The Container Tree Nursery Manual

Volume Two
Containers and Growing Media

Chapter 1
Containers: Types and Functions

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2.1.1 Introduction

2.1.1.1 History of container use in forest nurseries

Although ornamental plants have been grown in containers since the early days of human civilization (Matkin and others 1957), the production of forest tree seedlings in containers is a relatively recent innovation. One of the first large-scale uses of container tree seedlings in North America was during the Great Plains Forestry Project of the 1930's. A tarpaper pot system was developed to produce hardy container seedlings for the harsh environmental conditions encountered in shelterbelt plantings (Strachan 1974).

The first large-scale production of reforestation seedlings in modern plastic containers was in Canada: the "Walters Bullet" in British Columbia (Walters 1974) and the "Ontario Tube" in Ontario (Reese 1974) (fig. 2.1 .1). Based on these early prototypes, other containers were developed and tested in Canada and the United States during the 1960's and early 1970's, including some that are still popular today: Styrofoam® blocks (Sjoberg 1974), Spencer-Lemaire (S/L) Rootrainers® (Spencer 1974), and the Ray Leach Single Cell® syste m (Allison 1974). In addition to these North American products, the "Japanese paperpot" was adapted in Scandinavia (Rasanen 1982) and subsequently imported to the United States and Canada.

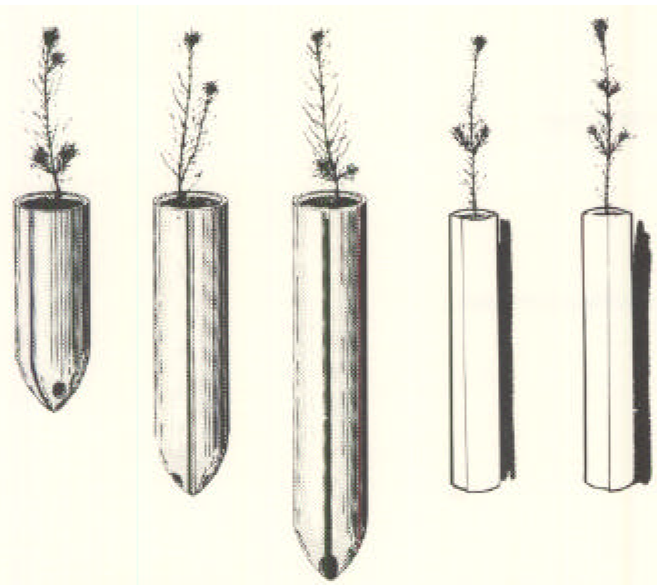


Figure 2.1.1—*The Walters bullet (left) and the Ontario tube (right) were two early container designs used for growing forest tree seedlings in Canadian nurseries (from Carlson 1983).*

Many types of containers have been tested in North American forest tree nurseries during the past 20 years (fig. 2.1.2), but the perfect container has yet to be developed. In reality, no single container will ever fill the needs of every nursery manager because of differences in nursery cultural practices or outplanting site conditions. Which is the best container for a given purpose will depend on the specific objectives of the nursery and of the reforestation system.

2.1.1.2 Terminology

Certain terms that are used to describe containers in forest tree nurseries need to be defined here. In container nurseries that produce ornamental tree seedlings, the individual containers are relatively large, single containers that are called **pots** or **cans.** Reforestation stock, by comparison, is grown in relatively small-volume containers. The individual containers are often referred to as **cells** or **cavities,** and are usually produced in aggregates called **blocks, trays, or racks** (fig. 2.1.3). In the common nursery vernacular, however, the term **container** can refer to a single cell or the entire block.

Seedlings grown in containers have been called containerized, or container-grown, but they will be known as **container seedlings** in this publication. This term is simple and definitive and is consistent with the most current terminology in the ornamental nursery trade.

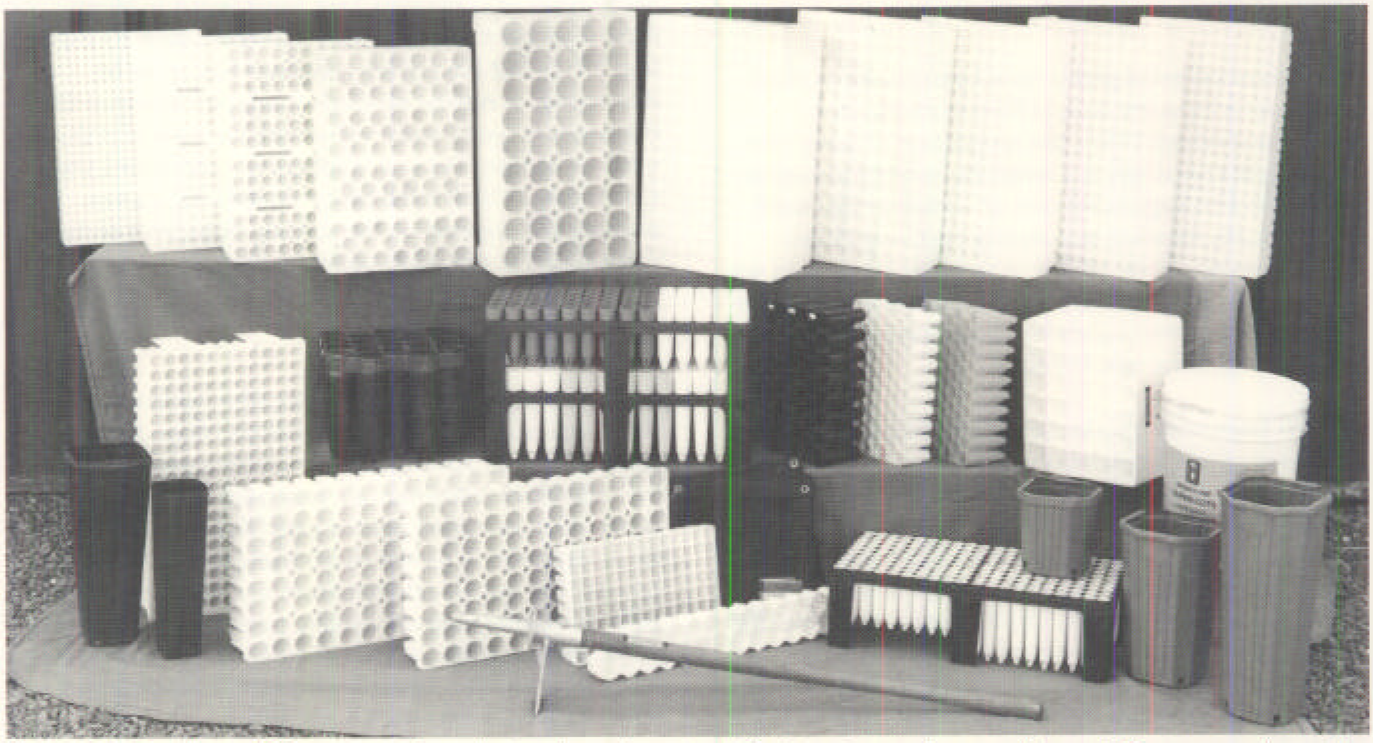


Figure 2.1.2—*Many different container designs have been tested in forest nurseries over the past 25 years, and a wide variety of brands and sizes is currently available (courtesy of Eric Stuewe).*

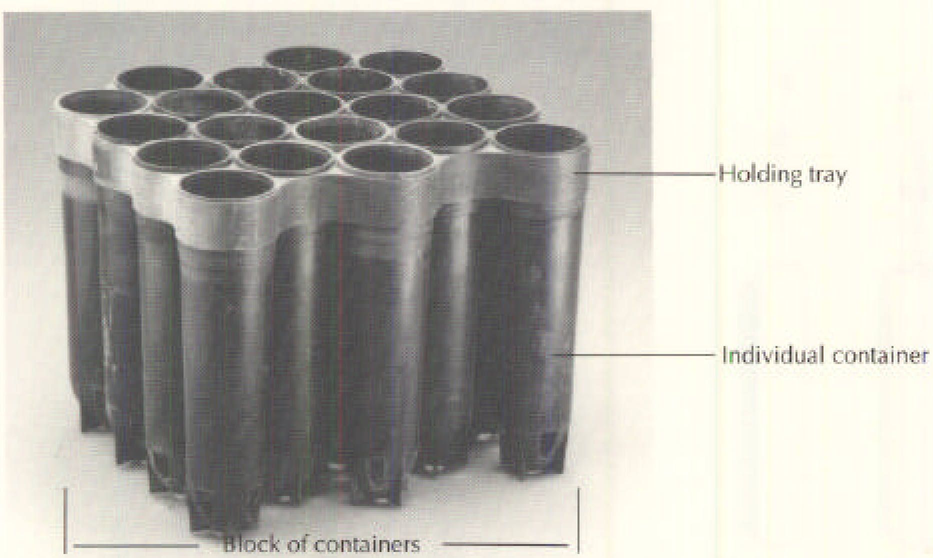


Figure 2.1.3—*Individual containers, or cells, are joined together by a tray or rack into a basic handling unit called a block; this container is the Deepot®.*

2.1.2 Characteristics of Containers for Forest Nurseries

The properties of the ideal container for raising forest tree seedlings have been debated for many years. Although containers can be compared in several different ways, the most appropriate is the functional approach. The primary function of any container is to hold a discrete supply of growing medium, which in turn supplies the seedling roots with water, air, mineral nutrients, and physical support while the seedling is still in the nursery.

Forest tree seedling containers must perform certain other functions, however, that reflect the special requirements of conservation or reforestation plantings. Some of these container characteristics shape seedling growth in the nursery, such as design features to prohibit root spiraling. Other operational characteristics of containers are related to economic and management considerations both at the nursery and on the outplanting site. These characteristics are listed and discussed in detail in the following sections.

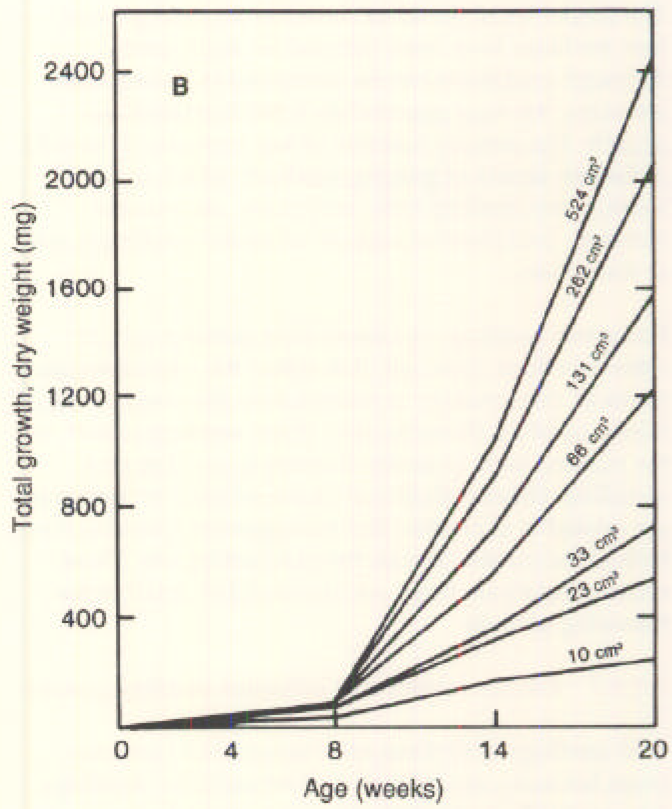
2.1.2.1 Characteristics that influence seedling growth

Tree seedlings differ from most ornamental container crops because conservation and reforestation seedlings are essentially a root crop. Most ornamental container crops are grown for their flowers or foliage, but the quality of a tree seedling is determined by its outplanting performance-both initial survival and subsequent growth. Tree seedling survival and growth are directly related to the ability of the root system to promptly regenerate new roots (known as **root growth potential,** or RGP) and grow out into the surrounding soil (Ritchie 1984). For this reason, many tree seedling container features are designed to encourage the seedling to form a good root system in the nursery and to protect these roots until the seedling is outplanted. The relative health and vigor of the root system is also reflected in the morphology and growth of the seedling shoot, and for this reason many of the following container characteristics were designed to enhance this root-shoot relationship.

Container size. The "best" container for a particular seedling crop will depend on both biological and economical factors. Biological considerations include the size of the seed or cutting, the ultimate size of the crop plant, and the environmental conditions on the Outplanting site. Economically, the initial cost and availability of the container and the amount of available growing space are primary considerations.

Although in the current forest nursery vernacular container size means volume, the concept of size includes all dimensional aspects, including volume, height, diameter, and shape. The volume of the cavity is one of the most obvious and important characteristics of a container because, in general, the larger the container, the larger the seedling that can be produced (Kinghorn 1974). North American container tree nurseries currently use containers ranging in volume from a minimum of 40 cm^3; (2.5 cubic inches) to a maximum of 492 cm^3; (30.0 cubic inches) (table 2.1 .l).

When tree seedlings are grown in a series of different container types, seedling size generally increases with the rooting volume of the container (fig. 2.1.4A) (Alm and others 1982). Container volume has a significant effect on the size and growth rate of lodgepole pine (fig. 2.1 .4B & C) (Endean and Carlson 1975) and white spruce (Carlson and Endean 1976) seedlings when they are grown in a variety of different container sizes. Root, shoot, and total dry weight as well as shoot length increased significantly with increasing container volume, whereas the shoot-root ratio was unaffected (table 2.1 .2). Seedling growth comparisons between different container types must consider both container volume and growing density (the spacing between containers), however, because containers with the same volume can have different growing densities. This important relationship between container capacity and growing density is discussed in the following section.



