Forest Seedling Nursery Practices in the Southern United States: Bareroot Nurseries

Tom E. Starkey, Scott A. Enebak, and David B. South

Research Fellow, Southern Forest Nursery Management Cooperative, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL; Professor of Forest Pathology and Director of the Southern Forest Nursery Management Cooperative, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL; Professor Emeritus, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL

Abstract

Nearly 80 percent of the 1.1 billion forest seedlings grown in 2012 in the United States were produced in the 13 Southern States. A survey of current nursery practices for southern bareroot nurseries was compiled and the results presented and compared with a similar survey conducted in 1980. Most notable changes during the past 32 years include reduction in the number of nurseries growing seedlings (including the phase-out of all Federal nurseries), increase in production capacity of industrial nurseries, more seedlings produced by the private sector, a shift in growing more crops under a single fumigation regime, the development of synthetic soil stabilizers, the widespread appearance of the weed spurge, the development of more efficacious fungicides for the control of fusiform rust and other diseases, root and top pruning of seedlings to facilitate the widespread use of full-bed belt lifters, the use polyacrylamide gels to protect roots system after lifting, the use of seedlings bags and boxes for shipping seedlings, and the use of migrant and legal foreign nationals as a source of nonpermanent labor.

Introduction

In 2012, more than 1.1 billion bareroot and container conifer seedlings were produced for reforestation in the United States (Harper et al. 2013), of which nearly 80 percent were produced in the 13 Southern States (table 1).

Table 1. Bareroot seedling (conifer and hardwood) production and percentage of total production by region.

Region	Bareroot seedlings produced	Bareroot percent by region
Southern	755,413,000	82.4
Northeast	8,828,000	1.0
North Central	57,701,000	6.3
Great Plains	5,430,000	0.6
Intermountain	3,301,000	0.4
Pacific Northwest	85,890,000	9.4
Pacific Southwest	—	—
Region Totals	916,563,000	

Source: Harper et al. (2013)

There have been several surveys of forest nursery practices since 1950 (Abbott 1956, Abbott and Eliason 1968, Abbott and Fitch 1977, Boyer and South 1984). These surveys can be used to document changes in technology and method of seedling production. Three surveys included nurseries throughout the entire United States (Abbott 1956, Abbott and Eliason 1968, Abbott and Fitch 1977). In 1917, a detailed report, not a survey, primarily describing equipment, growing techniques, and facilities at five U.S. Department of Agriculture (USDA) Forest Service nurseries was published for the interest and value "to all who are engaged in nursery work with forest trees" (Tillotson 1917:1). Because southern pines account for more than three-fourths of the total seedlings grown for reforestation in the United States, a 1980 survey of production practices for bareroot southern pine seedlings was conducted (Boyer and South 1984). The 1980 survey was the most recent survey of bareroot nursery practices; although annual surveys of seedling production numbers were initiated by the Southern Forest Nursery Management Cooperative (Nursery Cooperative) in 1997.

Since 1972, the Nursery Cooperative has worked with forest seedling nurseries to increase seed efficiency and seedling quality. The area represented by this research-based cooperative includes Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, (east) Oklahoma, South Carolina, Tennessee, (east) Texas, and Virginia (figure 1). Nurseries that are members of this cooperative grew more than 84 percent of the total seedlings produced in the Southern United States (Enebak 2012). Since the 1980 survey, many changes have occurred in seedling production practices. The purpose of this article is to document current nursery practices employed in southern bareroot conifer nurseries and changes that have occurred in the 32 years since the 1980 survey. Nursery practices in southern container conifer nurseries are documented in a companion manuscript, *"Forest Seedling*

