Forest nursery practices in the Southern United States

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ARTICLE INFO

Citation:
South DB, Starkey TE, Enebak SA (2016) Forest nursery practices in Sothern United States. Reforesta 1: 106-146. DOI: http://dx.doi.org/10.21750/REFOR.1.07.7

Editor: Steven Grossnickle, Canada
Received: 2016-02-07
Accepted: 2016-03-09
Published: 2016-05-25

This article is Chapter 6 of establishing issue of Reforesta Journal, edited in form of Thematic Proceedings, by Vladan Ivetić and Steven Grossnickle.

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Abstract

Over the past five decades, researchers in the southern United States have been working with nursery managers to develop ways to reduce the cost of producing seedlings. In this regard, the Southern Forest Nursery Management Cooperative (at Auburn University in Alabama) has helped reduce hand-weeding costs and losses due to nematodes and disease. As a result, nursery managers are able to legally use a variety of registered herbicides and fungicides for use in pine and hardwood seedbeds. Other changes over the last three decades include a reduction in the number of nurseries growing seedlings, a reduction in the number of seedlings outplanted per ha, an increase in the number of container nurseries, an increase in the average production per nursery, an increase in production by the private sector, growing two or more crops after fumigation, the development of synthetic soil stabilizers, applying polyacrylamide gels to roots and the use of seedling bags and boxes for shipping seedlings.

Keywords

Bareroot, Container, Nursery, Reforestation

Contents

1 Introduction

Nurseries in the South (i.e. thirteen southern states in the United States) have produced seedlings for reforestation for over a century (Schenck 1907; South 2015). In 1922, the Great Southern Lumber Company constructed a 0.2 ha nursery at Bogalusa, Louisiana (Wakeley and Barnett 2001) and by 1926, there were more than 1,100 ha of acceptable plantations in the South. At that time, tree planting was routine in northern states, which had several nurseries and over 115,000 ha of plantations. However, tree planting increased after several federal and state nurseries were established in the South (Fig. 1), and by 1944, seedling production exceeded that from northern nurseries (Zillgitt 1958). In 2013, over 82% of the 1.2 billion seedlings produced in the US were grown in the thirteen southern states (Tab. 1).

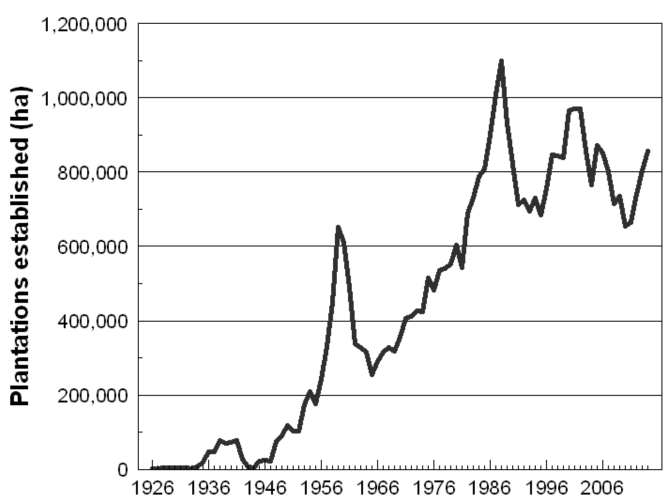

Figure 1. Annual establishment of plantations in the South (Hernández et al. 2016).

Since 1972, researchers at Auburn University began working closely with nursery managers to reduce hand-weeding costs, increase seed efficiency and improve seedling quality (Carter et al. 2015). This effort evolved into the Southern Forest Nursery Management Cooperative (SFNMC) which has conducted pesticide and seedling quality research throughout the South. The purpose of this paper is to summarize some of the research conducted by the SFNMC and to discuss current nursery practices employed in southern nurseries.

Table 1. Seedling production (fall 2013) in the United States, by region, and percentage of stock produced in containers for each region. Data are from Hernández et al. (2015).

Region of US	Total seedlings produced	% of total US	% container
South	1,015,563,654	82.8%	19%
Northeast	12,916,756	1.1%	6%
North Central	66,117,661	5.4%	6%
Great Plains	4,125,194	0.3%	26%
Intermountain	6,691,303	0.6%	72%
Pacific Northwest	104,669,088	8.5%	44%
Pacific Southwest	16,382,281	1.3%	100%
Totals	1,226,465,937	100%	22%

1.1 Planting density

The recommended number of seedlings per ha (SPH) to plant has declined and this directly impacts the demand for seedlings. Initially, tree planting recommendations were imported from Europe. For example, Carl Schenck (a German forester employed at the Biltmore Estate in North Carolina), planted pines at more than 9,000 SPH (Schenck 1907; McNab and Ritter 2000). However, high planting rates seemed unnecessary and, therefore, an inspector for the U.S. Forest Service suggested this rate be lowered to 3,000 SPH (Ashe 1915). By mid-century, a common recommendation was to plant 2,500 SPH (Grano 1956). Recommendations at this time were not based on optimizing economic returns for the landowner. Prior to 1970, many foresters (employed by pulp companies) recommended planting densities that would “maximize volume production.” By 1970, median planting rates for Continental Forest Industries ranged from 1,530 to 2,040 SPH (Xydias 1981).

The trend towards lower planting rates has continued into the 21st century (Fig. 2). In the early 1970’s the Weyerhaeuser Company was planting *Pinus taeda* seedlings at about 2,200 SPH as part of their “high-yield forestry” program (which included a pre-commercial thinning). They now are planting about half that density (i.e. 1,075 SPH) with tree rows about 6.1 m apart and 1.5 m between trees within the row. One commercial thinning (at mid-rotation) lowers stocking to about 270 crop trees per ha. Several landowners now plant bareroot pine seedlings at less than 1,150 SPH (Barlow and Levendis 2015).

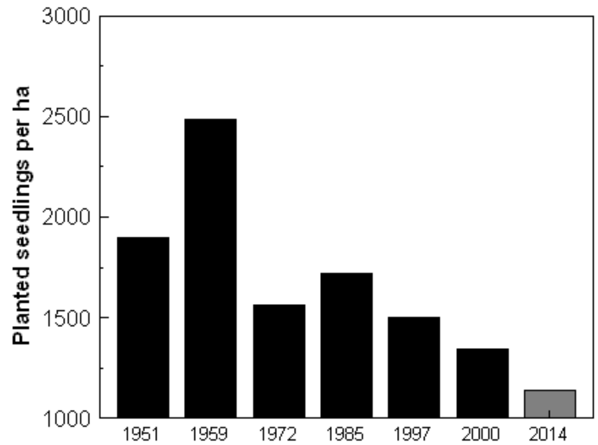

Figure 2. Change in planting rate for plantations in the South (1950-2014). Solid black bars determined by dividing total seedling production records by total area of plantations established for each year (Hernández et al. 2016). The 2014 data were obtained from Barlow and Levendis (2015).

There are various factors that contribute to this trend. For some, the overall objective has changed from maximizing volume production (e.g. pulpwood rotations) to maximizing return on investment (Caufield et al. 1992). Many paper companies sold their forests to financial investment organizations (Carter et al. 2015) that use various regeneration regimes to increase returns on investments. Other landowners were more concerned about wildlife and ecosystems (South 2006) and less concerned about growing pulpwood. Other landowners decide to reduce planting rates to offset the higher cost associated with planting improved genotypes. In addition, planting high-quality stock reduces the need for overplanting (due to expected low survival rates). For example, survival of bareroot *Pinus taeda* seedlings once averaged 73% (Weaver et al. 1980) and in some regions survival ranged from 56% to 84% (Zwolinski et al. 1995). The range reported for container-grown *Pinus palustris* seedlings was from 39% to 99% (South et al. 2012). When survival is increased from 73% (then) to 88% (now), in theory, the planting rate can be dropped by 17% (to achieve the same stocking level after two years in the field).

1.2 Nursery closings

The number of bareroot nurseries in the South has fluctuated over time (Hernández 2012). By 1950, there were about 33 bareroot nurseries in the South. The next three decades saw the construction of forty new nurseries (Fig. 3). Then a trend started of closing state and federal nurseries. From 1995 to 2007, nine state nurseries closed (Starkey et al. 2015a) along with a US Forest Service nursery located at Brooklyn, Mississippi. The states of Alabama, Louisiana and Mississippi no longer manage regeneration nurseries and Texas no longer manages a pine seedling nursery. The fate of state nurseries depends, in part, on politicians. For example, the Wallace State's Hopper Nursery (in Alabama) was established based on the desires of one politician.

The cost efficiency of nursery production depends on the nursery size (i.e. small nurseries are more likely to have higher overhead costs). For example, the average production of the ten closed state nurseries was 17 million (Starkey et al. 2015a). Eleven industry nurseries also closed between 1996 and 2012 (average annual production was 28 million seedlings). Other industry nurseries were purchased and managed by private companies. For example, six nurseries once managed by International Paper Company are now managed by ArborGen, LLC (Tab. 2). The transition away from state managed nurseries was gradual but the conversion of industry nurseries to private nurseries was relatively rapid (Fig. 3). In 2014, the majority of seedlings were produced by private nurseries (i.e. privately owned companies that did not own or manage forestland).

Table 2. A selected list of 48 reforestation nurseries in the southern United States (2015) including location and initial year of production. Nurseries with an asterisk are members of the Southern Forest Nursery Management Cooperative.