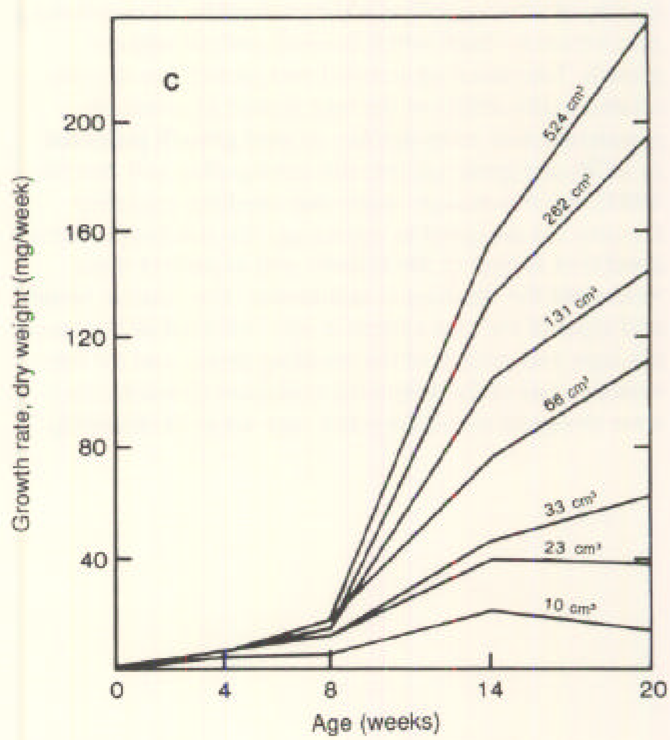


Figure 2.1.4—*Container size is one of the most significant factors affecting the ultimate size of tree seedlings, such as these lodgepole pines (**A**). In growth trials with this species, both total seasonal growth (**B**) and growth rate (**C**) were found to increase with the size (volume) of the container. (**B** and **C** from Endean and Carlson 1975).*

Table 2.1.1—*Characteristics of common container types used in U.S. and Canadian forest tree seedling nurseries*

	Dimensions of cell (diameter × height)		Maximum capacity		Cell density		1984 nursery use
	cm	in	cm^3	in^3	cells/m^2	cells/ft^2	%
Containers planted with seedling							
Paper containers							
Paperpot							
408	4 × 8	1.6 × 3.2	70	4.3	1,000	93	7
Other sizes							2
Total							9
Containers removed before outplanting							
Individual cells							
Ray Leach Single Cells®							
Fir cells	2.5 × 12.2	1.0 × 4.8	49	3.0	1,076	100	1
Pine cells	2.5 × 16	1.0 × 6.3	65	4.0	1,076	100	6
Super cells	3.8 × 20	1.5 × 8	164	10.0	527	49	8
Other sizes							1
Total							16
Book or sleeve containers							
Spencer-Lemaire Rootrainers®							
Ferdinand	2 × 2 × 10	0.8 × 0.8 × 4	40	2.5	1,280	119	4
Fives	2.5 × 2.5 × 10.5	1 × 1 × 4	62	3.8	882	82	1
Hillsons	3.8 × 3.8 × 12.5	1.5 × 1.5 × 5	165	10.5	398	37	2
Tinus	3.8 × 5.1 × 18.5	1.5 × 2 × 7.2	350	21.5	516	48	3
Total							10
Block containers							
Styrofoam® blocks							
2 (211)	2.5 × 11.4	1 × 4.5	41	2.5	1,032	96	9
2A (211A)	2.5 × 11.4	1 × 4.5	41	2.5	1,108	103	9
4 (313)	3 × 12.5	1.2 × 5	66	4.0	807	75	13
4A (313A)	2.8 × 13.2	1.1 × 5.2	62	3.8	936	87	5
5 (315)	3.0 × 15.2	1.2 × 6	77	4.7	667	62	2
7 (323)	3.0 × 22.9	1.2 × 9	121	7.4	764	71	2
8 (415A)	4.1 × 15.2	1.6 × 6	131	8.0	441	41	6
20 (615)	6.1 × 15.2	2.4 × 6	336	20.5	215	20	2
Colorado	5 × 5 × 20	2 × 2 × 8	492	30.0	270	25	2
Other sizes							1
Total							51
Ropak Multi-pot®							
#1	3 × 9	1.2 × 3.5	57	3.5	850	79	2
#2	3 × 12	1.2 × 4.8	65	4.0	850	79	8
Other sizes							1
Total							11
Other container types							3
Grand Total							100

Because containers types are continually evolving, some of these statistics may have changed. This information is presented to give the reader an idea of the products that are available. Contact suppliers (table 2.1.4) for current information.
Source: Container Nursery Survey (1984).

The major constraint on container volume is economical, not biological, because (a) larger containers take up more growing space, (b) seedlings grown in large containers require longer growing periods for the seedling root system to occupy the container completely, and (c) large containers are bulkier to handle during shipping and outplanting. Nursery managers should select a container that will produce an acceptable seedling at the highest practical growing density, in the shortest rotation time, and one that is suited to the conditions of the outplanting site (the effect of container volume on outplanting success is very important and is discussed in more detail in section 2.1 .2.2).

Optimum container size varies according to many different factors, including growing density, seedling species, size of seedling desired, type of growing medium, environmental conditions, and length of the growing season. There does appear to be a minimum container size for conservation and reforestation stock, however. Scarratt (1972) found that the growth of white spruce seedlings varied significantly in containers of three different diameters (12, 19, and 31 mm), but that only seedlings in the larger container (31 mm) achieved acceptable growth during a normal production period. Barnett and Brissette (1986) found that species that are intolerant of crowding, such as longleaf pine, grew bigger in large-volume containers with a low growing density. Other tolerant pine species, such as loblolly pine, could be produced in small-volume containers with a high growing density. Hardwood species generally require larger volume containers, with their concomitant lower growing density, than do conifer seedlings because the large leaves of hardwood species intercept more water and nutrients and generate more shade.

Other aspects of container size are also important. One of the most biologically and culturally important container dimensions is height, because of its effect on the water-holding properties of the growing medium (see section on container properties that affect growing medium moisture content). Carlson and Endean (1976) found that the height-diameter ratio had a significant effect on the growth of white spruce seedlings: a container with a 1 :1 height-diameter ratio produced heavier seedlings than containers with 3:1 or 6:1 configurations. This effect was apparently species-specific, however, because lodgepole pine did not show any growth differences when grown in the same three container sizes (Endean and Carlson 1975). Boudoux (1970) studied root system growth in relation to container dimensions and concluded that, to increase root density, diameter is more important than height.

Table 2.1.2—*Effect of container volume on the morphology of lodgepole pine seedlings at 20 weeks of age*

Container volume (cm^3)	Seedling biomass OD weight (mg) Root	Shoot	Total	Shoot/root ratio	Shoot length (mm)
10	96 g	150 f	246 g	1.6 a	34 g
23	222 f	319 e	541 f	1.4 ab	41 f
33	335 e	389 e	724 e	1.2 b	48 e
66	498 d	722 d	1,220 d	1.5 a	60 d
131	638 c	936 c	1,573 c	1.5 a	68 c
262	790 b	1,265 b	2,055 b	1.6 a	83 b
524	897 a	1,544 a	2,440 a	1.8 a	89 a

Values in columns with no letters in common differ significantly at the P = 0.05 level using Duncan's multiple range test.
OD = ovendry.
Source: Endean and Carlson (1975).

Forest tree seedling containers are produced in a variety of shapes: round, rectangular, hexagonal, or square in cross-section, and most are tapered from top to bottom. Although useful for seedling extraction, an extreme taper may be biologically detrimental, however, because normally the majority of roots are produced in the bottom of a container (Tinus 1974). The actual shape of the root plug is probably not operationally significant unless the seedling is going to be planted with a planting tool, such as a dibble, that has a specific size and shape. Container seedlings that are to be transplanted into bareroot nursery beds as plug-plus-one seedlings or outplanted in a transplanting machine must have a root plug that can be handled efficiently by the planting equipment.

***Container spacing*.** The distance between the individual cells in the block generates seedling growing density, one of the most important container characteristics affecting seedling growth. The spatial arrangement of cells within the block also has economical implications, however. Tree seedlings require a certain minimum amount of growing space, which varies with species and age. Nursery managers, on the other hand, need to produce the maximum number of seedlings per unit area of growing space.

In general, container seedling quality increases with a corresponding decrease in growing density. Tanaka and Timmis (1974) studied the effect of growing density on seedling characteristics and concluded that Douglas-fir seedlings produced at lower densities had physical and physiological properties that lead to improved outplanting performance, including greater dry weight and smaller height-diameter and shoot-root ratios.

When comparing tree seedlings produced in different container types, seedling growing density should be as important a consideration as cell volume. Direct comparisons are often difficult to interpret because there is a definite interaction between these two factors (Barnett and Brissette 1986). Most published comparisons of containers of the same volume do not consider the effects of seedling density and therefore their conclusions should be interpreted accordingly. Timmis and Tanaka (1976) reported the results of one of the few properly designed container comparison studies that considers the interaction between cell volume and cell density. They grew Douglas-fir seedlings at different growing densities in containers with the same volume, and found that seedling morphology and weight varied between the different seedling spacings (table 2.1.3). Shoot height increased with increasing density, probably as a result of greater competition for light between the seedlings. Stem diameter, shoot weight, and root weight, however, decreased with closer spacing (which is also reflected by the larger shoot-root ratio at the greater densities).

Seedlings produced at closer spacings grow taller and have smaller stem diameters (caliper) and lower biomass (dry weight) than those grown further apart. Scarratt (1972) grew white spruce seedlings in three different volume containers at three different growing densities and found that shoot height, stem caliper, and dry weight increased with both container volume or spacing (fig. 2.1.5). For this species, however, container volume was more important than seedling growing density, and the author concluded that the use of a larger container was both more biologically effective and cost efficient than using smaller containers at wider spacings. In trials

Table 2.1.3—*Spacing between containers generates seedling growing density and affects the morphology and weight of 5-month-old Douglas-fir seedlings*

Seedling spacing (cm)	Growing density (seedlings/m²)	Shoot height (cm)	Stem caliper (mm)	Shoot dry wt. (g)	Root dry wt. (g)	Shoot/ root ratio
6.0	270	11.0 a	1.93 a	0.67 a	0.45 a	1.5 a
4.3	540	11.9 b	1.80 b	0.62 b	0.33 b	2.0 a
3.5	810	11.6 ab	1.71 c	0.50 b	0.30 b	1.8 a
3.0	1,080	16.3 c	1.68 c	0.57 b	0.26 b	2.3 b

Values in columns with no letters in common differ significantly at P= 0.05, according to Duncan's multiple range test.
Source: Adapted from Timmis and Tanaka (1976).

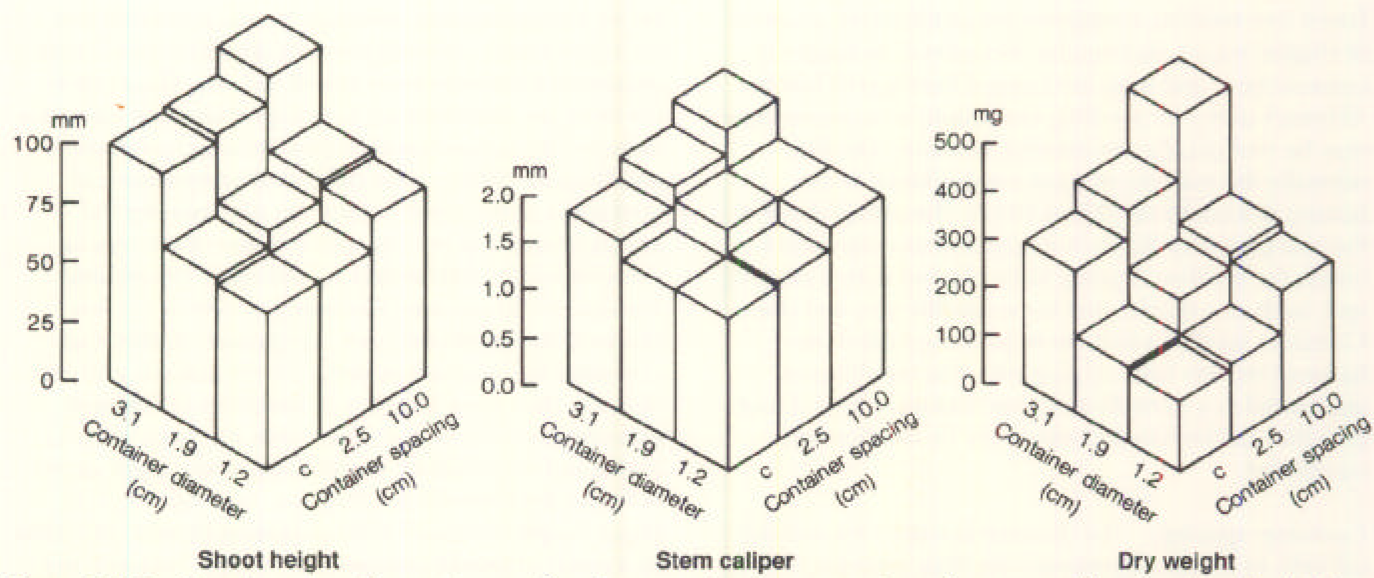


Figure 2.1.5—*Container size (diameter) as well as the space between containers dictates seedling growing density in the nursery, which in turn affects shoot height, stem caliper, and seedling dry weight (Scarratt 1972).*

with extruded peat containers, Hocking and Mitchell (1975) found that all growth characteristics of lodgepole pine, white spruce, and Douglas-fir seedlings increased when containers were larger or the space between cells was wider.

Container spacing also has some other biological and cultural implications on seedling growth. Timmis and Tanaka (1976) reported that seedlings grown at lower densities received ten times more photosynthetically active radiation in their lower crowns and had lower water potential than seedlings grown at closer spacings. The temperature of the growing medium was also higher in closely spaced containers. It is also more difficult for irrigation water and liquid fertilizers to penetrate dense patches of seedling foliage. Foliar diseases, such as grey mold, are more of a problem in densely grown seedlings because the fungus is able to invade the weaker, senescent foliage in the lower part of the seedling crown. Grey mold is also encouraged by the higher relative humidity and lower light in dense groups of seedlings. A Styrofoam block modified with vents between the cells reduced grey mold incidence on Douglas-fir seedlings due to better air circulation (Peterson and Sutherland 1989). Growing density apparently also affects seedling hardiness because seedlings grown at higher densities suffered more cambial frost damage than those grown at greater spacings (Timmis and Tanaka 1976).

The effect of seedling growing density is further complicated by the length of the growing season. Barnett and Brissette (1986) reported that, in southern pines grown for only 10 weeks, the effects of seedling density were not critical. However, when the growing season was extended to 12 or 14 weeks, seedling dry weight decreased with increasing growing densities (fig. 2.1.6A); the effects of growing density and age on seedling height were less pronounced, however (fig. 2.1 .6B). This size difference also had a carry-over effect: seedlings grown al the lower densities had higher survival rates and more height growth when measured 2.5 years after outplanting than did seedlings grown at higher densities. Based on these results, the authors recommend that southern pines should not be produced in containers with densities greater than 1,075 seedlings/m^2 (100 per square foot).

