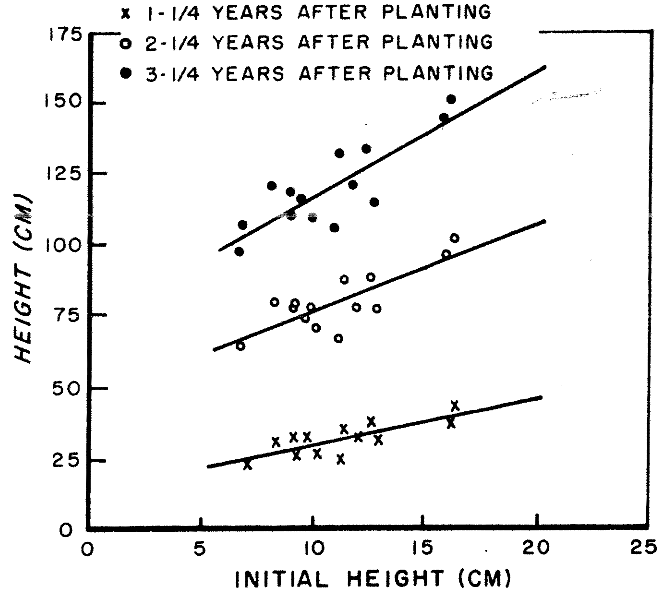

Figure 11-6.—*Comparison of initial seedling height to future height for loblolly pine seedlings.*

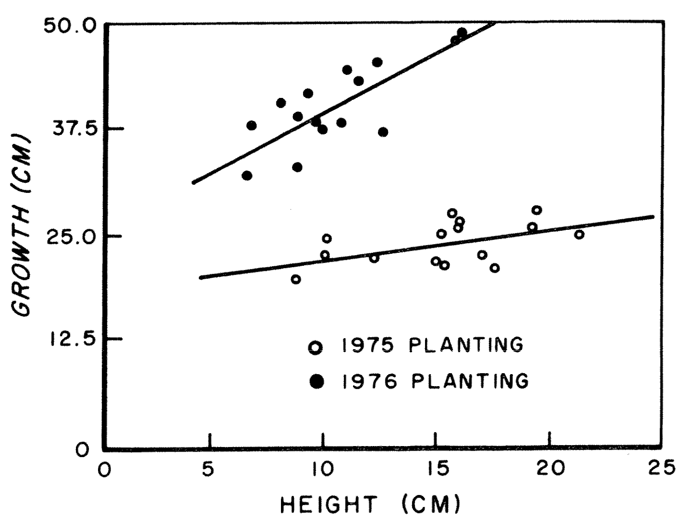

Figure 11-7.—*Relationship between initial height and growth over a 1-year period (Feb. 1978 to Feb. 1979) for loblolly pine seedlings based on two outplantings.*

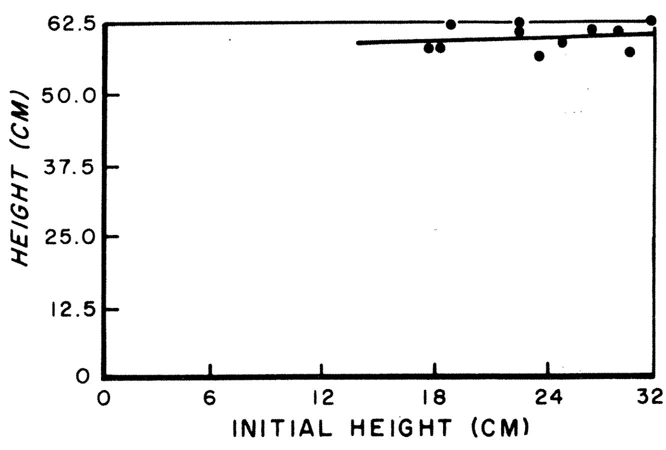

Figure 11-8.—*Initial height and field height relationship for loblolly pine seedlings 1-1/2 years after outplanting.*

12. PROCESSING, HANDLING, AND PLANTING

12.1 Extraction from Containers

Once high quality containerized stock is produced, growers face the equally demanding task of maintaining that quality until planting. How stock is processed will depend upon what type of container is used. If seedlings are grown in tubes or blocks, they are shipped and planted in their containers. If seedlings are grown in plug-type containers, a decision must be made whether or not to extract them from the containers before shipment. Both techniques have inherent advantages and disadvantages.