State	Nursery	City	Stock type	Year	Ownership
Alabama	SuperTree*	Selma	Bareroot	1974	ArborGen
	White City	Verbena	Bareroot	1980	Summit
	Pine Hill*	Camden	Bareroot	1980	Weyerhaeuser
	Elberta*	Elberta	Both	1991	Rayonier
	Westervelt*	Tuscaloosa	Container	1981	Westervelt
Arkansas	Baucum*	North Little Rock	Bareroot	1958	State of AR
	Fred Gragg*	Bluff City	Bareroot	1980	ArborGen
	Magnolia*	Magnolia	Bareroot	1972	Weyerhaeuser
Florida	Buckeye	Perry	Bareroot	1956	Private
	Dwight Stansel	Wellborn	Bareroot	1986	Private
	Andrews*	Chiefland	Both	1956	State of FL
	Central Florida	Mayo	Both	1984	Private
	Superior Trees	Lee	Both	1953	Private
	International*	Labelle	Container	2009	IFCO
	Blanton	Madison	Container	2001	Private
Georgia	Flint River*	Byromville	Bareroot	1987	State of GA
	SuperTree*	Shellman	Bareroot	1996	ArborGen
	Jesup*	Jesup	Bareroot	1956	Plum Creek
	Native Forest	Chatsworth	Bareroot	1978	Private
	K&L Forest*	Buena Vista	Bareroot	1999	Private
	Pinecrest	Buena Vista	Bareroot	2007	Private
	Bellville*	Claxton	Both	1957	ArborGen
	International*	Moultrie	Container	2003	IFCO
	Meeks' Farms	Kite	Container	1996	Private
	DeepSouth	Douglas	Container	2001	Private
	Lewis Taylor	Tifton	Container	1997	Private
	Whitfield	Twin City	Container	1996	Private
	Zellner Farms	Culloden	Container	2010	Private
Kentucky	John Rhody	Kentucky Dam	Bareroot	1956	State of KY
	Morgan	West Liberty	Bareroot	1961	State of KY
Louisiana	Evans*	Deridder	Container	2014	IFCO
Mississippi	Shubuta*	Shubuta	Bareroot	1981	Plum Creek
	Delta View	Leland	Bareroot	1987	Private
	Pearl River*	Hazlehurst	Both	1998	Plum Creek
North Carolina	Claridge*	Goldsboro	Both	1954	State of NC
	Walker*	Washington	Both	1970	Weyerhaeuser
	Linville River*	Linville	Container	1970	State of NC
	Bodenhamer	Rowland	Container	2000	Private
Oklahoma	Engstrom*	Goldsby	Both	1947	State of OK
South Carolina	SuperTree*	Blenheim	Bareroot	1983	ArborGen
	Quail Ridge*	Aiken	Bareroot	1985	Weyerhaeuser
	Taylor*	Trenton	Both	1959	State of SC
Tennessee	East Tennessee*	Delano	Bareroot	1989	State of TN
Texas	Richard Barham*	Bullard	Bareroot	1982	ArborGen
	Crown Pine*	Jasper	Bareroot	1976	Campbell Global
	West Texas	Idalou	Container	1978	State of TX
Virginia	Augusta*	Crimora	Bareroot	1967	State of VA
	Garland Gray*	Courtland	Bareroot	1986	State of VA

Nursery size has increased over time. In 1950, 1980, and 2012, the annual production of a bareroot nursery might be 5.7, 14.3 and 21.8 million, respectively. The average for industry nurseries is now about 28 million seedlings (Starkey et al. 2015a). The size has increased as many smaller, less efficient nurseries have closed. However, other factors (such as company mergers) were more important than efficiency. For example, seven industry nurseries that produced 30 to 40 million seedlings annually were closed from 1996 to 2010 (Starkey et al. 2015a).

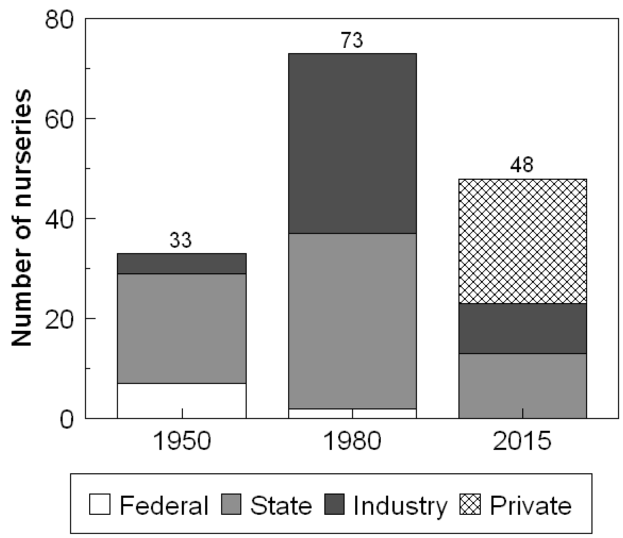

Figure 3. Number of tree nurseries operating in 13 southern states. In 1950, there were 7 Federal and 22 State operated nurseries. Three decades later there were 2 Federal and 35 State nurseries. By 2015, there were 13 state nurseries, 10 industry nurseries and at least 25 privately owned nurseries.

1.3 Nursery records

At various times, the largest regeneration nursery in the world (i.e. seedling production) has been located in the South. For example, the largest was in South Carolina (Tilghman Nursery at Wedgefield – 31 million seedlings in 1949 (Fig. 4)), Georgia (Morgan Nursery at Byron - 94 million seedlings in 1959), and Louisiana (Beauregard Nursery at DeRidder - 55 million seedlings in 1980). In 1998, the largest bareroot nursery in the world (Weyerhaeuser Nursery at Aiken, South Carolina) produced 122 million seedlings. The largest container nursery in the world might be the International Forest Company at Moultrie, Georgia (55 million seedlings in 2012). The two largest container nurseries in the South account for 43% of the total container production in the South and nearly 30% for the US (Enebak 2012; Harper et al. 2013). High production levels help to keep region-wide seedling prices relatively low. Currently, there are 10 industrial, 13 state, and 24 private nurseries operating in the South (Tab. 2).

Container seedling production was estimated at perhaps 0.01 million in 1909, 2 million seedlings in 1975 and 193 million in 2013 (South 2015). The first modern container nurseries were constructed in the early 1970s. The Herren Nursery (Punta Gorda, Florida), the Griffith Nursery (Clayton, North Carolina) and the Kirby Forest Nursery (Silsbee, Texas) began growing container seedlings in 1973 (South 2015). The International Forest Company (originally International Forest Seed Company) began producing container seedlings at Odenville, Alabama in 1983 (Bell 2015). Container production in the South now accounts for more than 68% of the total container seedlings produced in the US (Starkey et al. 2015b). Actual production may be greater than the estimate since several managers who produce *Pinus palustris* seedlings do not return SFNMC questionnaires.

Figure 4. Some of the largest nurseries in the world are located in the southern US. In South Carolina, the Tilghman Nursery (at Wedgefield) produced 31.8 million seedlings in 1949 and four decades later the Weyerhaeuser Nursery (at Aiken) produced 122 million seedlings.

1.4 Seedlings produced

In the fall of 2013, nurseries in the South produced more than one billion seedlings (Tab. 3). Conifers and bareroot *Pinus taeda* accounted for approximately 97% and 67% of the total seedling production, respectively. Container-grown *Pinus palustris* and bareroot *Pinus elliottii* accounted for 19% and 9%, respectively. In that year, nurseries that are members of the SFNMC currently produced 82% of the seedlings in the southern US (Enebak 2014).

In the South, private, industry and state nurseries produce 51%, 38% and 11% of the seedlings, respectively. Industry nurseries account for most (90%) of the bareroot conifer production. In 1970, state nurseries produced 84% of the bareroot hardwoods (Rowan 1972) and now they produce about 33% (Enebak 2014).

Choice of stock type is dramatically different for the three major pine species. About 90% and 94% of *Pinus taeda* and *Pinus elliottii*, respectively, are produced as bareroot stock (Tab. 3). In contrast, only about 5% of *Pinus palustris* is produced as bareroot stock due to lower field survival when compared to container grown seedlings. In 2013, *Pinus palustris* accounted for 55% of all container stock produced in the South and the top three pines account for 98% (Tab. 3). In the South, private, industry and state nurseries produce 84%, 11% and 5% of the container seedlings, respectively (Enebak 2014).

Table 3. Seedling production by species and stock type (fall of 2013) in the southern United States (Enebak 2014). Retail prices ($1 = €0.89) listed in this table were obtained from the internet. Higher prices are charged for improved genotypes.

Species	Bareroot	Container	Percent container	Total	Bareroot cost	Container cost
	X 1,000	X 1,000		X 1,000	€	€
Pinus taeda L.	679012	76635	10%	755647	0.05	0.16
P. palustris Mill.	5648	105458	95%	111106	0.05	0.17
P. elliottii Engelm	93599	6232	6%	99831	0.07	0.17
P. clausa (Chapm. ex Engelm.) Vasey ex	4937	0	0	4937	0.20	-
P. echinata Mill.	1937	1646	46%	3583	0.05	0.16
P. strobus L.	2401	0	0	2401	0.05	-
Taxodium distichum (L.) Rich.	1879	0	0	1879	0.07	-
P. virginiana Mill.	1052	30	3%	1082	0.13	-
P. elliottii var. *densa*	524	296	36%	820	0.05	0.18
P. rigida Mill.	352	0	0	352	0.11	-
P. X rigitaeda Kartesz & Gandhi	300	0	0	300	0.07	-
Picea abes (L.) H Karst. (2-0)	145	0	0	145	0.13	-
Pinus sylvestris L. (2-0)	7	0	0	7	0.11	-
Chamaecyparis thyoides (L.) B.S.P.	0	216	100%	216	-	0.20
Abies fraseri (Pursh) Poir.	0	600	100%	600	-	0.21
Other conifer	1141	222	16%	1363	-	-
Hardwoods	28701	1562	5%	30263	0.27	0.40
Total	**821635**	**192897**	**19%**	**1014532**	**-**	**-**

1.5 Seedling price

Seedling price varies depending upon species, seedbed density, propagation method, degree of genetic improvement, and nursery ownership. Container-grown pine seedlings might cost € 0.11 more than a bareroot seedling (Tab. 3) while container-grown hardwood seedlings might cost € 0.13 to € 2.80 more than a bareroot seedling (depending upon the size of the container). The higher cost may explain why over 95% of the hardwood seedlings in the South are produced at bareroot nurseries. Seedling price varies with genotype and propagation method. For bareroot pine seedlings, the cost of a *Pinus taeda* seedling might increase by € 0.014 when grown at 190 m^{-2} instead of 270 m^{-2}.

Likewise, bareroot hardwoods with root collar diameters (RCD) less than 7 mm (Jacobs et al. 2012) may cost € 0.27 each while higher quality hardwoods (RCD > 10 mm) may cost € 0.44 per seedling. Large hardwood stock can be produced at a low seedbed density (Kennedy 1988; Schultz and Thompson 1996) or by grading seedlings during the hand-lifting process (as practiced at a nursery in Tennessee).

1.6 Genotypes

A range of genotypes now are available for landowners to purchase (Fig. 5). *Pinus palustris* seed represents nearly all the unimproved stock sold in 2012 (Tab. 4) with most of the seed collected from seed production areas (i.e. natural trees reserved for collecting cones). Most hardwood seedlings also are produced from seed collected from trees in cities and forests. Currently, *Liriodendron tulipifera* seedlings are available from first and second-generation seed orchards and *Liquidambar styraciflua* and several *Quercus* spp. are from first-generation orchards.