Seedling species also respond differently to the effects of crowding and, theoretically at least, broadleaved species and shade-intolerant conifers should be produced at lower growing densities than conifers or more-shade-tolerant species. Although many studies that tested the relationship between species and container type have been published, few have attempted to separate the effects of container volume from growing density (see previous section). As an example, Stauder and Lowe (1984) reported that container density did not affect the growth or field survival of baldcypress seedlings, although the containers used in their study were relatively

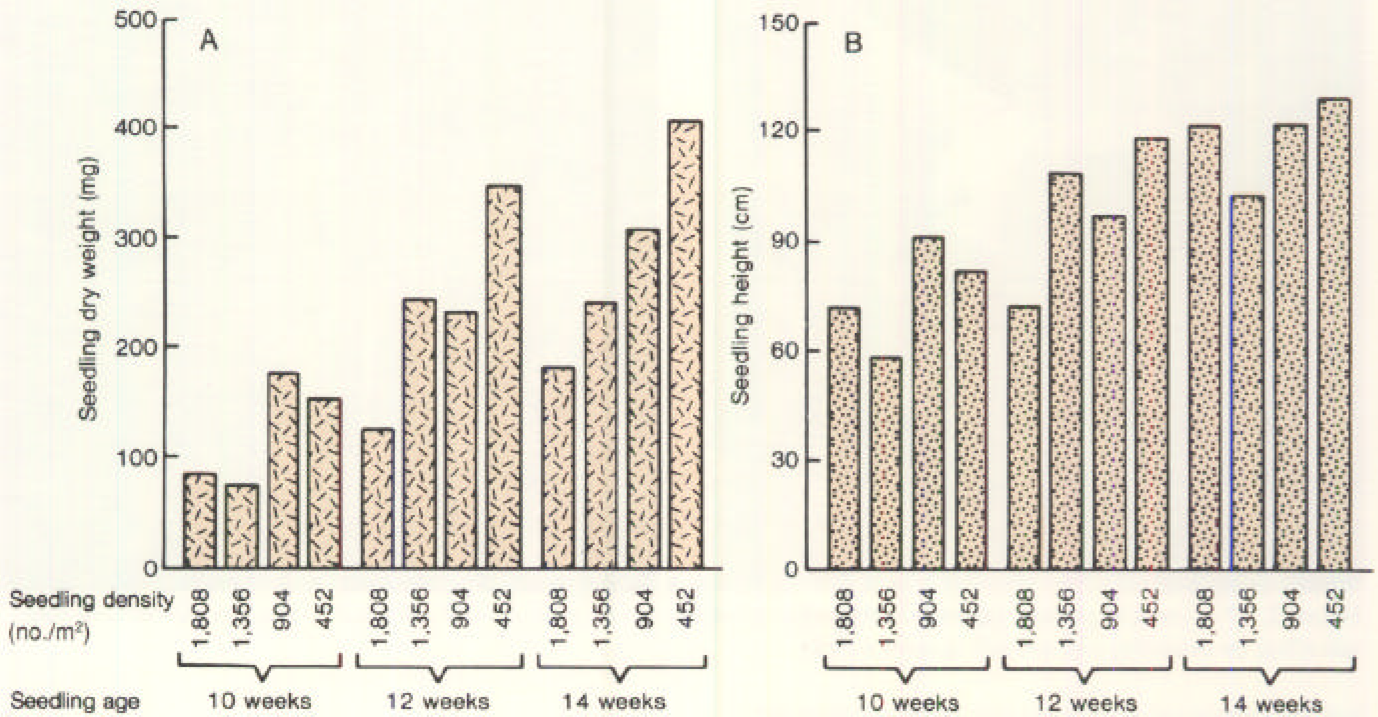


Figure 2.1.6—*Although both the dry weight and height of loblolly pine container seedlings are affected by growing density, height is less influenced as the seedlings grow older (adapted from Barnett and Brissette 1986).*

large Dee-pots®, which produce a very low growing density of 215 cells/m= (20 per square foot).

Design features to control root growth. One of the most serious problems in container tree seedling culture is the tendency of tree seedling roots to spiral around the inside of the container. Seedling roots grow geotropically, but if they do not meet any physical obstruction, they may tend to grow laterally around the side of the container.

Root spiraling will not adversely affect growth while the seedling remains in the nursery, but it can seriously reduce seedling quality after outplanting. Spiral roots prevent the seedling from becoming properly established in the surrounding soil, which can result in frost-heaving, toppling, or even strangulation (Burdett 1979).

Although it can occur in almost any container type, root spiraling is most serious in round, smooth-walled plastic containers. Girouard (1982) grew 4 species of conifer seedlings in 3 different types of containers and found that the only one in which root spiraling occurred was the round Quebec tube. Paper containers present two root control problems: root spiraling in polyethylene coated paper containers and root growth between cavities in untreated paper containers (bong and Burden 1986).

The problem of root spiraling has been at least partially solved by designing containers with vertically oriented ridges, ribs, or grooves (fig. 2.1.7A) that protrude into the growing medium and present an obstacle to spiral root growth; Kinghorn (1974) recommended ribs about 2 mm (0.08 inch) high on the inner cavity wall. These ribs intercept spiraling roots and force the developing roots to grow downward to the drainage hole (fig. 2.1 .7B), where they stop growing because of the low humidity and become **airpruned.** Most types of containers used in forest tree nurseries have some sort of anti-spiraling rib design, and one container manufacturer has even incorporated this feature into its brand name, the Spencer-Lemaire Rootrainer® (fig. 2.1 .7A).

Root spiraling occurs in most tree species but has been most serious in pines. Girouard (1982) found that all four species of conifers grown in Quebec tubes exhibited some degree of root spiraling but that it was worse in the pine species (fig. 2.1.8). Even with pines, however, there is variation; Barnett and Brissette (1986) report that

A B

Figure 2.1.7—*Vertical grooves* **(arrow)** *in the sidewall of this Spencer-Lemaire Rootrainer® container* **(A)** *prevent root spiralling by orienting root growth downward* **(B).**

longleaf pine is more prone to root spiraling than are loblolly and slash pines. Root spiraling and other types of abnormal root growth become more serious the longer the seedlings remain in the container (Barnett and Brissette 1986); this tendency was particularly significant for jack pine (fig. 2.1.8). (Chemical treatments to control root spiraling are discussed in section 2.1 .4.)

When the seedling roots reach the bottom of the container, they must be forced to air-prune or they will continue growing downward along the support bench (fig. 2.1.9A). This exterior root growth makes the seedling difficult to extract at the end of the growing season, resulting in damaged root systems. Air-pruning of roots at the drainage hole is encouraged by providing a layer of air below the container (fig. 2.1 .9B). Armson and Sadreika (1979) reported that a 1.25-cm (0.5-inch) air gap beneath the container was most effective. Some containers are formed with an external rib to create this air space (fig. 2.1.9C). With containers that have no built-in support to encourage air-pruning, some growers use benches with a mesh top (fig. 2.1.9D) or design their benches to support the containers so that an air layer is created. Other growers allow the roots to grow out the bottom of the container and then mechanically prune the roots before the seedlings are extracted. The biological implications of this practice have not been scientifically examined, but the authors recommend natural airpruning if at all possible.

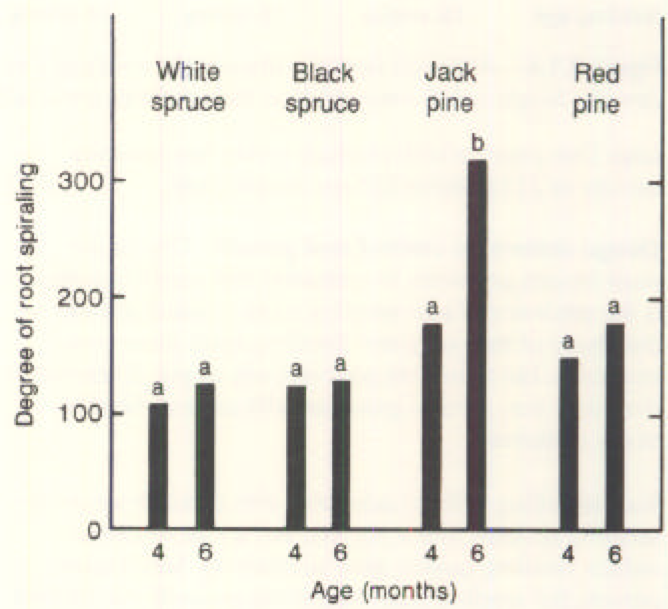


Figure 2.1.8—*Some degree of root spiralling occurred in all four species of conifer seedlings in the round, smooth-walled Quebec tube container, but was more extensive in the pines. Spiralling did not significantly increase with time, however, except for the jack pine seedlings. Bars with the same letter are not significantly different at the P = 0. 01 level. (Girouard 1982).*

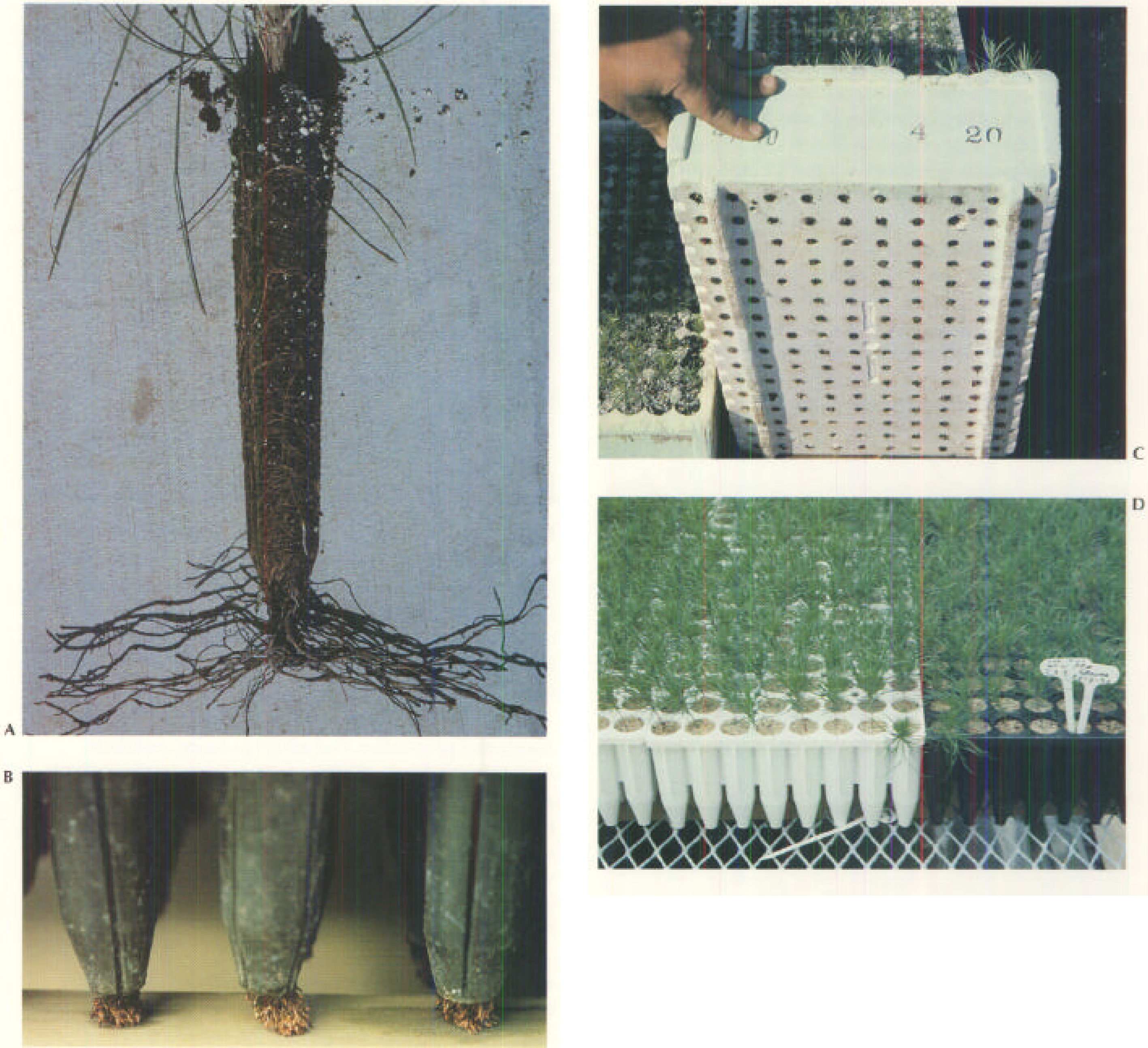


Figure 2.1.9—*If they are not forced to "air-prune," seedling roots will continue to grow downward and out the bottom of the container* **(A).** *Air pruning is encouraged by providing a layer of air under the container* **(B)**. *Some types of containers are structurally designed to develop an air layer* **(C)**, *whereas others should be placed on benches made of screen or other material that promotes air-pruning* **(D).**

One other container characteristic that affects root growth is the smoothness of the inside walls of the container cells. Roots of some seedlings are very fine and tend to grow into any cracks or seams in the walls of the containers. Western red-cedar and Alaska-cedar are notable in this respect and, in British Columbia, these species are grown in smooth-walled S/L Rootrainers instead of the standard Styrofoam blocks, which have rough walls (Matthews 1983). This root ingrowth makes these seedlings difficult to remove from the container during seedling extraction, and the roots extending from the extracted plugs make them difficult to plant (fig. 2.1.10A). Torn roots that remain in the containers (fig. 2.1.1 OB) provide an excellent substrate for root-rotting fungi and may be a significant factor in root disease carryover between successive crops.

A

B

Figure 2.1.10—*Certain species of tree seedlings, such as western redcedar, have very abundant and aggressive roots that penetrate the pores of the inner container wall, making these seedlings very difficult to extract from the container and plant (*(**A**)*. Torn roots left in the container (**B**) can also serve as root disease inoculum for the next crop.*

Container properties that affect growing medium moisture content. Certain features of containers such as container height, container wall permeability, and presence of a drainage hole affect the moisture relationships of growing media. Bassman and others (1989) grew western larch seedlings in 3 different types of containers and found a significant interaction between container type and water regimes.

The effect of container height is discussed in detail in chapter 2 of volume four of this series, but basically the taller the container, the greater proportion of well-drained medium that it will contain. All containers create a perched water table because they maintain a volume of growing medium above a layer of air. Because water molecules are attracted to the growing medium in a container, water does not freely drain from the medium in the bottom of the container, thus creating a perpetually saturated layer of growing medium. The depth of this saturated layer is a function of container height and the physical properties of the growing medium.

Moisture within the growing medium is also affected by the properties of the container wall. Containers composed of permeable materials such as paper or plastic mesh allow water and dissolved salts to move laterally through the container wall and into the growing medium in adjacent containers. The moisture relationships in a block of adjacent paper containers, such as a tray of paperpots (fig. 2.1 .l 1), are similar to a tray of unconfined growing medium, because water and dissolved salts can move freely from one container to the next. Containers with permeable walls, therefore, may require a growing medium with a coarser texture to increase porosity and thus prevent waterlogging.