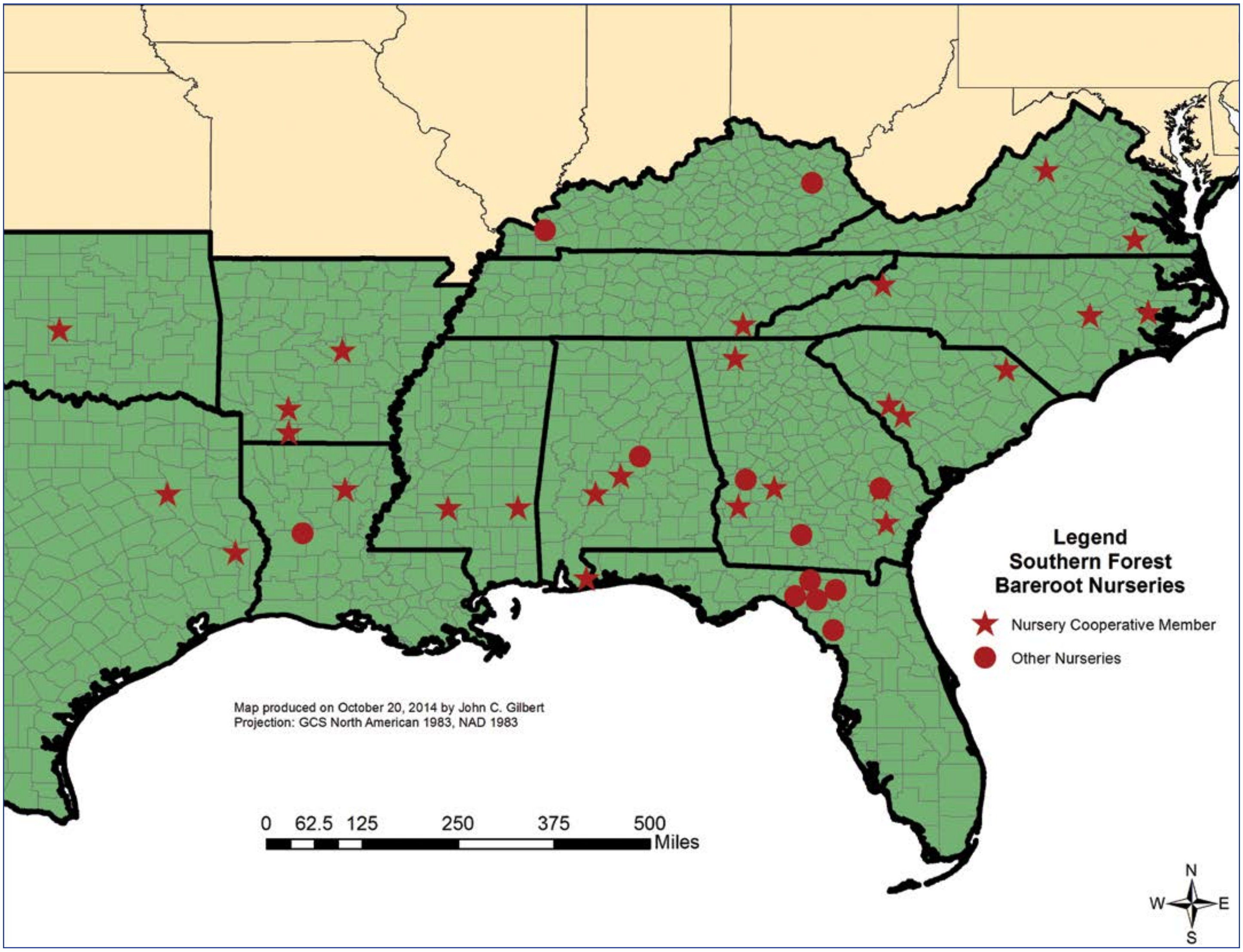

Figure 1. Southern States included in the bareroot survey and location of Nursery Cooperative and nonmember nurseries. (Map by John Gilbert 2014)

Nursery Practices in the Southern United States: Container Nurseries," also appearing in this issue of *Tree Planters' Notes*.

The Nurseries

In June 2012, a 28-page survey of nursery practices was mailed to 40 bareroot forest seedling nurseries in the 13 Southern States (figure 1) with completed returns received from 35 managers of which 26 were Nursery Cooperative members. Because some nursery managers choose not to answer some questions, results are based on the number of nursery managers responding to a question. In 1980, 63 bareroot nurseries received the nursery survey and 50 nurseries participated in the survey (Boyer and South 1984). For our purposes, nursery ownership was categorized as State (nursery owned by the State), industry (nursery owned by a company that also owns land and production facilities such as mills), or private (owned by a company with no land ownership or production facilities). In 1980, the Nursery Cooperative had 19 industry, 12 State, 1 Federal, and 0 private members. The first private nursery joined the Nursery Cooperative in 1988. Nursery closures and mergers have dramatically changed nursery ownership and production capacities. Since 1995, at least 28 nurseries in the Southern Region have shut down with a potential reduction in annual seedling production of more than 617 million (table 2). Some of this lost production has been recovered as remaining nurseries have increased seedling production by either expanding existing production systems or increasing the number of crops per rotation. The net reduction is estimated at 480 million seedlings (Sharp 2014). The effect of these mergers and acquisitions reduced Nursery Cooperative membership (2012) to 16 members (i.e., 3 industry, 4 private, 8 State, and 1 Federal) operating 28 nurseries (figure 1).