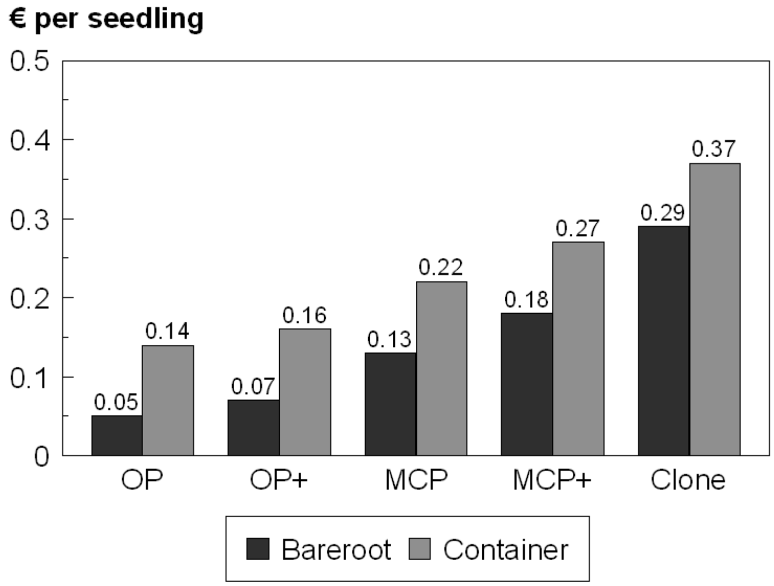

Figure 5. The relative price of container and bareroot stock increases with degree of genetic selection. Genotypes include open pollinated (OP) seedlings, elite OP (OP+), mass control pollinated (MCP) seedlings, elite MCP (MCP+), and clones (rooted cuttings).

Table 4. The percentage of genotypes sown in 2012 by level of genetic improvement (Starkey et al. 2015a, 2015b). The “advanced” category includes mass controlled pollinated seedlings and stock produced by vegetative propagation.

Species	Genetics	Bareroot	Container
Pinus taeda	1st generation	8%	4%
	2nd generation	57%	33%
	3rd generation	16%	24%
	Advanced	19%	39%
Pinus elliottii	1st generation	9%	48%
	2nd generation	75%	48%
	3rd generation	5%	0%
	Advanced	11%	4%
Pinus palustris	Wild	91%	73%
	1st generation	9%	27%

A range of genotypes are grown in containers. Wild sources or seed harvested from seed production areas (e.g. Blackwater State Forest, Eglin Air Force Base) represented 73% all the *Pinus palustris* seedlots sold in 2012. *Pinus elliottii* genotypes were equally divided between first and second generation families from seed orchards. The largest percentages of container-grown *Pinus taeda* were “advanced generation” genotypes that include controlled mass pollinated selections and somatic embryogenesis. The advanced genotypes may be purchased from industrial and private nurseries. Also, 20% of container-grown *Pinus taeda* stock in 2012 were clones produced by CellFor using somatic embryogenesis (Grossnickle and Pait 2008).

2 Bareroot culture

2.1 Soil texture

Efficient bareroot nurseries require sandy soils (Davey 1982). Eight out of 13 newly established nurseries (since 1980) were located on soils with greater than 75% sand and six were built on sites with greater than 88% sand. Soils with high sand content have advantages such as 1) mechanical belt-lifters are better able to lift seedlings without too much root damage, 2) following a rain, sandy soils allow quicker access into the fields, 3) the soils dry out faster in the spring for sowing and 4) they have good soil permeability. Since coarse textured soils typically have low cation exchange capacity, they require more fertilizer to achieve the target seedling growth. Philip Wakeley (1935) said "Fairly sandy soils frequently meet all forest nursery requirements if they are underlain by less pervious soils. The cost of enriching such soils with various fertilizers is offset by greater ease of working, and most pine species develop better root systems in light than heavy soils." Regions without sandy soils are likely to have more success growing seedlings in containers.

2.2 Organic matter

Bareroot nurseries located in the warm Coastal Plain are characterized by low organic matter when compared to nurseries located in cooler regions. The median soil organic matter for nurseries with sandy or loamy sand soil is 1.6% (range = 0.75% to 3%). Most managers have a regular program to increase soil organic matter (other than the use of a cover crop). Almost half of the managers apply sawdust (e.g. 115 m^3 ha^{-1}) to the soil while pine bark was the next choice. Due to microbial activity, about half of the pine bark applied (> 6 mm in size) remains 6 to 14 months after application (Figure 6). Due to high lignin content, bark would likely be the first choice were the price not about € 25/m^3. Aged pine bark is a preferred medium for containers at horticultural nurseries.

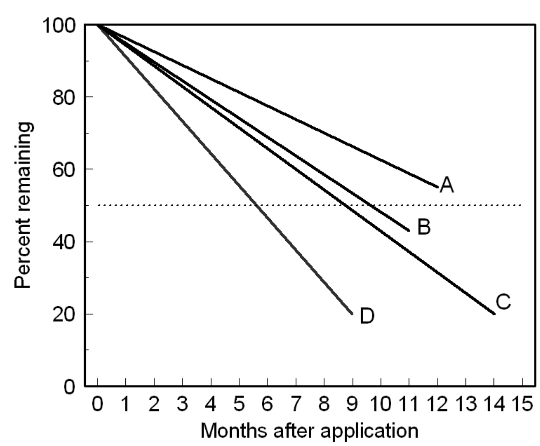

Figure 6. The percent of pine bark remaining in the soil varies with nursery (1981-1982). The "percent remaining" in the soil does not include bark particles that were smaller than 6 mm in diameter. Nursery location: A = Lee, Florida; B = Chiefland, Florida; C = Jasper, Texas; D = Archer, Florida.

2.3 Cover Crop / Fallow

Nurseries rotate their crops for many reasons including improving soil structure, managing weed and nematode problems, and reducing topsoil erosion. Currently most nurseries use either *Panicum ramosum* or *Sorghum* spp. as a summer cover crop and when a winter cover crop is sown, it typically is a species of *Lolium* (South and Zwolinski 1996; Starkey et al. 2015a). At one nursery, a strong relationship was observed between cover crop type and stunt (*Tylenchorhynchus claytoni*) and stubby–root (*Paratrichodorus minor*) nematode populations (Cram and Fraedrich 2006). Therefore, nurseries that traditionally have nematode problems now use cover crops other than Maize and Sorghum (both are hosts for these nematodes). Reasons managers keep land bare (i.e. fallow) is to address weed and nematode problems during the non-seedling production periods using herbicides.

2.4 Fumigation

Soil fumigation is an important part of a disease-nematode-weed control program at almost all bareroot nurseries in the South (Marx et al. 1984; South and Enebak 2006). The SFNMC has invested a considerable amount of time and money establishing over 55 fumigation trials (Starkey 2012; Enebak 2013; Enebak et al. 2013). One reason is because as the value of bareroot seedlings increases, the economic benefits of soil fumigation increase (South and Carey 2000; South and Enebak 2005). Since one ha of controlled mass pollinated seedlings may have a value of € 270,000, increasing this value by 4% with soil fumigation would equal € 10,800.

A 1:2 rotation means over a three-year period, one seedling crop is grown, followed by two cover crops. This ratio was typically 1:2 for state nurseries and private nurseries while a 2:2 rotation is often used at industrial nurseries. Although a 2:2 rotation reduces fumigation costs, it also tends to cause a slight decrease in seed efficiency. Newly fumigated fields may have a 2% greater yield than second-year fields of a 2:2 rotation and perhaps an 8% greater yield than third-year fields of a 3:1 rotation.

In 1980, half of nurseries fumigated the soil in the fall (Boyer and South 1984a) and now that percentage has increased to 68%. Fall fumigation provides a broader biological window in which fumigation can occur. During October and November, nurseries have more days with proper soil temperature and moisture for fumigation. Proper soil temperatures are important, especially for nurseries located in cooler regions. In 1980, 60% of nurseries fumigated a production unit every other year (Boyer and South 1984a) but now only 17% fumigate before a 1:1 rotation. Due to a higher fumigation cost, 56% now fumigate the same production area every third year (2:1 rotation) and 27% fumigate every fourth year (2:2 or 3:1 rotation).

One of the unique aspects of certain soil fumigants is they typically do not eliminate soilborne fungi which are beneficial for seedling growth. For example, researchers have shown that some fumigants will increase the population of *Trichoderma* while others are detrimental (Starkey 2012; Enebak et al. 2013). Even so, in some cases, fumigation has resulted in an ectomycorrhizal deficiency. There are three main reasons why ectomycorrhizal deficiencies are now rare in pine seedbeds in the South. First, *Telephora terristris* spores are wind-blown and ubiquitous. In most years, the surfaces of fumigated soils are quickly inoculated with *Telephora* spores. Second, in established seedbeds, ectomycorrhizal inoculum below the fumigation zone remains viable. When the taproots reach this zone, mycorrhiza forms on the short roots. Third, only one bareroot nursery has been established during the past 16 years (Tab. 2). In the past, ectomycorrhizal deficiencies were observed at several newly established nurseries. In years when there is little rainfall before April, ectomycorrhizal deficiencies can occur when seedbeds are formed using soil that has never produced a crop of pine seedlings (South et al. 1988). A deficiency occurs because there is a lack of wind-blown spores and a lack of soil-born inoculum.

Endomycorrizal deficiencies are more common after soil fumigation because spores are only soil-borne. SFNMC researchers have observed endomycorrhizal deficiencies at several nurseries (South 1977; South et al. 1988). Treating seedbeds after fumigation with spores is not practiced due to a relatively high cost. At a rate of 3,000 propagules per square meter, the cost to treat one ha might be as much as € 4,500 (Cram and Fraedrich 2015). Therefore, to reduce the risk of stunted seedlings (Yawney et al. 1982), managers are more likely to apply phosphorus to hardwood seedbeds soon after germination is complete in the spring.

2.5 Sowing

Prior to 1980, most managers used gravity-drop seed sowers such as Whitfield®, Love Oyjord®, Stanhay®, or Planet Junior® (Boyer and South 1984a). In 1982, Weyerhaeuser was the first to use vacuum sowers and in 1984, SFNMC researchers were the first in the South to test the New Zealand vacuum drum sower (Boyer et al. 1985). Soon afterward, nursery managers began purchasing precision vacuum drum sowers and vacuum disk sowers such as the Love® Model 816SL (Pryor and Vedder 1986). Although vacuum sowers are more precise in seed placement (Boyer et al. 1985; Cordell et al. 1990; Williams and Stewart 2006) their slower speed limits their popularity. Currently, gravity sowers are used in twice as many nurseries as the vacuum sowers (Starkey et al. 2015a).

In the southern US, most bareroot seedlings are sown in April or May of each year and seedlings are lifted about 9 to 10 months later (December to February). An exception is *Pinus palustris* which can be sown in either October or April (South 2000).