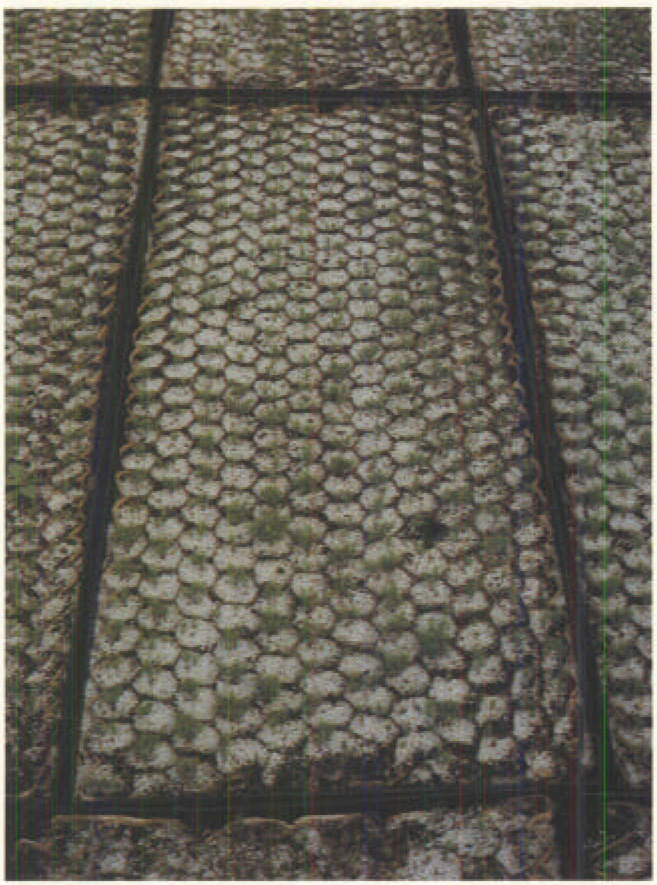


Figure 2.1.11—*Containers constructed out of permeable materials, such as paper, allow water and soluble salts to move laterally between individual cells, which affects the moisture and mineral nutrient relationships of the growing medium.*

All containers must have one or more drainage holes at the bottom to allow excess irrigation water to drain and to encourage excess fertilizer salts to leach out (fig. 2.1 .9C). These drainage holes must be as large as possible yet should not permit the growing medium to fall through during the filling operation. Because a mass of root tips eventually develops around drainage holes, they may eventually become plugged and cause drainage problems if they are too small (fig. 2.1 .9B). The other function of the drainage hole is to force the root system to air-prune when the roots reach the bottom of the container (see previous section). The benefits of these drainage holes are lost, however, if an air layer is not provided beneath the container (fig. 2.1.9D).

Container properties that affect growing medium temperature. The color and insulating properties of container materials affect the temperature of the growing medium and, therefore, root growth. These properties are important during the growing season because root temperature is affected by the sunlight absorption and the insulating properties of the container material. Insulation of the root system is also important when seedlings are subjected to freezing temperatures during hardening or over-winter storage.

The heat absorption and conduction properties of the container can be significant in the high-energy environment of a container nursery. High root temperatures can inhibit root growth and may even result in seedling mortality (Furuta 1978). Whitcomb (1988), in his discussion of the effects of high root temperatures in container nurseries, emphasizes that considerable variation exists in the heat tolerance of different plant species and even varieties of the same species.

Heat absorption is a function of container color, with darker colors absorbing more solar insulation than lighter ones (fig. 2.1.9D). Containers made of a thicker insulating material, such as Styrofoam®, will conduct less heat than thinner plastic materials. Bassman and others (1989) studied western larch seedling growth in 3 different container types, and concluded that medium in containers with walls made of thin plastic may heat up more rapidly than medium in thicker walled containers. Seedlings growing in the warmer medium had more root growth. However, excessively high root temperatures injure seedling roots. Whitcomb (1988) reported that the temperature of the growing medium just inside the wall of large ornamental seedling containers sometimes reached 48 °C (120 °F) in direct sunlight; Barney (1947) found that the root systems of several conifer seedlings were killed by only a few hours at these temperatures. Brown (1982) investigated the effect of container color on 3 ornamental species and found that changing the color of the container from black to white reduced growing medium temperatures 7 °C (11 °F) and produced plants of significantly higher quality. Seedlings on the outside of the bench on the sunny side of the growing area are most susceptible to root injury from high root temperatures.

Just as important as insulating seedling root systems against high temperatures is protecting them against cold injury. Roots are much more sensitive to cold injury than shoots, and container seedlings stored outside during the winter can suffer severe injury if their roots are not protected. Containers constructed of materials with a high insulating value, such as Styrofoam, provide more protection than thin-walled containers, although Edwards and Huber (1982) report cold damage even in Styrofoam blocks (cold injury is discussed in more detail in chapter 1 of volume five of this series).

2.1.2.2 Characteristics that affect nursery and outplanting operations

In addition to the characteristics that influence seedling growth, there are other container attributes that affect operational aspects of the nursery/outplanting process. Some container characteristics, such as size, affect operations both at the nursery and on the outplanting site. Because no one container is ideal for all purposes, a nursery manager should consider all the different characteristics and discuss them with customers during the container selection process.

Need to match containers to both the nursery and outplanting system. The entire nursery and outplanting system should be considered during the container selection process. In new nurseries, the physical attributes of the container, such as size and spacing, will determine bench design and therefore seedling production per growing area. Container volume and shape also influence the type of growing medium used as well as the type of filling and sowing equipment. Because of container effects on the moisture content of the growing medium, fertilization and irrigation systems should also be considered during the container selection process. Large volume containers with their inherent lower seedling growing densities will result in faster growth and therefore shorter greenhouse rotations, but large containers also take up more growing space. For container seedlings that will be transplanted into a bareroot nursery seedbed, the type of container affects the type of transplanting machine and the ease of handling at the bareroot nursery.

Container attributes also affect other aspects of the reforestation process, from seed collection to outplanting. Seed size must be considered: species with large seeds, such as oak acorns, will require wider containers than small-seeded species. Seedling handling, transport, and storage are also affected by the size and weight of containers or extracted plug seedlings. Seedlings in large-volume containers are inherently more heavy and bulky to handle at each stage of the harvesting, storage, and outplanting process. Container size and shape may also influence the type of planting tool and other logistical operations on the outplanting site because fewer large seedlings can be packed per shipping carton or carried per planting bag.

Some types of containers were specifically designed to be part of a completely automated sowing and outplanting system. The paperpot was one of the first containers for which a complete filling, sowing, handling, and outplanting system became commercially available (Hoedemaker 1974). The Hiko System®, which was developed in Sweden, can fill and sow about 250,000 cavities in one 8-hour shift, and the containers are mechanically handled at every step in the nursery. On the outplanting site, the containers are carried in specially designed backpacks (Twetman 1988). The convenience of a coordinated container system must be weighed against the cost and the inflexibility of these highly automated systems. Once the container is selected and the nursery and reforestation systems are designed around it, it becomes increasingly difficult to change container types or any other part of the equipment or facilities.

Cost and availability. Although the biological aspects of a specific container are important, cost and availability are often the controlling factors in container selection. Associated expenses, such as shipping and storage costs, must be considered in addition to purchase price. Many containers are produced at only one location and their shipping costs increase as a direct function of distance from the manufacturer; others, such as Styrofoam blocks, are produced or distributed from various locations around the continent and are therefore widely available. Long-term availability must also be considered in the selection process to insure that ample supplies of the container can be secured in the foreseeable future.

When conducting an economic analysis of different types of containers, the overall cost of seedling production including seedling growing density, amount of growing medium required, and value of the seedling produced must be considered.

Durability and reusability. Containers must be durable enough to maintain structural integrity and contain root growth during the nursery period. The intense heat and ultraviolet rays in container nurseries can cause some types of plastics to become brittle (fig. 2.1.12), although many container plastics now contain ultraviolet inhibitors. Container durability is especially important when considering biodegradable containers because these containers must be durable in the moist, humid conditions of a greenhouse, yet biodegrade within a reasonable period after outplanting.

Some containers are designed to be used only once, whereas others can be reused for 5 or more crop rotations. Reusability must be considered in the container cost analysis because the cost of reusable containers can be amortized over their life span, after adjusting for the costof handling, cleaning, and sterilizing of the containers between crops.

Ability to monitor growing medium condition and root growth. Although it is easy to monitor the ambient environment and observe seedling shoot growth and phenology, it is more difficult to monitor the condition of the growing medium and the degree of root activity. In a typical container, it is impossible to directly observe the moisture content of the growing medium or root growth without disturbing the seedling. Late in the growth cycle, however, seedlings become large enough to form a firm root plug and can be removed from the container and the condition of the plug examined. Containers have been developed that can be opened to examine the growing medium and root system. Book-type containers (fig. 2.1.7A) are hinged along the bottom of the containers so that they can be opened and re-closed whenever necessary. Sleeve-type containers have a similar feature consisting of two separate but matched sections that can also be opened to expose the growing medium and allow examination of the root system (fig. 2.1.13A). One operational drawback of these types of containers is that they must be assembled (fig. 2.1.13B) and placed in holding trays after they are purchased. When different

Figure 2.1.12—*Intense sunlight, especially ultraviolet radiation, can cause plastic containers to become brittle. Many containers are now constructed of plastics with "ultraviolet inhibiting" chemicals.*

container types are being evaluated, this added handling cost must be compared to the benefits of being able to monitor the condition of the growing medium and roots.

Ability to interchange and consolidate containers (unitization). One operational feature that has several management implications is unitization, in which individual containers fit interchangeably into a tray system. A typical example is the Ray Leach Single Cell'" container (fig. 2.1.14A-B). One of the significant operational benefits of a unitized container system is that unwanted individual cells can be removed from the tray and replaced with others. This is particularly useful during thinning, when empty cells can be replaced with cells containing a germinant, and during rogueing, when diseased or otherwise undesirable seedlings can be replaced with cells containing healthy seedlings. Such consolidation can save a considerable amount of growing space in the greenhouse (fig 2.1.14C), and during storage and shipping. Unitized containers are also commonly used for tree improvement crops where each seedling needs to be individually handled and labeled. One drawback of the unitized container design is the additional handling required to reposition the individual cells in the tray if the seedlings are shipped to the outplanting site in the cells.

Handling, shipping, and storage. Containers must be handled repeatedly from initial shipping, through the growing season, to storage, shipping, and outplanting. Collapsible containers, such as the paperpot, are purchased in a compressed form and have lower shipping and presowing storage costs (Hoedemaker 1974); however, these same containers must be expanded before filling and sowing and thus require additional handling. The size and filled weight of a container will also affect ease of handling. Containers must be sturdy enough to withstand repeated handling. Automated handling systems also place mechanical stress on the containers and racks.

The type of shipping and storage system also needs consideration during container selection. If the seedlings are to remain in the container, then some sort of shipping box must be used to protect them during shipping and interim storage. Many container nurseries are extracting the plug seedlings from their growth containers and wrapping them in plastic bags or film for refrigerated storage and subsequent shipping to the planting site. Different types of containers require different handling equipment, and these factors may have a significant influence on the best type of container for a given nursery and associated planting system.

A

B

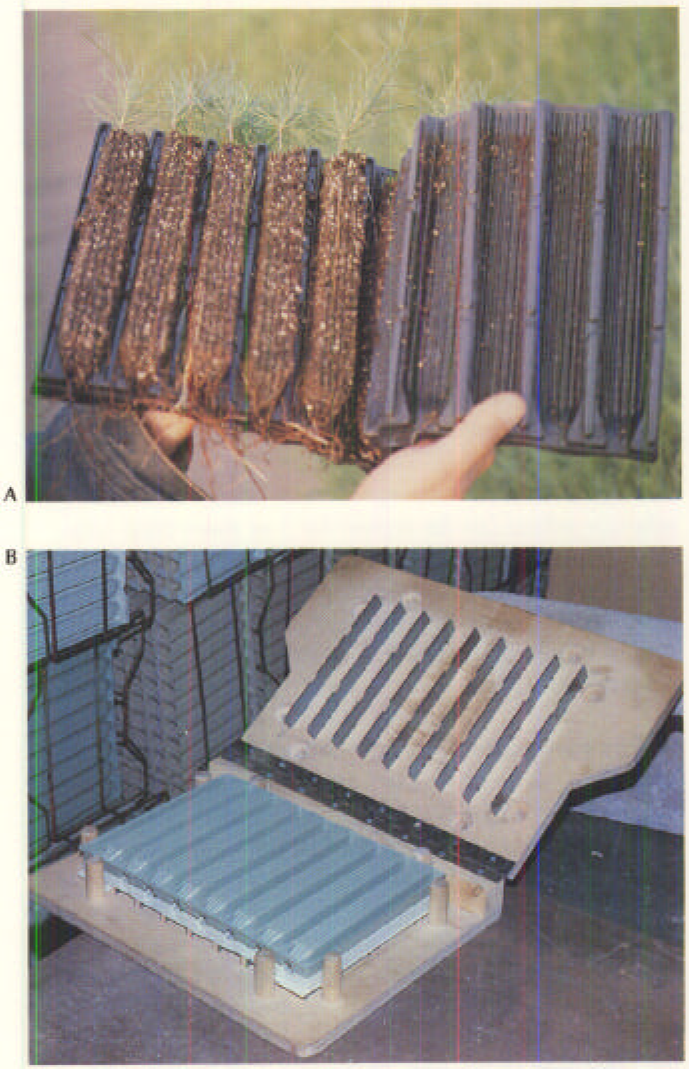
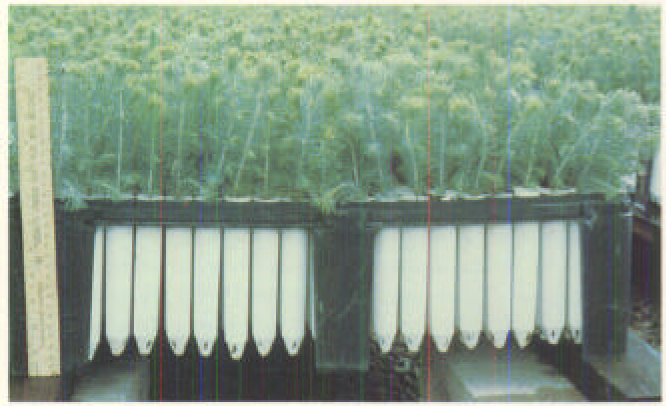


Figure 2.1.13—*Sleeve containers, such as this Tube-pack®, are designed to allow examination of the growing medium and root growth during the growing season* **(A)***. These containers come in two matched sections, which must be assembled before use* **(B)**.

A



B

C

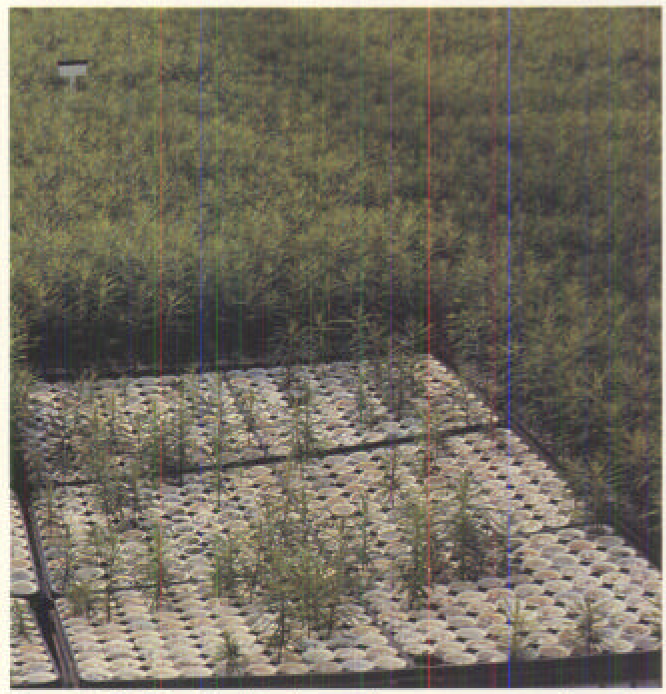


Figure 2.1.14— *Unitized container systems, such as the Ray Leach Single Cell®, consist of individual containers* (**A**) *that are interchangeable in a separate tray system* (**B**). *One practical feature of unitized containers is that they can be consolidated: cells that are empty or contain cull seedlings can be removed so that each space in the tray has a healthy seedling, thus optimizing the utilization of growing space. Trays in the foreground* (**C**) *contain cells that were removed from the now fully occupied trays in the background.*

2.1.2 Types of Containers

Container tree seedlings have been grown in many different types of containers over the years. Initially, standard horticultural containers were used, but nursery managers soon realized that woody plant seedlings required containers with special features, such as those discussed in the previous section. Many different types of containers have been tried but, after 2 decades of testing, only a relatively small percentage (28%) of the containers listed in "How to grow tree seedlings in containers in greenhouses" (Tinus and McDonald 1979) are still in use. New types of containers are still being designed and tested at the present time; this effort to develop the ideal container will undoubtedly continue because there is no single type of container that is perfect for all applications.