Table 2. Southern bareroot forest nursery closures and production losses by ownership type since 1995.

Year	Production
Industry	
1996	40,000,000
1999	10,000,000
2001	32,000,000
2001	25,000,000
2002	30,000,000
2002	22,000,000
2007	35,000,000
2010	30,000,000
2010	35,000,000
2010	30,000,000
2012	22,000,000
Total Industry	311,000,000
Private	
2000	15,000,000
2002	15,000,000
2003	25,000,000
2004	30,000,000
2005	33,000,000
2007	15,000,000
2009	8,000,000
Total Private	141,000,000
State	
1995	18,000,000
1996	15,000,000
1996	18,000,000
1997	25,000,000
2000	20,000,000
2005	12,000,000
2007	20,000,000
2007	5,000,000
2007	20,000,000
Total State	153,000,000
Federal	
2000	12,000,000
Grand Total	617,000,000

Sources: Sharp (2014), South (2014)

The oldest nurseries in the 1980 survey were the Miller State Nursery in Alabama, which operated from 1934 to 1993 and the Ashe Nursery in Mississippi that was operated by the USDA Forest Service from 1936 to 2000 (Boyer and South 1984). In 2012, the oldest reporting nurseries were the State nursery in Goldsby, OK, which began operation in 1947 and the State nursery in Goldsboro, NC, which began operation in 1954. The oldest private nursery was Superior Trees in Lee, FL, which began seedling production operations in 1953.

Seedling Production

In the 2012 season (i.e., the winter of 2011–2012), the total conifer and hardwood seedling production for both stock types (bareroot and container) in the South exceeded 936 million seedlings. This year was the third consecutive year that production fell to less than 1 billion seedlings since the Nursery Cooperative began tracking annual seedling production in 1997, and continues a downward trend in total seedling production that began in 2002. Hardwood production accounted for approximately 4 percent of the total seedling production in the South (Harper et al. 2013) and is not included in this paper.

In the Southern United States, bareroot loblolly pine (*Pinus taeda* L.) accounted for 86 percent of the total conifer production followed by slash pine (*P. elliottii* Engelm.) at 11 percent and longleaf pine at 1 percent (*P. palustris* Mill.) (Enebak 2012). The percentage of loblolly pine production was up since 1980 when it accounted for 77 percent of bareroot conifers (table 3) (Boyer and South 1984). During the early 1930s, longleaf pine and slash pine were the predominant conifers produced; no loblolly pines were grown (Boyer and South 1984). In 2012, 80 percent of seedlings produced in the Southern United States were bareroot whereas, in 1980, 99.8 percent were bareroot (Boyer and South 1984). The choice of stock type differs among the three major southern pine species. More than 91 percent of loblolly pine and 95 percent of slash pine were produced as bareroot stock whereas less than 4 percent of longleaf pines were produced as bareroot stock (Enebak 2012).

In 2012, nurseries in Georgia produced a total of 303.3 million seedlings, more than 2.7 times the seedlings produced by nurseries in South Carolina, the next highest State in production number (Enebak 2012). The largest number of forest seedling nurseries (13 bareroot and container) was found in Georgia, which explains why it has been the top seedling producer for years. The largest individual nursery (based on production) was an industry nursery located in South Carolina.

Private and industry nurseries produced 49 and 38 percent of the seedlings in the Southern United States, respectively. Although the State nurseries produced only 13 percent of conifer seedlings, they produced 40 percent of the bareroot hardwoods (Enebak 2012).

Generally, nursery production per nursery has increased from less than 1 million seedlings in 1934 to 17 million in 1980 (Boyer and South 1984), then decreased to 13 million in 2012. In 1980, State and Federal nursery annual seedling production averaged 22 million while in 2012 State nurseries averaged 6 million. By contrast, industry nurseries averaged 18 million seedlings produced per year in 1980 (Boyer and South 1984) and 29 million in 2012. On a per seedling basis, fixed costs have increased for State nurseries while they have decreased for industry nurseries.

Table 3. Conifer species grown in southern bareroot forest nurseries in 1980 and 2012.