Over 80% of the managers treat seed to control fusiform rust (*Cronartium quercuum f.sp fusiforme*) and repel birds (Runion et al. 1991; South and Zwolinski 1996). During the seed treating process, latex is typically used as a seed “sticker” for the chemicals.

The RCD and total seedling mass are related to seedbed density. Seedlings grown at 200 m^{-2} will have larger RCD than those grown at 300 m^{-2} (South et al. 1990). The measured seedbed density for *Pinus taeda* (1977-1979) was approximately 361 m^{-2} (Tab. 5). In the 2012 survey, managers reported an average seed bed density of 140 m^{-2} for *Pinus palustris* and 258 m^{-2} for *Pinus taeda* and *Pinus elliottii*.

Use of synthetic soil stabilizers (Carlson et al. 1987) after sowing reduces seed losses and increases seed efficiency (Fig. 7). In 1998, about 40% of nurseries were using this management tool (South 2000) and now the percentage has risen to 72%. Effective stabilizers also help to maintain seed bed integrity over the growing season.

Figure 7. Many nursery managers apply a soil stabilizer to reduce losses of seed from bed erosion during rainstorms. One advantage of this treatment is that it prevents soil crusting and increases the infiltration rate. In this photo, the portion of the bed with no standing water was treated with a soil stabilizer.

For many years, managers applied a mulch to protect germinating seed. During the 1970s, mulches included pine straw, wheat straw, sawdust, wood chips and hydromulch (South 1992). Pinestraw much was used at 37% of the nurseries. However, even with these mulches, seed losses occurred during heavy rainfall events which could disrupt seedbed integrity. Although the use of mulches has declined, at least three managers still apply pine bark (soon after treating the seedbeds with a soil stabilizer) to reduce the amount of irrigation required during the hot summer months.

Table 5. The root collar diameter (RCD), height, height/diameter ratio (H/D), root-weight ratio (RWR; dry weight), total seedling dry mass, culls, and seedbed density (plantable + culls) for bareroot seedlings of *Pinus taeda* have changed over the last four decades. Data below are from Marx et al. 1984; Larsen et al. 1989; South 2000; and data from the Southern Forest Nursery Management Cooperative. RWR is determined using dry weights except for numbers in [brackets] which were determined using fresh weights. Seedbed densities were from nursery plots except for numbers in [brackets] which were obtained from a questionnaire. Minimum RCD = the minimum average RCD reported (it is not the minimum RCD shipped from an individual nursery).

Years/ Lifting month		**RCD**	**Height**	**H/D**	**RWR**	**Total mass**	**Culls**	**Density**
		mm	**mm**	**mm/mm**		**mg**	**%**	**# m^{-2}**
1977-1980	Minimum	3.8	182	34 (266/7.9)	[0.14]	--	6	116
Oct-April	Median	5.1	232	50 (274/5.5)	[0.24]	--	19	361
(n=20)	Maximum	7.9	357	73 (277/3.8)	[0.38]	--	51	561
1984	Minimum	3.1	177	42 (177/4.2)	0.21	2377	16	200
Dec	Median	4.0	211	52 (208/4.0)	0.26	2807	20	274
(n=6)	Maximum	4.3	279	75 (279/3.7)	0.32	5739	28	315
1997-1998	Minimum	2.7	173	54 (221/ 4.1)	0.10	1653	--	149
Oct-Nov	Median	3.9	270	65 (254/3.9)	0.14	2813	--	236
(n=18)	Maximum	4.5	366	99 (366/3.7)	0.16	6643	--	283
2012-2014	Minimum	3.5	187	39 (273/7.0)	0.14	2200	--	[204]
Dec-Jan	Median	5.0	291	58 (296/5.1)	0.19	4760	--	[269]
(n=17)	Maximum	8.0	438	80 (280/3.5)	0.29	10800	--	[301]

2.6 Irrigation

Although impact head irrigation systems are the most common, three managers use a center pivot system (one used a pivot exclusively). The riser/nozzle layout for impact head irrigation systems are in either a rectangular design or a rhomboid pattern (in which nozzle on adjacent riser lines are staggered). Well water is used at 55% of the nurseries while others use water from surface ponds and rivers. In Georgia, water usage meters allow managers to report water use to state government agencies.

Most managers use the visual/touch/feel method to check soil moisture but some (8%) use either a tensiometer or electronic device. Using an objective method reduces over-watering and power bills (associated with irrigation). At two nurseries in Virginia, irrigating when the tensiometer reached 30 kPa resulted in stunted and chlorotic seedlings (Dierauf and Chandler 1991). During a wet summer at a nursery in Alabama, irrigating when the tensiometer reached 33 kPa resulted in only five irrigations that were required to wash fertilizer off of the foliage (Retzlaff and South 1985). Several managers irrigate sandy seedbeds when the soil tensiometer reaches 15 to 25 kPa.

The amount of irrigation applied varies with nursery location and season. About 25 mm of water (rainfall plus irrigation) is applied weekly during germination and the seedling growth phase (Huberman 1938). In one year, this might be equal to 10 mm of irrigation/week (+15 mm of rainfall) and in a drier year it might average 18 mm of irrigation/week (Dierauf and Chandler 1991). As seedlings are being "hardened off" in preparation for lifting, irrigation might average 13 mm of water per week (in months with little rainfall). On sandy soils, SFNMC researchers determined that ceasing all irrigation in the fall could negatively affect root growth and would increase the production of cull seedlings (South and Williams 1988; Williams et al. 1988b).

Irrigation is also used to "cool" seedlings during the summer to avoid sun scald. Short periods of irrigation can reduce bed temperatures by 11°C and ambient air temperatures by 5 to 8°C (May 1984b). When air temperatures exceed 34°C, most nurseries apply irrigation to reduce bed temperatures regardless of the recent precipitation. Despite measures to cool nursery beds and seedlings, 83% of responding managers indicated they have experienced heat related problems such as heat lesions (Barnard 1990). In some cases, young seedlings have suffered from "heat-shock" and normal seedling growth was impaired for most of the growing season (Mexal and South 1991).

2.7 Fertilization

There are three schools of thought for fertilization of bareroot pine seedlings. One recommends applying just enough nitrogen (N) so that seedlings are short and top-pruning is not required. This typically amounts to less than 110 kg ha^{-1} of N per crop and might result in 50% of the seedlings having a RCD of less than 3.6 mm by mid-October (Sung et al. 1997; Kormanik et al. 1999). In contrast, other managers fertilize at a rate between 110 and 300 kg ha^{-1} of N per crop (Davey 1984; May 1984c; Dierauf 1991; South and Zwolinski 1996) and produce *Pinus taeda* seedlings with an average RCD of 5 mm or more (Tab. 5) and an average foliar nitrogen content (December) of about 1.6% (Boyer and South 1985). The target seedling height at these nurseries is achieved by proper top-pruning.

The third school applies extra nitrogen in the fall so that foliar nitrogen of bareroot stock is greater than 2%. The term "nutrient loading" has been used to describe seedlings that receive additional fertilizations after height growth has ceased and prior to the winter solstice. This inexpensive practice has the potential to increase growth in the field (Bryan 1954; Hinesley and Maki 1980; Larsen et al. 1988; Irwin et al 1998; South and Donald 2002; VanderSchaaf and McNabb 2004; Islam et al. 2009). In addition, higher foliar nitrogen levels may increase freeze tolerance of *Pinus palustris* (Davis et al. 2011) and various northern pines (Rikala and Repo 1997; Islam et al. 2009; Taulavuori et al. 2014). International Paper Company was the leader in the South and began operational "nutrient loading" in 2001 (personal communication George Lowerts). To increase early root and shoot growth (after outplanting), managers would fertilize seedlings in mid-October to achieve a target foliar nitrogen concentration (in November) greater than 2%. Seedlings were shipped in boxes labeled "nutrient loaded" (Fig. 8). However, the practice declined after International Paper Company sold their nurseries. In a recent survey, two bareroot nurseries produced seedlings with foliar nitrogen concentrations greater than 2% in October-November and half had values less than 1.6% (Tab. 6).

Granular and liquid formulations are used to fertilize bareroot pine seedlings. More than 70% of managers purchased granular fertilizer by the bag rather than bulk. However bulk liquid fertilizers were used by 83% of nurseries. Nearly 60% of nurseries used liquid urea-ammonium nitrate (UAN) as a nitrogen source. UAN is mixed with water and applied with tractor-mounted sprayers to provide a uniform application to seedbeds. With long spray-booms, 20 ha of seedbeds may be fertilized in four hours.

Table 6. Foliar nitrogen concentration (N %) for bareroot and container-grown pines for October-November 2009 and January-February 2010 (Starkey and Enebak 2012). In the absence of fall fertilization, seedlings outplanted in January tend to have lower nitrogen concentrations than seedlings outplanted in October.

	***Pinus palustris* container**		***Pinus taeda* container**		***Pinus taeda* bareroot**	
	Oct-Nov	**Jan-Feb**	**Oct-Nov**	**Jan-Feb**	**Oct-Nov**	**Jan-Feb**
Minimum N%	0.6	0.5	0.9	0.6	1.1	0.6
Median N%	1.2	0.8	1.3	1.0	1.6	1.3
Maximum N%	1.5	1.1	1.5	1.5	2.3	1.4

At one time, potassium was applied in late summer in hopes of "hardening-off" pine seedlings (Davey 1984). However, to date, research studies have found this practice to be ineffective. Therefore, SFNMC researchers do not claim this practice increases freeze tolerance, drought tolerance or storability of *Pinus taeda* seedlings (South et al. 1993a; South and Donald 2002). Even so, over half of managers surveyed apply potassium in August to late September (Starkey et al. 2015a), even when foliar potassium levels were greater than 1.2%.

There are only a few documented cases of acute nutrient deficiencies in southern pine bareroot nurseries. Those include phosphorous (South et al. 1988), calcium (Davis 1949), sulfur (Lyle and Pearce 1968) and boron (Stone et al. 1982). When soil acidity is above pH 6, iron may be applied after chlorosis occurs during the summer (Lewis 1959; Richards 1965). Except for nitrogen and iron, nursery managers base their fertilization rates on keeping soil test values above a target minimum. When seedlings are adequately fertilized, some species grow well when soil acidity is below pH 5 (Marx et al. 1990; Harbin 1985; Yawney et al. 1982; South 2000; Carey et al. 2002). Some researchers say that pine seedlings will "thrive at pH's as low as 4.5."

One reason for a lack of documented nutrient deficiencies is because many managers consult with university professors. Prior to 1980, nursery personnel consulted with Drs. Davey, Gilmore, Lyle, May, Pritchett, Stone, Switzer and others. After 1980, many managers consulted with a single consultant and in 2011 Dr. Davey wrote fertility prescriptions for 58 nurseries.