Although several different systems for categorizing containers have been used, the most practical system divides containers into two functional categories: those that are planted with the tree seedling, and those that are removed before the seedling is planted (Tinus and McDonald 1979).

2.1.3.1 Containers planted with the seedling

Much of the original work on developing containers for forest tree seedlings centered on designing a container that not only would grow an acceptable seedling in the nursery, but also could be directly outplanted in the field. Two different types of these containers were developed. Containers of the first type are made of a biodegradable material, such as molded peat moss or wood fiber (for example, peat sticks or fiber pots), that decomposes after outplanting. Seeds are sown on the top and the seedling roots penetrate through the container. The major problem with these biodegradable containers is that they lack a solid wall with anti-spiraling features so that seedling roots grow randomly, often into adjacent containers. Another drawback is that they often become covered with algae and mold in the nursery and thus difficult to handle. Barnett and Brissette (1986) reported that some biodegradable containers, notably the KysTree-Start' produced acceptable southern pine seedlings and performed well in the field. Although some biodegradable conta iners are still available (table 2.1.4), none are currently in widespread use in North American container tree nurseries (table 2.1 .1). These containers are probably useful only for growing seedlings for short periods before their root systems become too expansive.

The second type of biodegradable container consists of a shell of hard plastic, plastic mesh, or specially treated paper that is tilled with growing media and sown with seed to produce a tree seedling under normal nursery culture. The tree seedling is then outplanted in the container, which theoretically would then expand, decompose, or somehow allow roots to grow out into the surrounding soil. Hard plastic containers that were designed to expand from root pressure after outplanting, for example, the Waiters Bullet and Ontario tube (fig. 2.1 .1), enjoyed some early successes (Waiters 1974, Reese 1974), but there were problems with inconsistent root egress and some cases of root strangulation (Barnett and McGilvray 1981, Van Eerden 1982). Tree seedlings have also been successfully grown in plastic mesh containers, but some root restriction still occurred after outplanting (Budy and Miller 1984, Barnett and McGilvray 1981). Because of concern over such problems with root form after outplanting, interest in hard plastic or plastic mesh containers that can be outplanted with the seedling had declined by the time of the Container Nursery Survey (table 2.1 .1).

One of the most successful containers that is still outplanted with the seedling is the paperpot (table 2.1.1), which was introduced in eastern Canada about 20 years ago to replace the Ontario tube. Barnett and Brissette (1986) concluded that the paperpot is the best container of this type. Paperpots are bottomless, hexagonally shaped paper tubes that are interconnected in a honeycomb-like design (fig. 2.1.15). They are constructed of a special paper, which is a mixture of easy decomposing paper and fibers that resist decomposition, and are available in three grades that resist decomposition for different lengths of time: **B** for 4 to 6 weeks, **V** for 7 to 9 weeks, and **F** for 3 to 12 months. Each individual paperpot is sealed with an insoluble glue to form a hexagonal, open-ended tube. Paperpots are interconnected to adjacent pots with a water-soluble glue that slowly breaks down during the nursery period so that the individual containers can be separated just before planting (fig. 2.1.15). The accordion-like sections of paperpots are shipped flat and must be expanded into a hard plastic tray before filling and sowing.

Several sizes of paperpots are available, but the 408 size was the most popular in North American container tree nurseries at the time of the Container Nursery Survey (table 2.1.1). One of the major concerns about paperpots is poor control of root form. Root spiraling and root growth between containers frequently occur (Barnett and

McGilvray 1981), and this characteristic is considered undesirable by many nursery managers and reforestation foresters. Barteaux and Kreiberg (1982), however, report that problems with root intergrowth between paperpots were "minimal," and that plantation checks have shown that paperpot container seedlings had better root form than bareroot seedlings. A newly developed product, the PS paperpot, is made of thin plastic containing a copper strip to eliminate rooting between containers during the nursery phase (Macdonald 1986). The Ecopot® is another new modification of the paperpot system that contains parallel plastic strips between the individual cells. This addition inhibits root growth between adjacent cells and produces a plug seedling that can be extracted from the container (Sims 1988).

The popularity of paperpots is strongly regional; in Canada, this container is very popular in central and eastern provinces but is rarely used in the West (Smyth and Ramsay 1982). Barteaux and Kreiberg (1982) compared paperpots to many other container types over a 10-year period in New Brunswick and found that paperpots were the least expensive and easiest to handle. Canadian container tree nurseries have recently shifted away from paperpots, however, because of concern about poor root egress after outplanting, especially on cold and wet sites (Sims 1988).

Table 2.1.4—*Listing of major types of containers currently available in the United States and Canada for growing forest tree seedlings*

	Construction material	Manufacturers/suppliers
Containers planted with seedling		
Paper containers		
Paperpot	Specially treated paper	Hakmet Ltd. PO Box 248 Dorion, PQ CANADA J7V 7J5
		Lannen Inc. 880 Calle Plano, I PO Box 3383 Camarillo, CA 93011
Stretch-A-Pot®	Specially treated paper	Pan Agro 2084 North, 1200 East North Logan, UT 84321
Wood fiber containers		
Jiffy pot Forestry pellet	Molded peat moss Molded peat moss in plastic mesh	Jiffy Products of America 1400 Harvester Road PO Box 338 West Chicago, IL 60185
		Jiffy Products Ltd. PO Box 360 Shippagan, NB CANADA E0B 2PO

Table 2.1.4 (continued)—*Listing of major types of containers currently available in the United States and Canada for growing forest tree seedlings*

	Construction material	Manufacturers/suppliers
Fiber pot	Molded wood pulp	Western Pulp Products Co. Box 968 Corvallis, OR 97339
Containers removed before outplanting		
Individual cells in trays		
Ray Leach Single Cell System®	Low-density polyethylene cell, with high-impact polystyrene tray	Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333
Stuewe Super Cell®	Low-density polyethylene	Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333
Hawaii dibble tube	High-density polyethylene cell, with high-impact polystyrene tray	Firewheel Manufacturing Co. Ltd. PO Box 72-41 Taipei, Taiwan Republic of China
Colorado container	High-impact polystyrene cell with an expanded polystyrene tray	Colorado Hydro, Inc. 5555 Ute Highway Longmont, CO 80501
Deepot®	High-density polyethylene cell and tray	J. M. McConkey & Co., Inc. PO Box 1690 Sumner, WA 98390
		Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333
Book or sleeve containers		
Spencer-Lemaire Rootrainer®	PET (polyethylene terephthalate) or ABS (acrylonitrile-butadienestyrene)	Spencer-Lemaire Industries, Ltd. 11413 120 Street Edmonton, AB CANADA T5G 2Y3
		A.H. Hummert Seed Co. 2746 Choteau Avenue St. Louis, MO 63103
Tubepack®	Polystyrene	Porter-Walton Wholesale Nursery 262 West, 400 South Centerville, UT 84014

Table 2.1.4 (continued)—*Listing of major types of containers currently available in the United States and Canada for growing forest tree seedlings*

	Construction material	Manufacturers/suppliers
Block containers		
Styroblock®	Expanded polystyrene	Silvaseed Company PO Box 118 Roy, WA 98580 Beaver Plastics, Ltd. 12150 160 St. Edmonton, AB CANADA T5V 1H5
First Choice® block	Expanded polystyrene	First Choice Manufacturing 19402 56th Avenue Surrey, BC CANADA V3S 6K4 Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333
Styrofoam® block	Expanded polystyrene	Plant-A-Plug Systems PO Box 1953 Pine Bluff, AK 71613
Colorado Styrofoam® block	Expanded polystyrene	Colorado State Forest Nursery Foothills Campus Colorado State University Ft. Collins, CO 80523
Ropak® Multi-pot seedling tray	High-density polyethylene	Sauze Technical Products Corp. 345 Cornelia Street Plattsburgh, NY 12901 Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333 Ropak Can-Am Ltd. PO Box 340 Springhill, NS CANADA B0M 1X0
Hiko System® Containerset	High-density polyethylene	International Forest Seed Co. PO Box 290 Odenville, AL 35120

Table 2.1.4 (continued)—*Listing of major types of containers currently available in the United States and Canada for growing forest tree seedlings*

	Construction material	Manufacturers/suppliers
Deep Groove Tube Tray®	High-density polyethylene	Growing Systems, Inc. 2950 North Weil Street Milwaukee, WI 53212
Capilano seedling tray	High-density polyethylene	Capilano Plastics Co., Ltd. 1081 Cliveden Avenue Annacis Island New Westminster, BC CANADA V3M 5V1 Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333
Todd® planter flat	Expanded polystyrene	Speedling Inc. Old Highway 41 South PO Box 7238 Sun City, FL 33586
Seedling tray	Expanded polystyrene	Castle and Cooke Techniculture, Inc. PO Box 1759 Salinas, CA 93902 Grow-Tech, Inc. 56 Peckham Road Watsonville, CA 95076
Ecopot	Plastic-laminated paper	Hakmet, Ltd. PO Box 248 Dorion, PQ CANADA J7V7J5 Lannen, Inc 880 Calle Plano, 1 PO Box 3383 Camarillo, CA 93011
Stretch-A-Pot	Polyethylene film	Pan Agro 2084 North, 1200 East North Logan, UT 84321

Table 2.1.4 (continued)—*Listing of major types of containers currently available in the United States and Canada for growing forest tree seedlings*

	Construction material	Manufacturers/suppliers
Separate containers		
Treepot	High-density polyethylene	Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333
		J.M. McConkey & Co., Inc. PO Box 1690 Sumner, WA 98390
Rootrainer® One Cell	PET (polyethylene terephthalate)	Spencer-Lemaire Industries, Ltd. 11413 120 Street Edmonton, AB CANADA T5G 2YE
		A.H. Hummert Seed Co. 2746 Choteau Avenue St. Louis, MO 63103
Polybag	Polyethylene film	HGP Inc. 761 Kanoelehua Avenue Hilo, HI 96720
		A.H. Hummert Seed Co. 2746 Choteau Avenue St. Louis, MO 63103
Miniature containers		
Techniculture® plug system	Expanded polystyrene	Castle and Cooke Techniculture, Inc. PO Box 1759 Salinas, CA 93902
Miniblock® 448	Expanded polystyrene	Same as Styroblock distributors
First Choice Hahn 408	Expanded polystyrene	Same as First Choice block distributors
Used containers		Stuewe and Sons, Inc. 2290 SE Kiger Island Drive Corvallis, OR 97333

Paperpots have not fared well in the United States based on several nursery and field tests. Barnett and McGilvray (1981) tested paperpots with southern pines and found that the paper used in the Japanese paperpot degraded slowly after outplanting and did not allow root egress, resulting in lower field survival and field growth. Barnett and Brissette (1986) reported that the paper used in the Finnish paperpot allowed faster root egress than the Japanese paperpot. Budy and Miller (1984) found that Jeffrey pine seedlings had very poor outplanting survival and growth in the Japanese paperpot. Dirmarsen and Alm (1979) outplanted red and jack pine in Japanese paperpots in Minnesota and found that the paperpot~ had not degraded and that roots had not penetrated t I paper after four growing seasons. One reason for this discrepancy between geographical regions may be due to climate or soil type. The outplanting sites in eastern Canada are probably wetter than those in the United States, and this higher soil moisture may hasten paper decomposition rate and root egress. Paper becomes impervious to root penetration if allowed to dry and so seedlings would become root-bound on dry outplanting sites.

One recent development in this container class is the jiffy 7® forestry pellet, a modification of the jiffy 7® horticultural peat pellet (Hatheway 1988). The forestry pellet utilizes a new type of plastic netting that tears apart as the roots grow out of the container. This new container is currently being used in the Maritime Provinces of Canada.

2.1.3.2 Containers removed before outplanting

Containers for producing seedlings that are extracted prior to outplanting (plug seedlings) were by far the most popular type (91 % of total) in forest nurseries in the United States and Canada at the time of the Container Nursery Survey (table 2.1.1). The term **plug seedlings** results from the fact that their roots bind the growing medium together into a relatively firm mass or plug (fig. 2.1.16). Containers for producing plug seedlings should have two common characteristics (Tinus and McDonald 1979):

1. The walls of the container should be relatively smooth so that roots do not penetrate and make the plug difficult to remove.

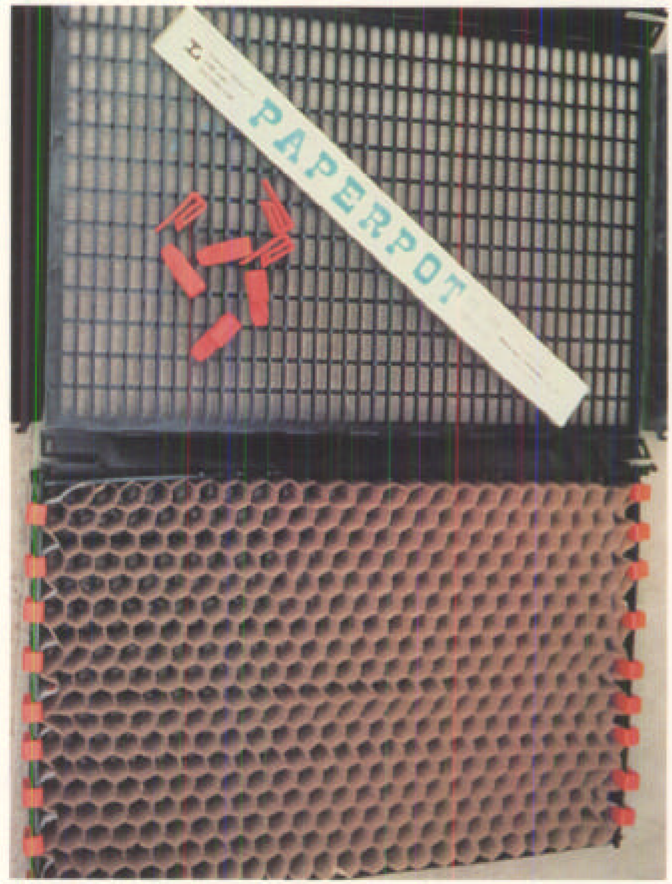


Figure 2.1.15—*Paperpots consist of a series of interconnected paper cells that are arranged in a honeycomb pattern and can be separated before outplanting (courtesy of Lannen, Inc., Camarillo, CA).*

2. The cavity of the container should be tapered from top to bottom so that the seedling can be easily extracted from the top.