The advantages of extracting seedlings from plug-type containers include significantly less shipping and storage volume, the ability to grade the root system as well as the seedling shoot, and not having to return the containers to the nursery. Disadvantages of this system are also significant, however. To avoid a serious reduction in stock quality, extracted seedlings must be completely dormant and cold-hardy (Landis and McDonald 1982). For southern pines this would be difficult, and the planting of extracted plug seedlings would be restricted to essentially the same planting season as for bare-root stock, thus nullifying the advantage of extending the planting season with container stock.

When seedlings are left in the container for shipping and handling, the root plug will receive maximum protection with the opportunity for more rapid establishment once outplanted. Leaving seedlings in the container until they are planted also allows for handling of nondormant stock necessary for extending the bare-root planting season. Disadvantages of this system are the increase in volume of material shipped and stored, which often includes empty cells, and seedlings can only be graded on shoot characteristics. Also, containers must be returned to the nursery, which is expensive and invariability results in some container damage.

Both system can be used to their greatest advantage. Seedlings shipped prior to becoming sufficiently cold-hardy, and those shipped in the spring after shoot growth has begun, should be left in the container until planting. Containerized seedlings shipped while dormant can be extracted and wrapped in bundles or packed in boxes. The Ray Leach single cells offer a unique alternative. These individual plastic containers can be removed from the growing racks and shipped much like extracted seedlings, but the container protects the root plug until planting. The empty cells must still be returned to the nursery for reuse.

12.2 Transporting Seedlings

Refrigerated transportation is best for either extracted seedlings or those shipped in the container. However, if refrigerated transport is not available, enclosed vehicles, slat-sided trucks, or trailers with tarpaulin tops can be used. Air circulation among seedlings is essential to prevent overheating. This can be accomplished by leaving the back of the vehicle open or by some other method that provides airflow without subjecting the seedlings to the wind created by highway speeds. Air temperature around the seedlings should not be allowed to exceed 29 °C (85 °F). In unrefrigerated trucks or trailers, monitor temperatures at the beginning and end of the haul. If the trip is longer than 3 or 4 hours, check the temperature around the seedlings periodically. If temperature in the vehicle begins to get too warm, it may be necessary to find a shady place and water the seedlings if possible. In hot weather, haul seedlings at night. Even for short trips, containerized seedlings should not be exposed in open trucks or trailers because they are susceptible to rapid desiccation and overheating.

For economy and efficient use of space, trucks or trailers should be fitted with racks or stacking pallets (Guldin 1983, Luchkow 1982). When shipping in boxes, the seedling boxes must be designed for proper stacking strength and size. Improperly designed boxes can waste valuable and costly cargo space (Hoehnke 1974). At the nursery, pallets can generally be loaded with a forklift. At the planting site, unloading can best be handled if the truck or trailer is fitted with a hydraulic tailgate and small swiveling crane.

Be sure that truck and trailer beds used for seedling transport are clean and clear of gasoline, diesel fuel, pesticides, and sharp implements. These can kill or injure seedlings, tear seedling boxes, or damage containers.

12.3 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 dormant, is often the key to reforestation success. However, temporary storage, either enroute or at the planting site, is common due to 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, unheated barn, or even a shady spot is better than exposing seedlings to direct sun. Do not forget to allow for adequate air circulation to prevent overheating. Monitoring the temperature of seedlings stored in boxes or bags is especially critical. Temperatures above 27 °C (80 °F) can initiate mold and decay, and 48 °C (118 °F) for 2 hours is lethal to loblolly pine seedlings (Ursic 1961).

In cold weather, containerized seedlings should also 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 the shoots. However, containerized seedlings waiting to be planted in the field can be subjected to low temperatures that will be lethal to their roots. Moreover, cold damage to roots is not as obvious as cold damage to shoots. Root mortality will not be observed until the shoots are placed in an environment favorable to growth. In an Arkansas study, survival was less than 50 percent for containerized seedlings exposed to −10 °C (14 °F) in February, compared to greater than 90 percent survival of seedlings from the same crop that were moved inside prior to the low temperature (Mexal and Carlson 1982). Styrofoam-type containers provide greater insulation from temperature extremes than hard plastic containers, tubes, or blocks.