Figure 8. In 2004, the International Paper Company Nursery was fertilizing *Pinus taeda* seedling in the fall and selling them as "nutrient loaded" seedlings. Seedlings would be fertilized in October so they would have foliage values of 2% nitrogen or greater at time harvesting began in November.

2.8 Pathogens birds and insects

Fusiform rust (*Cronartium querccum f.sp fusiforme*) is the primary stem disease of several pine species. The fungus is commonly found within a 250 km band extending from the Carolinas to Texas (Enebak and Starkey 2012). The SFNMC played a significant role in testing, labeling and maintaining the availability of fungicides to control this rust fungus. Triadimefon was registered in 1980 and prothioconazole (applied 4 to 5 times a season) was registered in 2011 using data supplied by SFNMC (Starkey and Enebak 2011). Fungicides occasionally used for other diseases (foliage, stem and root) include thiophanate-methyl, chlorothalonil, iprodione, and propiconazole (South and Zwolinski 1997). The fungicide aluminum tris was once used to control *Phytophthora* in *Abies fraseri* seedbeds, but phosphonate fungicides are rarely used on bareroot pines in the South.

Many managers lose less than 3% of their crop to factors other than weeds and nematodes. This mortality was generally attributed to post-emergent damping off. The percentage of nurseries reporting post-emergence damping-off as a major cause of mortality almost doubled (from 1980 to 2012).

Reported losses due to bird predation was 0.16% for both 1980 and 2012 (Boyer and South 1984a; Starkey et al. 2015a). Fortunately, the losses due to bed washing have decreased over this time period. This is likely due to the widespread use of soil stabilizers applied after sowing.

Losses due to insects are typically less than 1% annually. Most insect damage can be attributed to either *Lygus lineolaris* or *Taylorilygus pallidulus*. Injury to *Pinus taeda* from these insects was first reported by SFNMC researchers in 1983 (South 1991; South et al. 1993c; South 2012). Esfenvalerate and permethrin-based are the most commonly used insecticides to control these plant bugs. SFNMC researchers have observed damage on pine seedlings from several other insects (South and Enebak 2006).

2.9 Top pruning

SFNMC researchers have demonstrated that proper top pruning can increase seedling quality of both pine and hardwoods (Blake and South 1991a; South et al. 1993a; South and Blake 1994; South 1996; South 1998; South 2016). For most pines, the initial top pruning occurs in July followed by one or two additional clippings during the summer. The first pruning cuts only about 20% of the population, the second 50%, and the third about 33% (South 1998). The final height of top pruning varies and some managers prune *Pinus taeda* at a height of 180 mm (Dierauf 1997) to 250 mm. In the past, 70% of the nurseries produce seedlings that average 250 mm or less in height (Mexal and South 1991). Reasons given by managers for proper top pruning were: 1) it increases the root-weight ratio (RWR = root dry mass/seedling dry mass), 2) it increases crop uniformity (Mexal and Fisher 1984), 3) it increases the percentage of plantable seedlings (Marx et al. 1984; Duryea 1990; Johnson and Cline 1991; Dierauf 1997), 4) it effectively controls seedling shoot height (South 1998), and 5) it reduces shipping costs for hardwood seedlings (South 2016). For these reasons, top pruning is practiced at 91% of the bareroot nursery managers in the South (Starkey et al. 2015a).

Without proper top pruning, *Pinus taeda* seedlings fertilized with 170 kg ha^{-1} of N may exceed 350 mm in height by October or November (Kormanik et al. 1995; Kormanik et al. 1999) and some might be twice as tall as top pruned stock (Johnson and Cline 1991). Top pruning is not practiced by some managers who withhold fertilizer and irrigation in hopes of keeping seedlings short. For example at one nursery, December lifted seedlings (fertilized with 108 kg ha^{-1} of N) averaged 3 mm in RCD, 200 mm in height, 1.2% needle N concentration, and had a RWR that was less than 0.22 (Sung et al. 1997).

Proper top-pruning meets the objectives of the nursery manager while improper top pruning fails to meet the objectives (South 1998). Improper top pruning of pines results when pruning too much plant material or too late in the season (Johnson and Cline 1991). For example, pruning seedlings only once (in August) failed to meet the objective of reducing heights of *Pinus taeda* (Mexal and Fisher 1984; Blake and South 1991a) and pruning too short (Stanley 1986) failed to increase seedling survival. Likewise, clipping *Pinus palustris* needles too short or too frequently can fail to meet the objective of increasing field survival (Barnett 1984). Although proper top-pruning was not routinely recommended in the past (Johnson and Cline 1991 Sung et al. 1994), it is now an accepted cultural practice for most pines listed in Table 3. One exception is *Pinus strobus* which, after top pruning, can exhibit less height growth in the field (Dierauf 1997).

2.10 Root pruning

Prior to lifting, root pruning consists of: 1) undercutting to cut the tap root, 2) root wrenching to lower soil bulk density, improve bed aeration, and increase root proliferation, and 3) lateral pruning which separates seedlings from adjacent drills to facilitate mechanical lifting. Undercutting and lateral root pruning are typically done prior to lifting seedlings with mechanical belt lifters. Perhaps 89% of managers prune seedling roots prior to lifting (Starkey et al. 2015a). Undercutting or wrenching is not practiced at some state nurseries.

Undercutting is normally done in October with either a horizontal fixed or reciprocating blade that cuts the tap root at 15 to 20 cm below the soil surface. The main objective of undercutting is to confine new root growth to the upper soil layer (i.e. the "lifting zone"). Roots below this zone are lost during the lifting process. Approximately 79% of managers undercut their seedlings at least once during the growing season. Undercutting (once in July and once in September) can reduce shoot growth and increase seedling survival (Nebgen and Meyer 1986). Undercutting and lateral root pruning can greatly increase field survival of *Pinus strobus* seedlings (Dierauf et al. 1995).

Root wrenching is an operation that uses a blade mounted at a slight angle that tends to tear the roots and breakup the soil/root profile of the seedling bed. At one nursery a single root wrenching reduced soil bulk density to 1.3 g cm^{-3} (control = 1.4) and seedling biomass was reduced by 17% (Miller et al. 1985). Wrenching four times reduced foliar nitrogen concentrations at one nursery (South and Donald 2002) but had no effect at another (Miller et al. 1985). Approximately 50% of managers root-wrench problem areas, usually in July. When control seedlings have a RCD of 4.4 mm or more, root wrenching can reduce RCD of both *Pinus taeda* (Tanaka et al. 1976; Miller et al. 1985; South and Donald 2002) and *Pinus ellottii* (Kainer and Duryea 1990). However, at nurseries with low levels of nitrogen fertilization (i.e. average RCD of 3.7 mm), wrenching every 3-weeks may have no effect on diameter growth (Venator and Mexal 1981).

Lateral root pruning can greatly increase seedling quality of *Pinus palustris* (Hatchell and Muse 1990) but it typically does not affect the quality of *Pinus taeda* seedlings (Dierauf and Olinger 1982; Venator 1983; Nebgen and Meyer 1986). Managers who do not lateral root prune their seedlings use either a Fobro® (McBee 1986) or similar seedling harvester that undercuts, lifts and vibrates the seedling bed, minimizing root damage. Lateral root pruning is conducted at 83% of nurseries to reduce root stripping and increase lifting productivity.

2.11 Lifting, packing and shipping

Over the past four decades, nurseries have relied more on eight-row machines to lift seedlings (30% in 1980 and more than 75% in 2015). Disadvantages of one- and two-row lifting machines are they can lower outplanting survival (Xydias 1981; Greene and Danley 2001), they can reduce root-growth potential (Starkey and Enebak 2013) and they lift fewer seedlings per hour. In addition to stripping fine roots during lifting, washing roots with water (to remove soil) can also reduce seedling quality (Carey et al. 2001).

After lifting, several managers started treating roots with hydrophilic gels during the 1980s. In one test, treating *Pinus taeda* and *Pinus elliottii* roots with a gel increased survival by 31% (19.6 to 50.8%) and 4% (16.9 to 20.8%), respectively (Kroll et al. 1985). Now, 70% of managers use polyacrylamide gels while 24% coat roots with clay slurries (Starkey et al. 2015a). Nursery managers understand the importance of protecting pine roots from exposure (Dierauf and Marler 1967; Kroll et al. 1985) and SFNMC researchers have determined that not all gels behave equally (Starkey and South 2008; Starkey et al. 2012). Hardwood roots are also treated with gels and they can benefit under certain conditions (Percival and Barnes 2004).

Over 75% of managers package seedlings in a packing shed and the remainder pack in the field (either while riding on a lifter or when lifting seedlings by hand). In 1980, most seedlings were placed on a large piece of wax coated Kraft paper, rolled and strapped with a stick to facilitate carrying and lifting. When packed root to root, the bundle (a.k.a. bale) kept seedling roots protected and left foliage exposed. Currently, 21% of nurseries use bundles exclusively, 44% pack only in closed bags and 6% use coated cardboard boxes exclusively. The others package seedlings in bags or boxes according to the request of customers.

The number of chilling hours (typically 0° to 8°C at southern nurseries) is directly related to freeze tolerance of pines (Mexal et al. 1979). For example, *Pinus taeda* seedlings in northern latitudes (that received more chilling) were unharmed by a -14°C December freeze, but seedlings at southern latitudes were injured (South 2007). In contrast, the relationship between chilling hours and long-term storability (at +2°C) of either bareroot or container-grown seedlings has not been established (South 2013; Grossnickle and South 2014).

Good survival and growth of bareroot pine seedlings (lifted in October-November) can be achieved after planting if: (1) seedling root-growth potential and soil moisture are adequate, (2) seedlings are stored for less than 72 hours (a.k.a. hot-planting), (3) seedlings are properly planted, and (4) adequately supervised planting crews are available (Wakeley 1954; Bilan 1987; Hassan and Silva 1999; Garber and Mexal 1980; Akgul et al. 2004; Stumpff and South 1991; South and Mitchell 1999). However, hot-planting in November is not common in regions where migrant hand-planting crews are not available. When lifting bareroot stock before December 31, 54% of managers store bareroot seedlings in cool storage (+1° to +2°C) for less than a week and the remainder store for less than two weeks. When seedlings are lifted after December 31, some managers (35%) store bareroot stock for longer than three weeks (Garber and Mexal 1980; Stumpff and South 1991; Starkey et al. 2015a). Instructions on planting bags often say to plant seedlings soon after lifting (Fig. 9).