Individual cells in trays. An individual container that is part of a larger set of containers is termed a cell or tube. These cells or tubes are supported in a tray or rack, which determines the spacing of the cells and therefore seedling growing density (Allison 1974). Although the term rack is more descriptive, the term tray will be used here because it is the more commonly used in the forest nursery trade.

Although there are several types of individual cell containers available (table 2.1.4), the Ray Leach (R/L) Single Cell® system is the most common in North American container tree nurseries, constituting 16% of total container use at the time of the Container Nursery Survey (table 2.1.1). Several different sizes of R/L Single Cells are available, and each consists of a soft plastic tube that fits in a hard plastic tray (fig. 2.1.14). The capacity of the various cells ranges from 49 to 164 cm^3 (3.0 to 10.0 cubic inches), and the growing density ranges from 500 to 1,076 cells/m^2 (49 to 100 per square foot) (table 2.1.1).

One of the biggest advantages of the individual cell system is that the containers can be handled either separately or collectively. This unitization feature allows consolidation of individual cells during culling, so that greenhouse growing space can be used efficiently (fig. 2.1 .14). Seedling growing density can also be expanded by placing cells in every other location, which promotes larger seedlings and also decreases foliage diseases by encouraging air circulation around the seedling. After firm root plugs have formed, seedlings can be removed from the containers by gently squeezing the container or tapping the top of a cell on a hard surface. One disadvantage of the individual cell system is that the containers have to be replaced in the tray if the cells are removed for shipping or cleaning between crops (Tinus and McDonald 1979). The hard plastic trays of the R/L Single Cell system are relatively fragile and easily damaged if they are repeatedly handled while loaded with heavy seedlings. With the current trend towards extraction of shippable seedlings from the containers at the nursery, however, this is becoming less of a problem.

Figure 2.1.16—*Container seedlings that are removed from the container before outplanting are called plug seedlings because their root systems bind the growing medium together into a cohesive plug.*

R/L Single Cells are most popular in the Northwestern United States (Landis 1982), where they were developed. They and the other types of single cell systems are also used at scattered nurseries around the country and are especially popular at nurseries specializing in tree improvement stock. Another individual cell container, the dibble tube, is similar to the R/L Single Cell except that it was specifically designed to grow tropical species; the dibble tube is currently being used in Hawaii, Guam, and several foreign countries.

Extruded peat cylinders are another type of individual container. They are formed by extruding a peat-water mixture into a continuous, thin plastic casing; the filled casing is then sliced into uniform cylinders or "sausages." While conifer seedlings were successfully grown in these containers, they have never been used extensively in North American container tree nurseries (Mitchell and others 1972, Hocking and Mitchell 1975).

Other types of individual cell containers, such as the polytube or polybag (fig. 2.1 .17), are constructed of plastic film. These containers are inexpensive and easy to ship and store and are popular in nurseries in developing countries or remote locations. Several different sizes of polybags are commercially available; the 20 x 15 cm (8 x 6 in) size was found to produce better quality casuarina seedlings (Vinaya Rai and Natarajan 1987). Polybags come in clear and black plastic, but black polybags have proven to be superior because they retard the growth of algae (Liegel and Venator 1987). Proper root development is a problem in these containers because their smooth sides promote root spiraling and root balling is common in the bottom of the container (Venator and others 1985). Wilson (1986) evaluated the

Figure 2.1.17—*The polybag is an individual cell container that has been popular in nurseries in less industrialized countries; it does not prohibit root spiralling or allow air pruning, however.*

use of polybags and polytubes in tropical nursery culture, and concluded that their popularity was more a function of the hardiness of the seedlings being grown than in the beneficial attributes of the container system. Yharma (1987) discussed the use of polybags in tropical nurseries and the causes of root deformation, and listed some cultural practices that reduce root problems.

Book and sleeve containers. This container type consists of a row of cells made of relatively thin plastic, and is designed to be opened and closed without damaging seedling roots. About 10% of the containers used in forest nurseries in the United States and Canada at the time of the Container Nursery Survey were book or sleeve containers (table 2.1 .1). The original and most popular of these containers is the Spencer-Lemaire (S/L) Rootrainer® (fig. 2.1 .18), which is called a book container because it consists of two matched forms that are hinged together on the bottom and produce a row of rectangular cells when snapped together. A sleeve container consists of two matched sections that are independent but snap together to form a row of cells when assembled (fig. 2.1 .13). Once assembled, book and sleeve containers are held together in specially designed trays or taped together to form blocks of cells.

Book and sleeve containers are available from several distributors in the United States and Canada (table 2.1 .4). Rootrainers come in a variety of sizes, and the most popular sizes range in cell capacity from 40 to 350 cm^3 (2.5 to 21 .5 cubic inches) and in cell density from 516 to 1,280 cells/m^2 (48 to 1 19 per square toot) (table 2.1 .1). A new, large capacity S/L container (1,300 cm^3 or 80 cubic inches) has been recently developed that has a growing density of 172 cells/m^2 (16 per square foot).

Both book and sleeve containers are tapered and have well-defined vertical ribs that discourage root spiraling and guide roots to the drainage hole at the bottom of the container. One very practical feature is that they can be easily opened up to check the condition of the growing medium and root growth at any time during the growing cycle, even before a firm plug has developed (fig. 2.1 .7 and 2.1.13A). The durability of these containers depends on the type of plastic: the original polystyrene containers tended to breakdown in sunlight and could only be used for a couple of years. For extended use, the newer model Rootrainer constructed of ABS (acrylonitrilebutadienestyrene copolymer) plastic is considerably more durable. Another advantage is that the plugs are easily extracted

Figure 2.1.18—*Book or sleeve containers consist of two matched sections of molded plastic that fit together to form a row of rectangular cells. These Spencer-Lemaire Rootrainers® are book containers that are assembled and then placed next to each other in a holding tray to form a block (courtesy of Spencer-Lemaire Industries, Ltd., Edmonton, Alberta, Canada).*

for grading and packing. Book and sleeve containers are somewhat less durable than some of the other container types, and individual cells cannot be removed if they fail to produce a germinant or contain a diseased seedling. Because they are easily opened, however, empty cavities can be filled with other seedlings once they have formed a firm plug (Tinus and McDonald 1979).

Because the S/L Rootrainer was originally developed in Alberta, Canada (Spencer 1974), it is popular in that region, as well as other Canadian provinces (Smyth and Ramsay 1982, Kelly 1982). In the United States, both the S/L Rootrainer and sleeve containers are used at various locations around the country with no strong regional pattern.

Block containers. Block containers consist of a block, generally rectangular, that contains a number of cavities or cells arranged in a regular pattern (fig.2.1.19 and 2.1.20). The individual cells are cylindrical cavities that gradually taper from the top opening to the drainage hole at the bottom. Block containers were the most popular container type in use at the time of the Container Nursery Survey, and several brands and sizes are commercially available (table 2.1.4). In North America, the most common block containers are the Styrofoam® block (fig. 2.1.19) and the Multi-Pot® (fig. 2.1.20), which made up 51 and 11 % of container use at the time of the Container Nursery Survey, respectively (table 2.1.1).

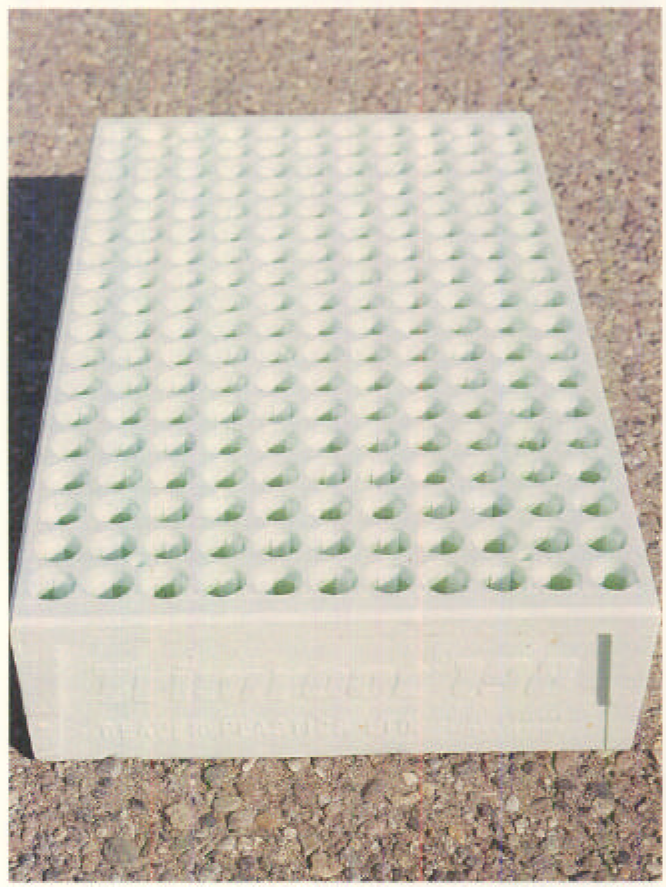


Figure 2.1.19—*Styrofoam® blocks are made of expanded polystyrene foam and contain cylindrical cavities or cells that are arranged in a regular pattern.*

Figure 2.1.20—*The Multi-pot® container is a molded hard plastic block with cylindrical cells arranged in alternate rows (courtesy of Ro-Pak, Inc., Springhill, Nova Scotia, Canada).*

Block containers are single, lightweight units that are easy to handle and have no individual cells or sleeves of cells that can become dislodged. Many of the Styrofoam blocks and Multi-pots with different cavity sizes have standard outside dimensions so that they can be used with the same filling, sowing, handling, and extraction equipment (Tinus and McDonald 1979). This feature is also useful during storage, because the Styrofoam blocks stack easily and the Multi-pots will nest together. Both types of block containers are resistant to breakdown in sunlight and are reusable; Multi-pots claim an operational life of 6 to 10 years. A new liquid coating, Speedling® Super-Cote, can be applied to Styrofoam blocks to extend their life expectancy. It has been used successfully on several southern pine seedlings, and reportedly makes the plugs easier to extract. Root control ribs inside the cavity are also standard on both types of block containers, although Barnett (1982) reported that roots of loblolly pine seedlings were deformed at the bottom of the plugs because the anti-spiral ribs did not extend all the way to the bottom of some Styrofoam block cavities. One of the drawbacks of all types of block containers is that empty cavities cannot be replaced, making high seed quality and proper sowing procedures necessary.

Styrofoam blocks are composed of expanded polystyrene foam and come in a wide variety of container capacities, ranging from 41 to 492 cm^3 (2.5 to 30.0 cubic inches), and growing densities ranging from 270 to 1,108 cells/ m^2 (25 to 103 per square feet). It is worth noting that environmentally polluting chloro-fluorocarbons are not used in the manufacturing of Styrofoam blocks.

Styroblocks® are one specific brand of Styrofoam block, and the term should not be used as a generic term for all Styrofoam containers.

An important characteristic of Styrofoam blocks is their inherent insulating value, which protects seedling root systems against extreme temperatures. One cultural problem with Styrofoam containers is that roots of some species grow into the pores in the cavity walls, making the seedlings difficult to extract and the blocks difficult to clean and sterilize between crops. A new Styrofoam block, called the Ventblock®, offers a series of ventilation holes between the cavities to promote air circulation between seedlings; this feature has proven effective in controlling the grey mold fungus (*Botrytis cinerea),* which thrives in the humid environment in densely growing seedlings (Peterson and Sutherland 1989).

Multi-pots are composed of high-density polyethylene and are available in a range of sizes, although only the 57 and 65 cm^3 (3.5 and 4.0 cubic inches) were commonly used in the United States and Canada at the time of the Container Nursery Survey (table 2.1.1). Multi-pots are one of the most durable containers that are currently available, and their smooth inner cell walls facilitate seedling extraction and make cleaning and sterilizing between crops easy.

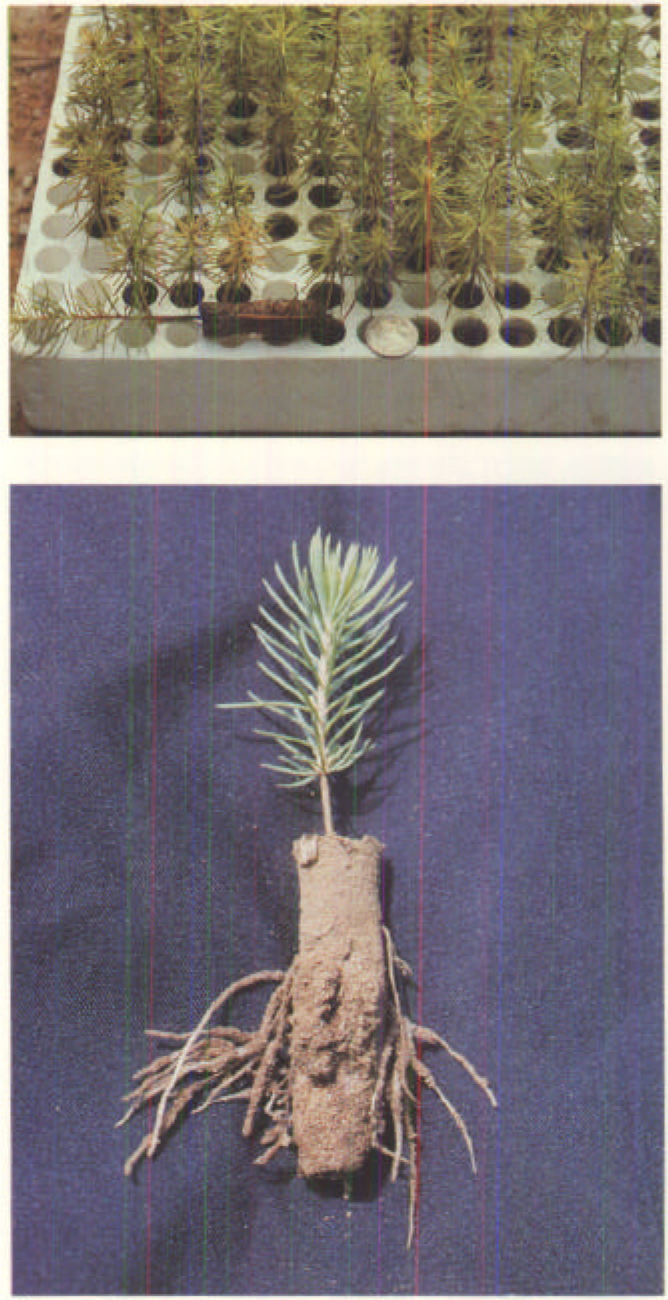
The Ecopot® is another block container that is a modification of the paperpot system. This container resembles the paperpot in the way it is bought and used, but contains parallel plastic strips in between the individual cells. These plastic strips are removed one row at a time during packing, producing a plug seedling. For nurseries that already have the paperpot sowing and handling system, the Ecopot is an inexpensive way to shift to a plug seedling system (Sims 1988).