Because of the relatively small volume of media containerized seedlings are grown in, they 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 bare-root seedlings; that is, they should be kept shaded, the packages reclosed if opened, and watered when necessary to keep the root plug moist. Seedlings shipped in the container should be thoroughly watered at the nursery and rewatered as necessary to maintain the media at field capacity until planting.

12.4 Selecting and Preparing Suitable Planting Sites

As indicated in Chapter 3, containerized seedlings perform as well as, or better than, bare-root stock on a variety of sites. Due to limitations of planting season or seedling physiology, bare-root stock does not always survive and grow well when planted on such adverse sites as wet flatwoods, deep sandy soils, highly erodible fragile soils, spoil banks from mining operations, and drier tension-zone soils (Barnett 1980a). Containerized seedlings, however, have performed well under such adverse conditions in the South (Amidon and others 1982, Barnett 1975, Goodwin 1980, Ruehle 1982a). These successes can be attributed to more rapid establishment of the undisturbed root system or to planting during a season when advantage can be taken of more favorable planting conditions on a particular site. As with bare-root seedlings, success depends on using the most appropriate species and seed source for the intended planting site.

12.4.1 *Site Suitability*—Several environmental factors must be considered before planting containerized seedlings, especially on adverse sites or outside the normal planting season. Factors that will affect planting success include: 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 (Hite 1976).

Available soil moisture is the most critical factor in evaluating the suitability of a site for planting. Soil texture and moisture content determine the soil water potential, which is a measure of the amount of water in the soil available for plant growth. At field capacity, soil water potential is about −0.3 bars. 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 or less (Hite 1976). Soil water potential can be determined with a portable tensiometer or by obtaining pressure chamber measurements of plant water potential taken before sunrise from established vegetation on the site.

Tensiometer and pressure chamber readings, however, do not indicate the rate at which soil water potential is likely to change. Soil water potential will decrease more rapidly in sandy soils or when the weather is hot and dry than in clay soils or under cool, humid conditions. With advanced planning, soil moisture retention curves can be developed by a soils laboratory for specific planting sites or generalized by soil types. These curves indicate the rate of water depletion from the soil. Tensiometer or pressure chamber readings can then be used to determine where the current soil moisture potential of the site is located on the curve. Thus, an estimate is obtained of how much water is available in the soil and how long it will last (Legard 1977). Such detailed site evaluation is especially valuable if the intended planting site is particularly severe or if planting under droughty conditions is anticipated.

12.4.2 *Site Preparation*—The degree of site preparation can have dramatic effects on the performance of outplanted seedlings. Site preparation prior to planting can be designed to do any or all of the following: reduce slash residues, limit vegetative competition, or alter the microsite to enhance seedling performance. Since containerized seedlings are generally smaller than bare-root stock, competition control is a particularly important aspect of site preparation. In a comparison study on a low-competition site, containerized shortleaf pine had 2.5 times the plot volume index of bare-root seedlings (Ruehle and others 1981). But on a site with dense herbaceous vegetation, containerized seedlings had only 60 percent of the plot volume index of bare-root seedlings.

In another study, loblolly pine seedlings planted in July survived better on mechanically prepared sites than on a fresh burn, particularly when planted on a silt-loam soil where herbaceous growth following the burn resulted in severe competition (table 12-1) (Barnett 1980a). On the silt-loam soil, a 1-foot wide scalped area was as effective as disking in increasing survival, but disking was more effective in promoting height growth. On a sandy-loam soil where competition was less severe, fewer differences in survival were related to site preparation. Again, disking was the most effective treatment in promoting height growth.

The amount of site preparation necessary also differs by species. Longleaf pine seedlings are more intolerant of competition than the other southern pines, so their survival and growth are enhanced by more intensive site preparation (Barnett 1974a).

12.5 Planting Techniques

Despite their bulk and weight, ease of planting is one of the most attractive features of containerized seedlings. The uniformly shaped root systems of container-grown seedlings are easy to plant by hand or by machine, with the potential for automated planting much greater than for bare-root stock. Descriptions of available hand planting tools and planting machines have been compiled by Larson and Hallman (1980). A discussion of the advantages, disadvantages, and operation of each piece of equipment is provided in addition to a list of suppliers.

12.5.1 *Hand Planting*—Containerized seedlings can be hand planted with conventional bare-root 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 up to twice the rate of hand planting bare-root stock (Appelroth 1971, Vyse 1971, 1973). These planters work by displacing or dibbling the soil to make room for the seedling root ball, with the effectiveness depending a great deal on the soil type and soil moisture. They work well on midrange soil types such as sandy loam, loam, and silt loam (Edwards 1974). For clay soils, tools 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 by properly planted. Hand-held power augers can be used for planting stock grown in very large containers.