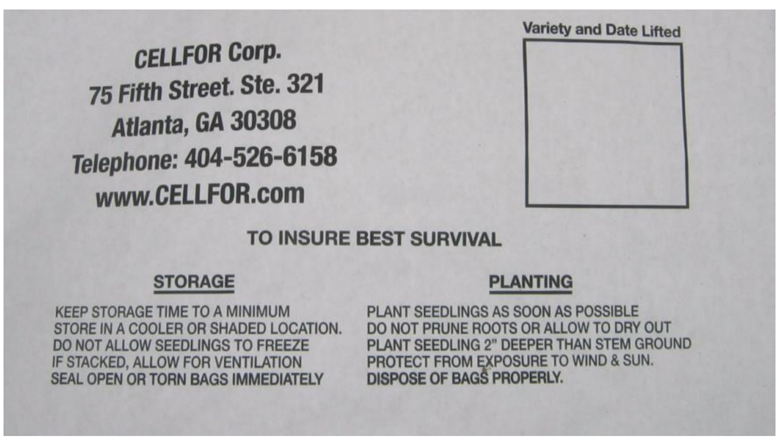

Figure 9. In 2010, CellFor Inc. contracted with bareroot nurseries to produce miniplug+1 transplants. Planting bags often have instructions for storage and planting. To increase the probability of survival, *Pinus taeda, Pinus elliottii* and *Pinus echinata* seedlings should be planted with the root collar about 8 to 15 cm below the surface.

Since research has failed to demonstrate cause-and-effect relationships between natural chilling and storability of *Pinus taeda* or *Pinus palustris* seedlings, Federal and SFNMC researchers developed an alternative theory regarding the reason why storage of bareroot seedlings (in the fall) reduces root-growth potential. Lifting seedlings injures roots and the root-growth potential will decline when roots are infected with certain *Pythium* species (Jackson et al. 2012b). Since treating roots with a fungicide can increase survival of stored seedlings (Barnett et al. 1988), SFNMC researchers suggest that root disease explains why bareroot pine seedlings typically store well in January but not when lifted in November.

At one nursery in Tennessee, hand-lifters grade hardwood seedlings into three classes (i.e. cull, small diameter, and large diameter). In contrast, most managers do not grade seedlings into two or more plantable sizes. Some do cull *Pinus taeda* seedlings that are too small (RCD < 3 mm) or damaged prior to packing while others do not cull since this slows down production. With pines, it can be expensive to cull seedlings and, therefore, managers have an economic incentive to grow seedlings at seedbed densities that produce less than 8% culls.

Many researchers define a cull seedling based on RCD but the size varies with researcher. For example, some define a plantable bareroot *Pinus echinata* seedling as having a minimum RCD of 5 mm (Marx et al. 1984), 4 mm (Mexal and South 1991), 3.2 mm (Wakeley 1954) or 1.6 mm (Barnett 1992). For *Pinus palustris*, the minimum RCD for a plantable bareroot seedling might be 12.7 mm (May 1984a), or 10 mm (Cordell et al. 1990) or 7 mm (Marx et al. 1984) or 4.8 mm (Wakeley 1954). In the past, many managers grew *Pinus taeda* seedlings at densities greater than 300 m^{-2} and produced more than 10% culls (Tab. 5).

A "firm" or "well formed" terminal bud is not required for a southern yellow pine seedling to perform well after outplanting (Wakeley 1954; Dierauf 1973; Shiver et al. 1990; Dumroese et al. 2009). Root growth potential is not affected by bud removal or the presence of an immature bud (Williams et al. 1988a). In fact, for bareroot hardwoods, height growth can be increased by removing a significant portion of the shoot just prior to planting (South 2016).

Pine seedlings increase in mass during the lifting season (October to February). At one nursery in Virginia, the mass increased from 1.8 g per seedling (October) to 3.0 g by the end of February (Garner and Dierauf 1976). At more southern nurseries, the increase in mass may even be greater. SFNMC sampling indicates the average RCD for *Pinus taeda* seedlings in late November is 4.6 mm and by February it has increased to 5.5 mm. Seedling shoot height (about 30 cm) does not change appreciably over the winter (Sung et al. 1997). Over decades (Tab. 5), however, there has been a gradual increase in average seedling height. This can decrease the RWR and can lower the potential for survival after outplanting.

Lifting pine seedlings after a long period of saturated soil is not advised, especially when lenticels have formed on the stem near the groundline. SFNMC researchers have observed low survival when seedlings were lifted after a period of rainfall that averaged 65 mm per week (South and Carey 1999). When the roots remain saturated for a week or more, lenticels form on the stem, aerenchyma form in the roots and root growth potential is reduced. Fortunately, these events are rare and, with enough time, unextracted seedlings can recover.

2.12 Increasing seedling height

In regards to seedling quality, some nursery managers have a saying that "short and fat is where it's at." When seedlings are top pruned, the height/diameter ratio declines as seedling diameter increases (Fig. 10). Even so, the median seedling height for *Pinus taeda* has been increasing at a rate of about 1.6 mm per year (Tab. 5). Since the median RCD has remained about the same (if measurements are taken in December), the height/diameter ratio has been increasing and the RWR has decreased. Although some might attribute this height increase to genetic selection, managers are the ones who determine the height of top pruning and when to top prune. For example, when growing the same genotype, depending upon management practices, seedling height at lifting can range from 177 to 279 mm (Larsen et al. 1989).

2.13 Two bareroot seedling ideotypes

There are two views regarding the target seedling size that managers should produce when growing *Pinus taeda, Pinus elliottii* and *Pinus echinata*. Some say the RCD should be between 5 and 10 mm (Brissette and Lantz 1983; South and Mitchell 1999; South et al. 2015; Kabrick et al. 2015) while the other says the range should be 3 to 6 mm. Mexal and South (1991) classified these two seedling groups as "ideotype A" and "ideotype B" and elaborated on other desirable morphological attributes. Ideotype A has a larger RCD, a smaller height/diameter ratio, a greater RWR than ideotype B (Fig. 10) and expected survival and growth in the field is greater (Tab. 7). Better survival and early growth of large-diameter seedlings has been well documented by SFNMC researchers (South 1993; South et al. 2001a). Ideotype A may be planted using either shovels (Blake and South 1991b) or machines while ideotype B is preferred by hand-planters who make shallower holes using planting dibbles (Haywood et al. 2013) or hoedads (Harrington and Howell 1998).

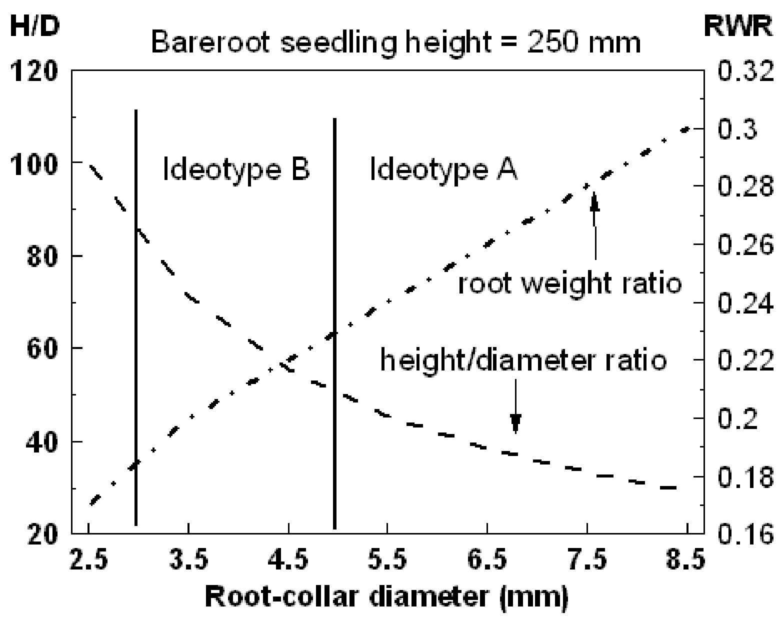

Figure 10. "Ideotypes A" seedlings have a higher root weight ratio (RWR) and a lower height/diameter ratio than "ideotypes B" seedlings (Note: seedling dry mass measured after January 1). Hand-planters like to plant ideotypes B seedlings since they have smaller roots. Ideotype A seedlings are ideal for use with machine planting (which currently amounts to about 15% of tree-planting). In a recent nursery comparison, 200 mm tall bareroot seedlings with a RWR of 0.24 averaged 92% while 260 mm tall seedlings with a RWR of 0.20 averaged 77% survival (personal communication Chris Rosier).

Table 7. Descriptions of two seedling ideotypes for bareroot seedling of *Pinus taeda, Pinus elliottii and Pinus echinata* lifted in December. Table adapted from Mexal and South (1991).

Characteristic	Ideotype A	Ideotype B
Median root collar diameter	>5 mm	>4 mm
Height	150-250 mm	150-300 mm
Median root volume	>4 cm^3	>2 cm^3
Median RWR (dry weight)	>0.25	>0.2
Median height/diameter ratio	<50	>50
Well-formed terminal bud	Not required	Not required
Median foliar N content	> 25 mg	> 20 mg
Root collar diameter of culls	< 4 mm	< 3 mm
Expected field survival 2-yr	>90%	>80%
Expected field height 4-yr	> 3 m	< 3 m

Although planting machines make deeper holes and usually plants roots deeper in the soil (i.e. less shoot is exposed), only about 15% of tree-planting is conducted using machines (Barlow and Levendis 2015). This is because the cost of machine planting can be 75% more than hand-planting and because many sites are not suitable for machine planting since they receive a low level of mechanical site preparation. Hand-planters like to plant seedlings with small roots and their desires may explain why many managers produce ideotype B seedlings even though studies show better survival when seedlings have a RCD of 6 or 7 mm (Mexal and South 1991; South and Mitchell 1999; Kabrick et al. 2015). Operators of machines typically do not complain about large root systems. One company in Georgia relies mainly on machine planting because they consistently have higher survival than typically occurs for hand-planting.

3 Container culture

Since greenhouses were used in Canada, some also assumed container-grown stock should also be produced in greenhouses in the South. Some believed the link between greenhouses and container production was so great that “strictly controlled greenhouses” would be needed to produce quality seedlings (Mann 1975). Over time, industry realized covered greenhouses just added to the cost and produced seedlings of inferior quality. Secondary needles, freeze tolerance, wax thickness, RCD and shoot mass were increased by growing seedlings outside (Mexal et al. 1979; Boyer and South 1984b; Barnett 1989; Jackson et al. 2012a). Even when grown in covered greenhouses, containers were typically moved outside to improve seedling quality (i.e. “harden-off”). In one study, *Pinus taeda* seedlings grown outside (for three months) were shorter, weighed half as much, and had a higher RWR than stock grown in a growth-chamber. As a result, field survival after four years was increased by 11% (Retzlaff et al. 1990). Today, over 190 million pines are grown outside in containers.