Block containers have a regional usage pattern in Canada: they are most popular in the provinces where they were originally developed. Styrofoam blocks are most popular in British Columbia, and Multi-pots are gaining increasing popularity in the Maritime Provinces (Smyth and Ramsay 1982) and the southern United States. In the United States, Styrofoam blocks are one of the most common containers in the Northwest (Landis 1982), and about 80% of the container seedlings produced in the Lake States come from Styrofoam blocks (Alm 1982). Barnett (1982) reports that southern pine seedlings grew well and also had good outplanting performance when produced in Styrofoam blocks.

Miniature containers. A recent innovation in the container tree nursery industry, borrowed from the vegetable transplant industry, is the use of very small containers (mini-containers) to produce young plug seedlings for container/bareroot transplants (Hee and others 1988, Klapprat 1988). Seedlings are produced in rectangular plastic or Styrofoam containers (fig. 2.1.21 A), that contain a grid of small cells [4 to 18 cm^3 (0.25 to 1.1 cubic inches)] and produce high seedling growing densities [948 to 3,813 cells / m^2 (88 to 354 per square foot)]. After a relatively short growing period in a greenhouse, the container seedlings are transplanted to bareroot nursery beds for an additional period of growth. Although a number of different miniature container systems are on the market, two of the most commonly used in container tree nurseries in North America are the Mini Plug® system (Hee and others 1988), and the Techniculture® plug system (Klapprat 1988).

The objective of the mini-container system is to produce a fully extractable seedling with a dimensionally stable root plug that will tolerate transplanting within a relatively short growing period (3 to 4 months) (fig. 2.1.21 B). Both the Mini-plug and Techniculture systems are fully automated, from sowing the seed through transplanting. Because the seedlings grow in them for only a short time, mini-containers are radically different from typical container types: the cells are very short and closely spaced, and do not have ribs to control root spiraling. In some systems, the mini-containers are carried to the bareroot nursery where they are used as magazines for feeding the seedlings to the transplanter; other nurseries extract the seedlings before transplanting.

The future of miniature container systems appears promising. They can be used to shorten the rotation for slow-growing species or species that do not grow well in bareroot nurseries. Because all transplants are relatively more expensive than seedlings, economic analyses and outplanting trials of mini-container transplants are currently being performed. A series of trials with the Mini-plug system showed that the container transplants performed as well or better than traditional bareroot seedling or transplant stock types on a variety of coastal sites in the Pacific Northwest (Tanaka and others 1988).



A

B

Figure 2.1.21—*Miniature containers are used to grow small seedlings* (**A**), *which are then transplanted to bareroot beds when only a few months old to produce plug + one transplants. The spruce seedling in* (**B**) *had only been transplanted for a few weeks, and already shows new roots growing out of the plug.*

2.1.4 Chemical Root Pruning

There has been widespread concern over the root form of container seedlings and the potential problems with root-bound plug seedlings after outplanting. Burden and others (1986) relate the problem of physical instability (toppling) of lodgepole pine seedlings in British Columbia plantations to poor lateral root egress after outplanting, and discuss chemical and mechanical root pruning treatments to overcome this problem. Carlson and others (1980) studied the root system morphology of Sitka spruce that had been direct-seeded, or grown as bareroot or container seedlings, and concluded that the root deformation that was caused by outplanting was probably not severe enough to cause instability or growth retardation. Obviously, species rooting characteristics, type of planting tool, and soil characteristics on the outplanting sites have a significant effect on the root form of the seedling after outplanting. Nevertheless, container nursery managers and reforestation foresters are interested in any cultural treatment that will generate a better root system in container tree seedlings.

One option is to coat the interior walls of the containers with chemicals that inhibit root growth, such as cupric carbonate ($CuCO_3$) or indolebutryic acid (IBA), carried in a binding material such as latex paint (Pellett and others 1980, McDonald and others 1984a). Chemicals for root pruning must inhibit root growth and remain in the application zone throughout the growing season without diffusing into the growing medium or becoming phytotoxic to the seedling. These chemicals must also not be toxic to nursery personnel or the environment (Hulten 1982). Tinus (1987) tested a variety of heavy metals including copper, silver, cobalt, nickel, lead, zinc, and antimony and found that only copper would stop root growth without injuring the seedling. $CuCO_3$ has been the most popular root pruning chemical used in subsequent trials, and recommended application rates range from 60 to 200 g/liter (2.0 to 6.7 ounces per gallon) depending on seedling species and container type (Wenny and others 1988).

Chemicals for root pruning can be either sprayed into the container cavities or used as a dip for the entire block. The blocks are then filled and sown in the usual manner, but when the seedling roots contact this chemical barrier they cease growing and suberize (fig. 2.1.22). New lateral roots are generated and are subsequently pruned when they reach the treated container wall, resulting in a more fibrous, branched root system that is evenly distributed throughout the container. These pruned root tips resume normal root growth when the seedling is removed from the container, creating a more natural, branched root system after outplanting (Burden and others 1983, McDonald and others 1984a).

Burden and Martin (1982) treated the inside of Styrofoam block containers with latex paint containing $CuCO_3$ and grew 10 different species of conifer seedlings in them (fig. 2.1.23). They reported that this chemical root pruning prevented root spiraling, but their results varied with seedling species, container volume, type of growing medium, and the concentration of CuCO; in the wall coating. McDonald and others (1984a) found that both $CuCO_3$ and IBA arrested root growth of ponderosa pine seedlings when applied to container walls, but the copper treatment was more effective. Romero and others (1986) reported that treatment with $CuCO_3$ significantly increased the number of lateral roots and both root and shoot weight in Caribbean pine container seedlings. Green ash and red oak seedlings grown in $CuCO_3$--treated containers were larger than controls and had more fibrous and evenly distributed root systems (Arnold and Struve 1989). Dong and Burden (1986) reported that treating paper contain-

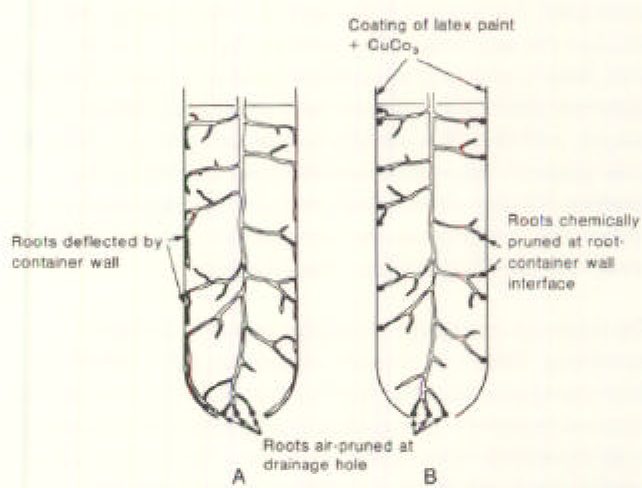


Figure 2.1.22—*Chemical root pruning involves treating the interior container wall with a growth-inhibiting chemical, such as cupric carbonate ($CuCO_3$). In an untreated container* **(A)**, *roots are deflected downward until they are air-pruned at the drainage hole. The chemical barrier in a treated container* **(B)** *causes the lateral roots to be chemically pruned at the container wall. These pruned laterals become suberized but will begin to grow again after outplanting, resulting in a more natural, well-distributed root system (after Ruehle 1985).*

Figure 2.1.23—*Chemically root-pruned seedlings (left of each pair) of four different conifers produce a much more fibrous and well-balanced root system after outplanting compared to normal container seedlings (right of each pair) (from left to right: Pacific silver fir, Douglas-fir, western redcedar, and western hemlock) (courtesy of Burdett and Martin 1982).*

ers with cupric sulfide (CuS) prevented root spiraling in paper containers with a polyethylene coating and also stopped root growth between non-polyethylene-coated paper containers. Root distribution within the container has often been a problem, with the majority of new root tips forming at the drain hole at the bottom of the container. Copper-treated containers produced more new roots in the middle and upper zones of the container, which should promote better seedling stability after outplanting (Wenny and others 1988).

Chemical root pruning has also been found to have other benefits for container tree seedlings. Romero and others (1986) analyzed root development of $CuCO_3$-treated Caribbean pine seedlings and found that treated seedlings had more lateral roots as well as significantly larger stem diameters than control seedlings. They also noted that the $CuCO_3$ treatment caused a change in root morphology: treated seedlings had finer, more fibrous root systems than did untreated seedlings. Ruehle (1985) studied the effect of $CuCO_3$ on the root morphology of southern pine seedlings and found few significant differences in shoot or root dimensions, weight, or ectomycorrhizal formation. McDonald and others (1984b) found that a combination of $CuCO_3$ treatment and inoculation with ectomycorrhizal fungi increased the number of short roots of lodgepole pine seedings, and ectomycorrhizai formation on both lodgepole pine and ponderosa pine seedlings. Donald (1986) reported that copper salts also kept bryophytes from growing on the containers.

The real benefits of chemical root pruning should occur after outplanting, and results have generally been favorable. Green ash and red oak seedlings transplanted from containers treated with CuCO; had higher root growth potential compared to the controls; Arnold and Struve (1989) attributed this to the greater number of root tips produced after chemical root pruning. McDonald and others (1984a) planted $CuCO_3$-treated ponderosa pine seedlings in vermiculite, and found that treated seedlings had 3 times more root egress and were also significantly taller than untreated seedlings. Burden and others (1983) studied the root development of chemically pruned lodgepole pine seedlings after outplanting and found that treated seedlings have more uniform root growth ;fig. 2.1.24) and significantly better height growth than controls. However, seedlings of three western conifer species, when examined 3 years after outplanting, showed no significant increase in survival or growth

Figure 2.1.24—*Four years after outplanting, the untreated lodgepole pine seedling (left) had fewer and smaller new roots than the chemically pruned lodgepole pine seedling (right) (courtesy of Burdett and others 1983).*

even though the seedlings did have more new roots in the upper zones of the soil (Wenny 1988). The practical benefits of chemical root pruning may only become obvious when the outplanted seedlings ire exposed to physical or environmental stresses.

Although the use of copper-treated containers has not been implemented operationally in North America, chemical root pruning is currently being used in South Africa (Donald 1986); containers are dipped in a polymer suspension of Cu^{2+} ions called Styrodip prior to filing and sowing (Nelson 1989). Beaver Plastics has recently introduced the Trimroot Styroplug®, which uses a "differential coating" system (fig. 2.1.25) to control and prune roots within a Styrofoam container; they stress that operational trials are needed to test this new system, however. Another option is to stimulate natural air pruning of roots around the periphery of the plug by designing a container with air slits at regular intervals on the sides. The Rootmaker® container incorporates a series of drainage slots around the perimeter but is currently available in only one relatively large size (Whitcomb 1988).

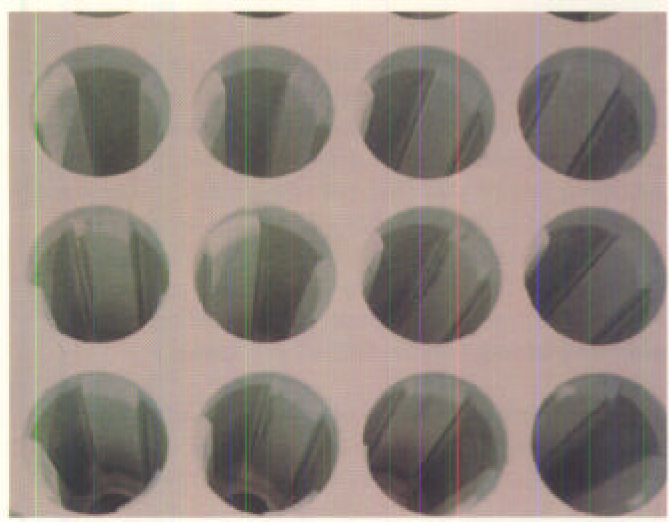


Figure 2.1.25—*The Trimroot Styroplug® features container cavities that have been treated with $CuCO_3$ to promote chemical root pruning.*

2.1.5 Conclusions and Recommendations

As evidenced by the variety of containers that are currently in use in container tree nurseries, acceptable seedlings can be produced in many different types of containers. There is no one container that exhibits all the many different characteristics, and thus, no single type of container is best for all nurseries and outplanting sites. In the final assessment, the choice of a container system depends on the objectives and cultural characteristics of each individual container tree nursery operation (Landis 1982).

2.1.6 Literature Cited

Allison, C.J., Jr. 1974. Design considerations for the RL single cell system. In: Tinus, R.W.; Stein, W. I.; Balmer, W.I. Proceedings, North American Containerized Forest Tree Seedling Symposium; 1974 August 26-29; Denver, CO. Publ. 68. Great Plains Agricultural Council, 1974: 233-236.

Alm, A.A. 1982. The status of container planting programs in the Northern United States. 2. Lake States-Minnesota, Wisconsin, Michigan. In: Scarratt, J.B.; Glerum, C.; Plexman, C.A., eds. Proceedings, Canadian Containerized Tree Seedling Symposium; 1981 September 14-16; Toronto, ON. COJFRC Symp. Proc. O-P-10. Sault Ste. Marie, ON: Canadian Forestry Service, Great Lakes Forest Research Centre: 63-65.

Alm, A.; Olsen, D.; Lacky, M. 1982. Comparisons after planting of jack pine grown for varying time periods. in different container systems. Minn. For. Res. Notes 279. St. Paul, MN: University of Minnesota College of Forestry. 4 p.

Armson, K.A.; Sadreika, V. 1979. Forest tree nursery soil management and related practices. Toronto, ON: Ontario Ministry of Natural Resources. 179 p.

Barnett, J.P. 1982. Selecting containers for southern pine seedling production. In: Guldin, R.W.; Barnett, J.P., eds. Proceedings, Southern Containerized Forest Tree Seedling Conference; 1981 August 25-27; Savannah, GA. New Orleans, LA: USDA Forest Service, Southern Forest Experiment Station: 15-24.

Barnett, J. P.; Brissette, J.C. 1971 . Producing southern pine seedlings in containers. Gen. Tech. Rep. SO-59. New Orleans, LA: USDA Forest Service, Southern Forest Experiment Station. 71 p.

Barnett, J.P.; McGilvray, J.M. 1981. Container planting systems for the South. Res. Pap. SO-167. New Orleans, LA: USDA Forest Service, Southern Forest Experiment Station. 18 p.

Barney, C.W. 1947. A stu dy of some factors affecting root growth of loblolly pine, Pinus *taeda.* PhD Dissertation. Durham, NC: Duke University School of Forestry.

Barteaux, M.K.; Kreiberg, N.H. 1982. The status of container planting programs in Canada. 7. New Brunswick. In: Scarratt, J.B.; Glerum, C.; Plexman, C.A., eds. Proceedings, Canadian Containerized Tree Seedling Symposium; 1981 September 14-16; Toronto, Ontario. COJFRC Symp. Proc. O-P-10. Sault Ste. Marie, ON: Canadian Forestry Service, Great Lakes Forest Research Centre: 45-48.

Boudoux, M.E. 1970. Effect of tube dimension on root density of seedlings. Canadian Department of Fisheries and Forestry Bi-monthly Research Note 26(3):29-30.