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 12-2) (Barnett 1980a). Survival and height growth of lodgepole pine (*Pinus contorta* Dougl. ex Loud.) in a compacted clay loam with bulk density of 1.9 g/cm^3 (119 lb/ft^3) or higher in Saskatchewan, Canada, was best when a soil core was removed for planting (Bohning 1981). In both studies, seedlings planted in dibbled holes on lighter textured soils or in soils with bulk density of less than 1.6 g/cm^3 (100 lb/ft^3) performed as well or better than seedlings planted in core holes.

When containerized 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. The root systems were classified longitudinally and radially into 13 zones, and

Table 12-1.—*Average survival and heights for loblolly pine seedlings on different prepared sites*[1]

Site preparation method	Silt loam soil			Sandy-loam soil		
	Container			Container		
	PP[2]	KTS	S-2	PP	KTS	S-2
	survival (percent)					
Burn	36	40	32	45	78	71
Scalp	68	77	65	51	91	70
Disk	33	73	53	58	92	90
	height (cm)					
Burn	0.40	0.43	0.43	0.31	0.46	0.43
Scalp	0.34	0.49	0.40	0.34	0.43	0.34
Disk	0.43	0.58	0.43	0.40	0.58	0.46

[1]Measurements taken 1½ years after outplanting in July 1978.
[2] PP = Paperpot
KTS = Keyes Tree Start
S-2 = Styroblock-2

Table 12-2.—*Average survival of loblolly pines using two planting methods with three different soils*

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

[1]Numbers within columns followed by the same letter are not significantly different at the 0.05 level.

on the 325 seedlings excavated, egressed roots were found in an average of 11 of the available zones of the plug mass (Rischbieter 1978). In general, poor root egress was found only where soils had been damaged, aeration was poor, or seedling vigor was markedly reduced due to factors other than soil texture.

12.5.2 *Mechanical Planting*—Most mechanical planters designed for bare-root seedlings can be adapted for planting container stock with only minor modifications. Conventional planting machines are either of the continuous or intermittent furrow type and are usually manually fed. The only modifications necessary for containerized seedlings on continuous furrow machines may be in operator technique, while on intermittent planters some changes to the seedling holding mechanisms may be necessary.

Sophisticated, self-propelled, prototype machines for automatic planting of seedlings grown in particular containers have been developed in Finland and Canada (Kohonen 1982, Pease 1980, Walters and Silversides 1979). These machines plant 2 or 3 seedlings simultaneously and have the capacity to plant up to 3,000 trees per hour, depending on the site. Both the prototypes are capable of scarifying the planting spot just prior to planting the seedling. Although expensive, such machines may be justified for very large scale reforestation activities in areas where hand planting labor is not available or is inadequate. The price a land manager is willing to pay for any planting machine depends on the machine production rate and the local hand planting costs (McKenzie and others 1981). Few potential buyers realize how much they can pay for a tree planting machine when all factors are considered.

12.5.3 *Depth of Planting*—As with bare-root stock, planting containerized seedlings to the proper depth is important to ensure good survival and growth after outplanting. Containerized seedlings should be planted deep enough so that the top of the root plug is covered with about 1 cm (0.4 in) of soil. Covering the container reduces drying in the root zone caused by the wicking effect of the media or planted container. Planting below the ground line also prevents frost heaving of fall-planted container stock (Walker and Johnson 1980).

Care must also be taken not to plant containerized 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 stock than with bare-root seedlings (Robbins and Harris 1982).

12.5.4 *Season of Planting*—One of the greatest potential benefits of containerized seedlings is being able to extend the planting season. In central Louisiana, containerized 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 (Barnett 1980a, Amidon and others 1982). For winter planting of containerized southern pines, it is essential that they receive sufficient hardening-off before outplanting.

Trends in field performance were similar for both loblolly and slash pine container-grown seedlings outplanted monthly from January to September on a silt loam soil (see figs. 5-2, 5-3). The poor survival of loblolly pine planted in January was attributed to the fact that the stock had not been hardened off. The greater average height of bare-root trees compared to containerized trees of both species indicated that the bare-root seedlings had maintained the size advantage they had at planting throughout the three growing seasons of the study.