One disadvantage of growing seedlings outside is that seedling physiology is adversely affected when rainfall is constant in the fall. When the plugs remain saturated for a week or more, lenticels form on the stem, root growth potential is reduced, and seedling mortality increases (South and Starkey 2010). Fortunately, these events are rare and, with enough time, unextracted seedlings can recover.

3.1 Container

Container size (South et al. 1994; Davis et al. 2011; Haywood et al. 2012; Sung et al. 2013) and composition (Barnett and Brissette 1986; South et al. 2005) are important considerations when producing seedlings that perform well after outplanting. Most managers use hard plastic containers while others use polystyrene containers (530 m^{-2} with a cell volume of 108 ml). The median seedling density for the most commonly used hard plastic containers is 569 m^{-2} with a cell volume of 110 ml (Tab. 8). One manager grows seedlings in 66 ml containers and typically, they are planted in the field from mid-September to late November (Larson 2002).

3.2 Growing media

Compressed bales (6.2 m^3) of peat moss are used at several nurseries (Bell 2011). One manger uses composted bark as the main component in their media mix. Chlorosis has occurred when the pH of the medium is too high (Bell 2013). In addition, some conifers and hardwoods grow better when media pH values are less than 5.0 (Marx and Zak 1965; Bryan et al. 1989; Davis 2003). At sowing, the average acidity of media is about pH 4.7. In the past, spores of *Pisolithus* (McRae and Starkey 1997) or *Rhizopogon* spp. were incorporated into the media mix but this practice is now rare. Fruiting bodies of *Pisolithus* were once easy to collect on coal mine reclamation sites, but establishment of grasses has reduced the production of sporocarps. In some cases the media is mixed with *Trichoderma harzianum* (Kelley 1976) as a biocontrol agent. However, the SFNMC has not yet conducted research on this treatment.

3.3 Sowing

Sowing seed in containers typically begins in March, about one month earlier than at bareroot nurseries. Sowing a million seed is slower in container nurseries, which might explain an earlier sowing date for nurseries with a single sowing line. A March sowing date allows seed germination to be complete before air temperatures begin to exceed 32°C.

The production of native understory plants for *Pinus palustris* ecosystem restoration is a growing segment in container production. Due to customer requirements and length of time in the nursery, native understory plant sowing covers March to June with the peak sowing period occurring after sowing pine is complete.

Vacuum-drum sowers are commonly used when crop size is greater than 6 million seedlings. A single vacuum-drum sower can efficiently sow 300,000 to 400,000 cavities a day. Small nurseries, especially those growing primarily *Pinus palustris*, sow seedling crop by hand. Due to use of high-quality seed, most managers now sow only one *Pinus taeda* seed per cavity. This eliminates the cost of thinning and produces more seedlings per kg of seed. However, some sow two *Pinus palustris* seeds per cells when seed germination tests are less than 80% (Barnett and McGilvery 1997). This requires thinning since plugs that contain two seedlings (at time of planting) are culls (Hainds and Barnett 2006). When double sowing seedling with 75% germination, the maximum seed efficiency obtainable would be 72%.

After sowing, most managers cover seed to minimize seed desiccation. Materials used to cover seed are vermiculite, grit and sawdust. Following sowing and capping, container sets are moved outside to production areas. An exception is where container sets are stored for a short time, under cover, to allow germination to begin. After this pre-germination process, container sets are moved outdoors. Once trays are outside, they are protected by shade cloth (at about half of the nurseries). The use of shade cloth protects the young germinates from drying out, from excess rain splash and deters bird predation. Soon after germination, the shade cloth is removed.

3.4 Irrigation

Stationary head sprinklers, single-span center pivot irrigation and traveling booms are used to irrigate seedlings. The two largest nurseries predominately use center pivot irrigation systems (Bell 2015). The largest nursery has 14 single-span center pivot systems (each covering about 1.2 ha). Seven of eight responding nursery managers obtain irrigation water from wells. Water usage is reported to government agencies by several managers. It is important that pH of the irrigation water does not increase to alkaline levels (Bell 2013).

Currently, nursery managers use a touch-and-feel system to monitor plug moisture as opposed to using an electronic moisture device or the scale/weight system (typically used at nurseries in Oregon and Washington). During the seed germination phase (4 weeks post sowing), several nurseries irrigate every day with a goal of keeping the top 40% of the media moist. After the germination phase (beyond 4 weeks sowing), the goal increases to keeping 93% of the plug moist. During shipping season managers reduce the frequency and/or amount of irrigation in order to “harden-off” seedlings. In years when excessive amounts of rainfall occur in the fall, anaerobic conditions may result and outplanted seedlings might die (South and Starkey 2010).

Most managers have observed heat related problems with seedling growth. During the summer (June-September), air temperatures in the South regularly exceed 32°C and may exceed 38°C. After temperatures reach 34°C, most managers will irrigate their seedlings to reduce air and container temperatures.

3.5 Fertilization

Fertilization is accomplished by mixing slow-release fertilizer in the media and/or the application of water soluble fertilizers. A liquid solution is applied using either tractor-mounted sprayers or irrigation systems equipped with fertilizer injectors. Most managers mix slow-release fertilizers with the media prior to sowing. About half use a 3-4 month formulation whereas the remaining use an 8-9 month formulation. The 3-4 month formulation is common at nurseries that also apply liquid fertilizers. This allows manager to better control seedling growth later in the season. Managers who rely only on full-season slow release fertilizers typically produce seedlings with the lowest foliar nitrogen concentration (October to January) (Starkey et al. 2015b). By August, the needles may not be as green as some prefer (Pittman 2002). In contrast, managers who use liquid fertilizers may produce seedlings with greener foliage and higher foliar nitrogen concentrations.

Four surveyed managers use slow release fertilizers and three use both slow release fertilizers and water soluble fertilizers injected into the irrigation system. Tractor mounted sprayers are used at several nurseries to address specific nutrient problems (e.g. iron chlorosis). All nurseries that use an injector apply water soluble fertilizer with micronutrients or individual nutrients to correct deficiencies.

Container-grown pine seedlings tend to have lower nitrogen concentrations than bareroot stock (South et al. 2005; Tab. 6). The foliar nitrogen concentration of *Pinus palustris* needles at time of planting can be less than 0.9% especially when seedlings are fertilized with less than 15 mg of nitrogen (Dumroese et al. 2013). In contrast, when fertilized with 66 to 88 mg of nitrogen, *Pinus palustris* foliage may have 1.5% N in November (Jackson et al. 2010; Dumroese et al. 2013). Five managers indicated they sample foliage two times a year; eight do so three or more times per growing season and one manager samples foliage for nutrient levels once a month. A few managers do not monitor the nutrient status of seedlings.

The amount of nitrogen applied varies depending on customer specifications or what the manager considers to be important. Some say that a good nutrition program is one that keeps needle length of *Pinus palustris* to less than 32 cm (Dumroese et al. 2005) since this avoids the need to clip needles. In contrast, others say the objective of fertilization should be to increase freeze tolerance (Davis et al. 2011), root-growth potential (Williams and South 1995) and field growth (Jackson et al. 2012a). When fertilization produces long needles, they can be clipped back to 25 cm (Fig. 11). Although fall fertilization can increase nitrogen concentrations (Davis et al. 2011) and root growth potential (Williams and South 1995), most managers choose not to fertilize in the fall. Instead, some withhold fertilization in the fall in order to slow diameter growth and avoid producing seedlings with a large root-bound index (South and Mitchell 2006).

The amount of slow-release fertilizer applied per seedling is easy to determine when both the container volume and mixing rate are known (Dumroese et al. 2005). However, when using liquid fertilizers, the amount of nitrogen applied per seedling cannot be determined when the amount of solution applied is not known. For example, when applying 150 ppm of nitrogen (20 weekly applications), the mg N/seedling applied will be doubled when applying twice the volume of solution (Tab. 8). The mass (or volume) of solution applied must be known in order to convert ppm to mg N per seedling. Research studies cannot be replicated when authors fail to provide critical information about the amount of solution applied.

Table 8. Examples of four nitrogen (N) regimes used at a nursery with trays that contain 600 seedlings per m^2 and 100 cc cells.

Fertilizer	Rate applied	# of fertilizations	mg of N per seedling	g m^{-2} of N	kg ha^{-1} of N
Liquid	150 ppm N	20 (water mass not known)	??	??	??
Liquid	150 ppm N	20 (5 mm solution/application)	25 *	15	150
Liquid	150 ppm N	20 (10 mm solution/application)	50 *	30	300
Slow release	400 g m^{-3} of N **	1	40	24	240

*Assumes all nitrogen applied to the container surface drains into cells.

** One cubic meter of media determined after filling cavities.

3.6 Weed control

Salix nigra is regarded as the most troublesome weed at several container nurseries. The tree is common along the margins of the nursery property and produces copious amounts of wind-blown seed in March and April. Thus, *Salix nigra* seedlings appear in container sets that were outside during the time of seed dispersal. The second most troublesome weed was *Euphorbia* spp. The main source of new weeds is wind-blown seed (not seeds present in the peat mix). Seven mangers use non-permanent labor for hand-weeding, whereas, one indicated that he was the only hand-weeder. The most commonly used herbicides for broadleaf weeds in pine sets were oxyfluorfen and lactofen. Sethoxydim was the most common herbicide used for killing emerged grasses (Starkey et al. 2015b). Tank mixes of broadleaf and grass herbicides were applied at seven nurseries.

3.7 Birds, pathogens and insects

Bird predation (of seed and young germinants) can cause a 1% decrease in seedling production. Even so, only a few managers treat seed with compounds to reduce bird predation. Some managers use shade cloth to aid in reducing bird predation. When summing all types of losses, about 3% of the crop is lost due to animals, fungi and weeds.

Injury due to insects was reported to be less than 1% with most damage caused by tip moth (*Rhyacionia* spp.) and plant bugs (*Lygus lineolaris* Miridae and *Taylorilygus pallidulus* (Blanchard)). Several managers monitor seedlings to determine when to apply insecticides. The most frequently reported insecticides used were chloropyrifos, permethrin, and esfenvalerate (Starkey et al. 2015b).

Six out of seven nursery managers use fungicides to reduce losses from *Cronartium querccum f.sp fusiforme*. Spore production coincides with susceptible seedling tissue in April and May. Triadimefon or prothioconazole are used to control rust at 70% of nurseries. Without treatment, annual losses may exceed 3% (South and Enebak 2006) and one nursery in 2012 had a 20% infection rate (Starkey et al. 2015b).