Brown, W.L. 1982. Temperature in container affects growth of ornamentals. Louisiana Agriculture 26(1): 8-9.

Burly, J.D.; Miller, E.L. 1984. Survival, growth, and root form of containerized Jeffrey pines. In: Murphy, P.M., comp. The challenge of producing native plants for the intermountain area. Proceedings, Intermountain Nurseryman's Association 1983 Conference; 1983 August 8-11; Las Vegas, NV. Gen. Tech. Rep. INT168. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station: 82-88.

Burden, A.N. 1979. Juvenile instability in planted pines. Irish Forestry 36(1):36-47.

Burden, AX; Martin, P.A.F. 1982. Chemical root pruning of coniferous seedlings. HortScience 17(4):622-624.

Burden, AX; Simpson, D.G.; Thompson, C.F. 1983. Root development and plantation establishment success. Plant and Soil 71 :103-110.

Burden, A.N.; Coates, H.; Eremko, R.; Martin, P.A.F. 1986. Toppling in British Columbia's lodgepole pine plantations: significance, cause and prevention. Forestry Chronicle 62(5):433-439.

Carlson, W.C.; Preisig, C.L.; Promnitz, L.C. 1980. Comparative root system morphologies of seeded-inplace, bareroot, and container-cultured plug Sitka spruce seedlings after outplanting. Canadian Journal of Forest Research 10:250-256.

Carlson, L.W.; Endean, F. 1976. The effect of rooting volume and container configuration on the early growth of white spruce seedlings. Canadian Journal of Forest Research 6:221-224.

Carlson, L.W. 1983. Guidelines for rearing containerized conifer seedlings in the Prairie Provinces. Info. Rep. NOR-X-214E. Edmonton, AB: Canadian Forestry Service, Northern Forest Research Centre. 64 p.

Dirmarsen, S.C.; Alm, A.A. 1979. Paperpot biodegradability experience in Minnesota. Tree Planters' Notes 30(1):20-21
.

Donald, D.G.M. 1986. South African nursery practice; the state of the art. South African Forestry Journal 139:36-47.

Dong, H.; Burden, A.N. 1986 Chemical root pruning of Chinese pine seedlings raised in cupric sulfide impregnated paper containers. New Forests 1 :67-73.

Edwards, I.K.; Huber, R.F. 1982. Contrasting approaches to containerized seedling production. 2. The prairie provinces. In: Scarratt, J.B.; Glerum, C.; Plexman, C.A., eds. Proceedings, Canadian Containerized Tree Seedling Symposium; 1981 September 14-16; Toronto, ON. COJFRC Symp. Proc. O-P-10.

Sault Ste. Marie, ON: Canadian Forestry Service, Great Lakes Forest Research Centre: 123-127.

Endean, F.; Carlson, L.W. 1975. The effect of rooting volume on the early growth of lodgepole pine seedlings. Canadian Journal of Forest Research 5:55-60.

Furuta, T. 1978. Environmental plant production and marketing. Arcadia, CA: Cox Publishing Co. 232 p.

Girouard, R.M. 1982. Greenhouse production of white spruce, black spruce, jack pine, and red pine seedlings in three types of containers. Rep. No. LAU-X-57E. Sainte-Foy, PQ: Canadian Forestry Service, Laurentian Forest Research Centre. 14 p.

Hatheway, H. 1988. "Jiffy" pellets are growing challenge to paperpots. Silviculture Magazine 3(4):18-21 .

Hee, S.M.; Stevens, T.S.; Walch, D.C. 1988. Production aspects of mini-plug transplants. In: Landis, T.D., tech. coord. Proceedings, combined meeting of the Western Forest Nursery Associations; 1988 August 8-1 1 ; Vernon, BC. Gen. Tech. Rep. RM-167. Ft. Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 168-171 .

Hocking, D.; Mitchell, D.L. 1974. The influences of rooting volume: seedling espacement and substratum density on greenhouse growth of lodgepole pine, white spruce, and Douglas-fir grown in extruded peat cylinders. Canadian Journal of Forest Research 5:440-451.

Hoedemaker, E. 1974. The Japanese paperpot system. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E. Proceedings, North American Containerized Forest Tree Seedling Symposium; 1974 August 26-29; Denver, CO. Pub. 68. Denver: Great Plains Agricultural Council: 214-216.

Hulten, H. 1982. Chemically controlled root formation. In: Hulten, H., ed. Root deformation of forest tree seedlings. Proceedings, a nordic symposium; 1981 January 21-22; Garpenberg, Sweden. Rep. No. 11 . Garpenberg, Sweden: The Swedish University of Agricultural Sciences, Department of Forest Yield Research: 95-98.

Kelly, G. 1982. The status of container planting programs in Canada. 9. Prince Edward Island. In: Scarratt, J.B.; Glerum, C.; Plexman, C.A., eds. Proceedings, Canadian Containerized Tree Seedling Symposium; 1981 September 14-16; Toronto, ON. COJFRC Symp. Proc. O-P-10. Sault Ste. Marie, ON: Canadian Forestry Service, Great Lakes Forest Research Centre: 51-54.

Kinghorn, J.M. 1974. Principles and concepts in container planting. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., ed. Proceedings, North American Containerized Forest Tree Seedling Symposium; 1974 August 26-29; Denver, CO. Publ. 68. Great Plains Agricultural Council: 8-18.

Klapprat, R.A. 1988. Greenhouse transplants for bareroot stock production. In: Landis, T.D., tech. word. Proceedings, combined meeting of the Western Forest Nursery Associations; 1988 August 8-1 1; Vernon BC. Gen. Tech. Rep. RM-167. Ft. Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 165-167.

Landis, T.D. 1982. The status of container planting programs in the Northern United States. 3. Northwestern United States. In: Scarratt, J.B.; Glerum, C.; Plexman, C.A., eds. Proceedings, Canadian Containerized Tree Seedling Symposium; 1981 September 14-16; Toronto, ON. COJFRC Symp. Proc. O-P-10. Sault Ste. Marie, ON: Canadian Forestry Service, Great Lakes Forest Research Centre: 67-70.

Liege], L.H.; Venator, C.R. 1987. A technical guide for forest nursery management in the Caribbean and Latin America. Gen. Tech. Rep. SO-67. New Orleans, LA: USDA Forest Service, Southern Forest Experiment Station. 156 p.

Macdonald, B. 1986. Practical woody plant propagation for nursery growers. Portland, OR: Timber Press. 669 p.

Matkin, O.A.; Chandler, P.A.; Baker, K.F. 1957. Components and development of mixes. In: Baker, K.F., ed. The U.C. system for producing healthy containergrown plants. Ext. Serv. Man. 23. Parramatta, Australia: The Australian Nurserymen's Association [first printed by the University of California, Division of Agricultural Sciences, California Agricultural Experiment Station]: 86-107.

Matthews, G. 1983. Seedling production for Crown Lands in British Columbia: guidelines for commercial container nurseries. Victoria, BC: Ministry of Forests Silviculture Branch. 45 p.

McDonald, S.E.; Tinus, R.W.; Reid, C.P.P. 1984a. Modification of ponderosa pine root systems in containers. Journal of Environmental Horticulture 2(1):l-5.

McDonald, S.E.; Tinus, R.W.; Reid, C.P.P.; Grossnickle, S.C. 1984b. Effect of CuCO; container wall treatment and mycorrhizae fungi inoculation of growing medium on pine seedling growth and root development. Journal of Environmental Horticulture 2(1):5-8.

Mitchell, D.L.; Hocking, D.; Kay, W.C. 1972. Extruded peat cylinders: their physical characteristics as affecting tree seedling growth and greenhouse drought tolerance. Canadian Journal of Forest Research 2:479-486.

Nelson, W.R. 1990. Personal communication. Pietermaritzburg, South Africa: Starke Ayres.
Pellett, H.; Litzow, M.; Mainquist, L. 1980. Use of metal compounds as root pruning agents. HortScience 15:308-309.
Peterson, M.; Sutherland, J.R. 1989. Grey mould control by seedling canopy humidity reduction through under-bench ventilation and Styroblock aeration. FRDA Rep. 077. Victoria, BC: Forestry Canada, Pacific Forestry Centre.
Rasanen, P.K. 1982. Containerized forest tree seedling production and development prospects in Finland and Scandinavia. In: Scarratt, J.B.; Glerum, C.; Plexman, C.A., eds. Proceedings, Canadian Containerized Tree Seedling Symposium; 1981 September 14-16; Toronto, ON. COJFRC Symp. Proc. O-P-10. Sault Ste. Marie, ON: Canadian Forestry Service, Great Lakes Forest Research Centre: 9-17.
Reese, K.H. 1974. The Ontario tube. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E. Proceedings, North American Containerized Forest Tree Seedling Symposium; 1974 August 26-29; Denver, CO. Publ. 68. Great Plains Agricultural Council: 211-213.
Ritchie, G.A. 1984. Root growth potential: principles, procedures, and predictive ability. In: Duryea, M.L. Proceedings, Evaluating seedling quality: principles, procedures, and predictive abilities of major tests. 1984 October 16-18; Corvallis, OR. Corvallis, OR: Oregon State University, Forest Research Laboratory: 93-105.
Romero, A.E.; Ryder, J.; Fisher, J.T.; Mexal, J.G. 1986. Root system modification of container stock for arid land plantings. Forest Ecology and Management 16:281-290.
Ruehle, J.L. 1985. The effect of cupric carbonate on root morphology of containerized mycorrhizal pine seedlings. Canadian Journal of Forest Research 15:586-592.
Scarratt, J.B. 1972. Effect of tube diameter and spacing on the size of tubed seedling planting stock. Info. Rep. O-X-170. Sault Ste. Marie, ON: Canadian Forestry Service, Great Lakes Forest Research Centre. 16 p.
Sharma, R.D. 1987. Some observations on coiling of roots in nursery raised plants. Journal of Tropical Forestry 3(3): 207-212.
Simpson, D. 1988. Controlling cold hardiness and seedling size in southern interior container nurseries. FRDA Res. Memo 014. Vernon, BC: British Columbia Forest Service, Kalamalka Research Station. 1 p.
Sims, 1. 1988. Shifting from paperpots to ecopots. Silviculture Magazine 3(2): 10-12.
Sjoberg, N.E. 1974. The Styroblock container system. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American Containerized Forest Tree Seedling Symposium; 1974 August 26-29; Denver, CO. Publ. 68. Great Plains Agricultural Council: 217-228.
Smyth, J.H.; Ramsay, K.L. 1982. Statistical summary of containerized seedling and bare-root programs in Canada: 1980 situation and projections for 1983. In: Scarratt, J.B.; Glerum, C.; Plexman, C.A., eds. Proceedings, Canadian Containerized Tree Seedling Symposium; 1981 September 14-16; Toronto, ON. COJFRC Symp. Proc. O-P-10. Sault Ste. Marie, ON: Canadian Forestry Service, Great Lakes Forest Research Centre: 5 7-5 8.
Spencer, H.A. 1974. To "engineer" the container. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American Containerized Forest Tree Seedling Symposium; 1974 August 26-29; Denver, CO. Pub]. 68. Great Plains Agricultural Council: 229-232.
Stauder, A.F., III; Lowe, W.J. 1984. Container density does not affect baldcypress growth. Tree Planters' Notes 35(4): 20-21.
Strachan, M.D. 1974. Tar paper containers. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American Containerized Forest Tree Seedling Symposium; 1974 August 26-29; Denver, CO. Publ. 68. Great Plains Agricultural Council: 209-210.
Sutherland, D.C.; Day, R.J. 1988. Container volume affects survival and growth of white spruce, black spruce, and jack pine seedlings: a literature review. Northern Journal of Applied Forestry 5(3):185-189.
Tanaka, Y.; Carrier, B.; Dobkowski, A.; Figueroa, P.; Meade, R. 1988. Field performance of mini-plug transplants. In: Landis, T.D., tech. coord. Proceedings, combined meeting of the Western Forest Nursery Associations; 1988 August 8-1 1; Vernon, BC. Gen. Tech. Rep. RM-167. Ft. Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 172-181.
Tanaka, Y.; Timmis, R. 1974. Effect of container density on growth and cold hardiness of Douglas-fir seedlings. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American Containerized Forest Tree Seedling Symposium; 1974 August 26-29; Denver, CO. Publ. 68. Great Plains Agricultural Council: 181-186.

Timmis, R.; Tanaka, Y. 1976. Effects of container density and plant water stress on growth and cold hardiness of Douglas-fir seedlings. Forest Science 22(2):167-172.

Tinus, R.W.; McDonald, S.E. 1979. How to grow tree seedlings in containers in greenhouses. Gen. Tech. Rep. RM-60. Ft. Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 256 p.

Tinus, R.W. 1974. Large trees for the Rockies and Plains. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American Containerized Forest Tree Seedling Symposium; 1974 August 26-29; Denver, CO. Publ. 68. Great Plains Agricultural Council: 1 12-1 18.

Twetman, J. 1988. Production and use of containerized seedlings in Sweden. Irish Forestry 45(2):112-116.

Van Eerden, E. 1982. The fundamentals of container seedling production. In: Scarratt, J.B.; Glerum, C.; Plexman, C.A., eds. Proceedings, Canadian Containerized Tree Seedling Symposium; 1981 September 14-16; Toronto, ON. COJFRC Symp. Proc. O-P-10. Sault Ste. Marie, ON: Canadian Forestry Service, Great Lakes Forest Research Centre: 83-90.

Venator, C.R.; Liegel, L.H.; Barnett, J.P. 1985. Bareroot versus container production in pines in the American tropics. In: South, D.B., ed. Proceedings, International Symposium on Nursery Management Practices for the Southern Pines; 1985 August 4-9; Montgomery, Alabama. Auburn, AL: Auburn University, Alabama Agricultural Experiment Station: 72-82.

Vinaya Rai, R.S.; Natarajan, N. 1987. Studies on nursery technology and planting density in *Casuarina equisetifolia.* Van Vigyen 25 (1): 10-15.

Waiters, J. 1974. Engineering for injection planting. In: Tinus, R.W.; Stein, W.I.; Balmer, W.E., eds. Proceedings, North American Containerized Forest Tree Seedling Symposium; 1974 August 26-29; Denver, CO. Publ. 68. Great Plains Agricultural Council: 241-243.

Wenny, D.L. 1988. Growth of chemically root-pruned seedlings in the greenhouse and the field. In: Landis, T.D., tech. coord. Proceedings, combined meeting of the Western Forest Nursery Associations; 1988 August 8-1 1; Vernon, BC. Gen. Tech. Rep. RM-167. Ft. Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 32-37.

Wenny, D.L.; Liu, Y.; Dumroese, R.K.; Osborne, H.L. 1988. First year field growth of chemically root pruned containerized seedlings. New Forests 2(2): 111-118.

Whitcomb, C.E. 1988. Plant production in containers. Stillwater, OK: Lacebark Publications: 633 p.

Wilson, P.J. 1986. Containers for tree nurseries in developing countries. Commonwealth Forestry Review 65(3):233-240.