Caution must be exercised if planting under drought conditions is contemplated. Adequate soil moisture is essential for seedling establishment and survival. Methods of evaluating soil moisture available for plant growth were discussed in section 12.4.1. In addition to estimating soil moisture, weather forecasts should also be considered during the normally hot and dry months from late spring through fall. While planting containerized seedlings during other than the normal planting season has been sucessful, adequate planning and operational flexibility are required.

12.6 Sampling for Quality and Establishment of Evaluation Plots

The use of container-grown stock for reforestation is relatively new in the South. Containerized seedlings are often planted in comparison trials with bare-root stock to determine suitability on particular sites, during specific times of the year, or using various techniques. It is very important that proper sampling and evaluation techniques are used to adequately determine the performance of containerized seedlings in the field.

In many cases the land manager will only be interested in first year stocking or survival. The words stocking and survival are often used interchangably when discussing planting success. The two concepts are different, however. Stocking refers to the number of trees per acre and is often estimated to determine the need for replanting. Survival is the number of living trees at a given time, expressed as a percent of the number of trees planted. Survival estimates are most useful for identifying problem areas and comparing stock types or planting methods.

Stocking is generally estimated by counting the number of live trees on fixed-area circular plots spaced either randomly or systematically over the planting site. Large-scale aerial photography offers a monitoring alternative to such conventional ground surveys. Photographic surveys are faster and may be more economical in some situations. Conifer seedlings 30 cm (12 in) or more in height can be readily indentified during the winter months on imagery at scales of 1:500 to 1:1000 (Ball 1981).

For ground surveys, the number of sample plots required for stocking estimates depends on the plot size, the degree of accuracy desired, and the stocking variability from plot to plot. Sample variability increased with decreasing plot size; therefore 40-m^2 (0.01-acre) plots have been recommended for stocking estimates (Ursic 1960, Xydias and others 1983). Tract size also affects sample variation. Consequently, the practice of specifying one plot per planted 0.4 ha (1 acre) will likely undersample plantings of 12 ha (30 acres) or less and oversample tracts of 40 ha (100 acres) or more (table 12-3) (Xydias and others 1983). If survival data is required from a planting, the best method is to establish and stake the center of the 40-m^2 (0.01-acre) plots at the time of planting. When the plots are established, the number of trees planted is recorded and the number of live trees is tallied after the desired time interval. Survival can then be easily and accurately calculated. Methods of estimating planting rate, such as bale counts or spacing, are seldom accurate enough to be used as reliable indicators of the number of trees in survival calculations (Xydias and others 1983).

To determine if there are differences between stock types or planting methods, as well as for other comparisons, measurements of growth are also important. Heights, stem diameters, and dry weights are seedling characteristics useful in evaluating outplant performance.

A simple experimental design of field plots has been recommended that will allow valid, statistical comparisons between two or more variables (Owston and Stein 1974). They suggest locating four plots (replications) within the locality of interest. Site conditions within each plot should be as uniform as possible, but conditions among the plots can be varied or uniform. The plots should be accurately mapped.

Each of the four plots should contain two rows of each treatment being studied. For a bare-root versus container comparison, each plot would consist of four rows, two of container-grown trees and two of bare-root seedlings. Each row should contain at least 25 trees. Treatments should be assigned to the rows randomly, and the randomization should be made independently for each plot. The plot corners and row ends should be permanently marked to facilitate relocation and measurement.

Other factors to consider when planning comparison evaluations include: the seed source used, the size of seedlings planted, handling and care prior to outplanting, and postplanting care. If the field plots are laid out as suggested, and the seedlings are treated identically except for those characteristics being compared, differences in performance should be due to the variables tested and not to other factors.

Table 12-3.—*Number of 40-m^2 (0.01-acre) plots required to estimate first-year stocking by area planted (from Xydias and others 1983)*

Hectares (acres) planted	Confidence[1] 90%	95%
8 (20)	20	28
16 (40)	31	44
24 (60)	42	60
32 (80)	49	69
49 (120)	52	74
65+ (160)	57	81

[1]Confidence interval = 124 trees/ha (50 trees/acre).

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Provides information on types of containers, use of media, cultural treatments, seed selection, disease and environmental controls, and planting preparation for container grown seedlings.

Keywords: planting guidelines, *Pinus* spp., survival and growth, quality, physiology.

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