Additional fungicides used were thiophanate-methyl, chlorothalonil and a product containing etridiazole and thiophanate-methyl. Several phosphonate fungicides such as aluminum tris (used as a root drench) were used by five managers for the control of damping-off diseases. Other commonly used fungicides include iprodione, azoxystrobin and propiconazole. Approximately 19 fungicides are used in container nurseries (Enebak and Carey 2002). Some managers top prune *Pinus palustris* seedlings in order to reduce the probability of foliar disease caused by needle lodging.

3.8 Top pruning

When container-grown *Pinus taeda* seedlings were less than 140 mm tall and younger than 5 months-old at lifting (Barnett and Brissette 1986), top pruning was not necessary. However, now seedlings are typically kept in container nurseries for 8 months, and heights at lifting may exceed 300 mm (Tab. 9). Mike Coyle developed a system in 2001 to mechanically clip needles and other managers quickly adopted this technology. The cost of a single top pruning is less than € 0.18 per thousand seedlings. Some managers top prune *Pinus taeda* seedlings once (generally in July) while about 60% prune two or more times during the year. Objectives for top pruning *Pinus taeda* seedlings include increasing crop uniformity and reducing the height/diameter ratio.

Clipping *Pinus palustris* needles (Fig. 11) can increase seedling survival (Barnett 1984; South 1998; South et al. 2011c) and can reduce shipping costs. The benefit/cost ratio of clipping long needles might be 2/1 if; (1) a seedling box costs € 2.50 each, and (2) 334 clipped seedlings can be placed in a box versus 316 unclipped seedlings.

However, needles should not be clipped to a 10 cm length since this will reduce early root growth. The preferred needle length (after clipping) is 15 to 25 cm (Barnett and McGilvery 1997; Barnett et al. 2002). One economically driven objective for top clipping *Pinus palustirs* seedlings is to reduce the risk of diseases caused by lodging of long needles (Barnett and McGilvery 1997; Dumerose et al. 2009).

Table 9. The average root collar diameter (RCD), height, height/diameter ratio (H/D), root-weight ratio (RWR; dry weight), total seedling dry mass (total), cell volume, and container density for *Pinus taeda* seedlings produced in containers. Data prior to 1986 are from Barnett and Brissette (1986) for container-grown seedlings less than 5 months old; and recent data are from Auburn University Southern Forest Nursery Management Coop (approximately 8-9 months old). Minimum RCD = the minimum average RCD reported (it is not the minimum RCD shipped from an individual nursery).

Years		**RCD**	**Height**	**H/D**	**RWR**	**Total mass**	**Cell volume**	**Density**
		mm	**mm**	**mm/mm**		**mg**	**cc**	# m^{-2}
	Minimum	1.2	102	44 (133/3.0)	0.12	185	64	441
1975-1985	Median	1.6	121	81 (129/1.6)	0.19	411	64	807
	Maximum	3.1	133	101 (121/1.2)	0.26	1719	130	1808
	Minimum	4	229	45 (243/5.4)	0.50	7700	60	517
2012-2014	Median	4.9	326	66 (323/4.9)	0.61	10600	110	569
	Maximum	5.6	393	84 (393/4.7)	0.66	13300	135	883

Figure 11. A single top clipping of *Pinus palustris* seedlings can reduce needle length, increase seedling uniformity and seed efficiency, reduce shipping costs, and increase the probability of survival after outplanting. Needle length is approximately 33 cm before clipping and 25 cm after clipping. The cost of this treatment (< € 0.00018 per seedling) can be recovered if the number of plantable seedlings is increased by one per 900 cells.

3.9 Root pruning

In plastic containers with solid cell walls, lateral roots grow downward in the shape of a "bird-cage." Most container-grown seedlings planted in the South have "bird-cage" roots and in many cases they have good survival and growth. However, some think stability of saplings (i.e. toppling at a young age) might be increased if lateral roots grew horizontal near the soil surface (Ruehle 1985; Ortega et al. 2006; Sword Sayer et al. 2011). Although toppling of container-grown *Pinus taeda*, *P. elliottii* and *P. echinata* is rarely reported, toppling of fast-growing *Pinus palustris* does occur (South et al. 2001b; South 2015). Root-pruning techniques used to reduce the "bird-cage" appearance include copper treatments (Sword Sayer et al. 2011) and side-slits in container walls for air pruning (Ortega et al. 2006; Bell 2015). Although the copper treatment increased volume growth of *Pinus palustris* at some locations (Haywood et al. 2012), others observed no increase in early height or diameter growth (South et al. 2005). Since the copper treatment can increase the cost of container trays by 33%, this tool is use more by researchers than by nursery managers.

The ability to extract copper treated seedlings from containers depends on container type. The copper treatment makes plugs "much easier to extract" (Barnett and McGilvray 2002) from polystyrene trays but they are harder to extract from hard-plastic cells (with more media left in the cells). In some cases, root mass for copper treated *Pinus taeda* seedlings needed to be 20% greater (than untreated stock) to avoid loss of potting medium during extraction (personal communication Steve Grossnickle). No loss of potting medium during the extraction process is viewed as an important attribute (Barnett et al. 2002).

Not all container-grown *Pinus palustris* seedlings have a long taproot (Sung and Dumroese 2013) and a lack of a taproot increases the chance of toppling (South et al. 2001b). Air-pruning the taproot (at the bottom of the container) produces a callus ball on the taproot and typically adventitious "sinker" roots are formed just above the callus. However, occasionally no sinker root is produced leaving the seedling without a replacement taproot. When this occurs, the length of the main taproot stays the same as the length of the container cell. If a container-grown *Pinus palustris* sapling that is over 3.5 m tall has a 65 mm long taproot (Sung et al. 2013) stability will be compromised. Copper treating container walls will affect lateral roots and might affect root mass, but this treatment will not reduce the frequency of short taproots.

3.10 Lifting, packing and shipping

The planting window for stored container-grown stock is longer than for stored bareroot seedlings (Grossnickle and South 2014). However, to reduce the risk of freeze injury in outdoor nurseries, it is best to ship and plant container-grown stock in the fall (McRae and Starkey 1996). After seedlings are outplanted, the roots are protected by insulation from the topsoil. When seedlings remain outside in nurseries, large financial losses can occur when roots are exposed to a -10°C December freeze (Tinus et al. 2002). For this reason, nearly 80% of container seedlings are shipped before January and half are shipped by early December. In contrast, shipping bareroot seedlings normally does not begin until after late November.

Prior to shipping, seedling trays are either brought into a packing shed or they are packed outside in the nursery. Seedlings are extracted from the containers, packed and shipped in wax-coated, cardboard boxes. Depending upon tree species plug size, needle length, and box volume, a box typically holds 250 to 334 seedlings. Large nurseries have a cooler (2-3°C) in which to store seedlings while others store boxes under a shed.

In the South, soil and air temperature conditions are such that pine seedlings roots continue to grow during the winter months. Therefore, root biomass and RCD increase from December to February. The average reported target RCD for *Pinus taeda* is 4.0 mm for stock shipped in late November and 4.5 mm for stock shipped in January (Starkey et al. 2015b). A sampling of several container nurseries indicates the average RCD at shipping is about 4.9 mm for this species (Tab. 8). For *Pinus palustris* the minimum RCD for a plantable container seedling is 4.8 mm (Barnett et al. 2002).

4 Optimum seedling

The term "high quality seedling" is used in sales brochures, but it typically has no definition and frequently is a meaningless term. In contrast, the "target seedling" is defined by nursery managers and researchers in quantifiable terms (median height, RCD, RWR, H/D, etc.). For *Pinus taeda*, the target seedling might be in the ideotype B group or it may have a lower height/diameter ratio and qualify as ideotype A (Fig. 10). Defining the target seedling is very easy and it is useful for determining when managers apply various cultural treatments. In many cases, the primary economics that is considered when identifying the target seedling is time required for hand-planters to make a planting hole (Harrington and Howell 1998).

The optimum seedling is "the ideotype that will minimize overall reforestation costs while achieving established goals for initial survival and growth" (South and Mitchell 1999; Jobidon et al. 2003). A more expensive seedling ideotype will qualify as the "optimum seedling" when: (1) total costs for weed control and/or site preparation are reduced, (2) goals for early survival and growth are met, and (3) the overall cost of reforestation is less than when using less expensive stock. In one study, the more expensive bareroot seedling (RCD = 10 mm) reduced overall reforestations costs by € 80 per ha (South and Mitchell 1999). The "optimum seedling" should not be proposed without an economic analysis that includes examining relative cost and performance of a range of stand establishment practices.

For example, container stock of *Pinus echinata* may cost €195 per ha more than when planting bareroot stock (at 1,100 SPH). This is because they cost more to purchase (€110 per ha), ship (€8 per ha) and plant (€77 per ha) (Barlow and 2015). When these extra costs are offset by significant reductions in weed control and site preparation costs (normally associated with bareroot stock), then container stock will qualify as the optimum seedling (assuming targets for survival and growth are achieved). In contrast, on sites where early field performance goals (3 to 5 years after planting) are achieved by both stock types (South and Barnett 1986) or when bareroot seedlings achieves the survival and growth goals (South 2011), then bareroot stock will be the "optimum seedling" since it achieves target goals at a lower overall cost.

Evaluating the trade-offs in performance and costs (of site preparation, seedling price and planting method) is rarely conducted when comparing the growth of bareroot stock of different sizes (South 1993; South et al. 1993; Kabrick et al. 2015) or when comparing container sizes (Sword Sayer et al. 2011) or when comparing bareroot stock with container stock (South and Barnett 1986; Taylor et al. 2007; South 2011). A problem is that many research trials are established using only one level of weed control and site preparation. Therefore, instead of using short-term growth goals and economics to identify the "optimum seedling," researchers typically rely on performance rankings and statistics when recommending the "target seedling." Perhaps a new generation of reforestation researchers will collaborate with economists to determine the "optimum seedling" for use in future reforestation systems.

5 SFNMC Research

The SFNMC currently consists of 17 members, 8 forest industries, 8 state forestry organizations and the U.S. Forest Service. Annually, these members produce about eight pine seedlings for every person in the southern U.S. Currently, most of the published nursery research in the South is conducted by the SFNMC and the U.S. Forest Service. Due to SFNMC research, members have reduced their hand weeding costs and have reduced losses due to nematodes and disease. Trials at SFNMC field days have demonstrated improved technologies involving precision sowing, soil stabilizers and soil fumigation.

6 Acknowledgements

We thank Mike Coyle and James West for providing some information regarding top-clipping of container-grown seedlings.

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