Species	Scientific name	1980 bareroot production	1980 percent of bareroot total	2012 bareroot production	2012 percent of bareroot total
Loblolly pine	*Pinus taeda* L.	965,620,000	77.1	615,588,000	85.7
Slash pine	*P. elliottii* Engelm.	167,214,000	13.4	80,042,000	11.1
White pine	*P. strobus* L.	22,640,000	1.8	1,834,000	0.3
Shortleaf pine	*P. echinata* Mill.	12,914,000	1.0	1,548,000	0.2
Longleaf pine	*P. palustris* Mill.	10,293,000	0.8	5,247,000	0.7
Sand pine	*P. clausa* (Chapm. ex Engelm.) Vasey ex Sarg.	8,175,000	0.7	6,204,000	0.9
Virginia pine	*P. virginiana* Mill.	6,858,000	0.5	1,069,000	0.1
Scots pine	*P. sylvestris* L.	1,220,000	0.1	1,069,000	0.1
Spruce pine	*P. glabra* Walter	157,000	< 0.1	11,000	< 0.1
Pond pine	*P. serotina* Michx	30,000	< 0.1	219,000	< 0.1
Other pines		54,420,000	4.3	1,411,000	0.2
Red cedar	*Juniperus virginiana* L.	1,807,000	0.1	230,000	< 0.1
Baldcypress	*Taxodium distichum* (L.) Rich.	290,000	< 0.1	3,870,000	0.5
Arizona cypress	*Hesperocyparis arizonica* (Greene) Bartel	31,000	< 0.1	0	0.0
Totals		**1,251,669,000**		**718,344,000**	

Sources: Boyer and South (1984), Enebak (2012)

In 2012, a range of genotypes was used for reforestation in the South. Nearly all the longleaf pine sold in 2012 were wild collected, with seed collected from production areas rather than specific families selected for specific traits. Most loblolly and slash pine seedlots sold in 2012 were grown from second-generation improved seed (table 4). Although most loblolly and slash pine seedlots were open pollinated, a portion were from controlled, mass-pollinated selections. The industry and larger private nurseries with access to seed orchards tend to market the advanced genetic seedlots. In addition, a small portion of the 2012 loblolly pine crop was clonal stock produced for CellFor Inc. using somatic embryogenesis (Grossnickle and Pait 2008).

Table 4. Bareroot seedlot genetics sown in 2012 in southern bareroot forest nurseries. More than one genotype was listed for most nurseries.

Species	Genetics	Percent sown
Loblolly pine (n = 29)	1st generation	8
	2nd generation	57
	3rd generation	16
	Advanced	19
Slash pine (n = 14)	1st generation	9
	2nd generation	75
	3rd generation	5
	Advanced	11
Longleaf pine (n = 4)	Wild	91
	Improved	9

Nursery Soils

Texture

In 1980, 74 percent of nurseries were built on soils with more than 75 percent sand (Boyer and South 1984) (table 5). In 2012, this percentage was nearly the same but also reflected a shift toward sandier sites. Since 1980, 7 out of 13 newly established nurseries were located on soils with more than 75 percent sand and 6 nurseries were established on sites with more than 88 percent sand. Soils with high sand content have several advantages, including they (1) are conducive to mechanical lifters; (2) drain quickly following a rain event, thereby allowing for quick access into the fields; (3) warm up faster in the spring for sowing; and (4) have good permeability. A minor disadvantage is that coarse-textured soils may have lower cation exchange capacity and require more fertilizer to achieve seedling growth targets. For at least a century, it has been known that it is much easier to add fertilizer to a sandy soil than to manage seedlings on a clay soil (Tillotson 1917). Likewise, Wakeley (1935:37) 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."

Table 5. Soil types in southern bareroot forest nurseries in 1980 and 2012.

Soil type	Description	Percent in 1980 (n = 51)	Percent in 2012 (n = 31)
Sand/loamy sand	More than 75 percent sand	33	38
Sandy loam	52 to 75 percent sand	41	35
Sandy clay loam	More than 45 percent sand and 20 percent clay	16	15
Loam/silt loam	Less than 52 percent sand to more than 50 percent silt	10	12

Source for 1980 data: Boyer and South (1984)

Organic Matter

Nurseries located in the Coastal Plain are characterized by low soil organic matter when compared with nurseries located in the Piedmont region and more northern portions of the country. The median percent soil organic matter for nurseries with sandy or loamy sand soil in 2012 was 1.6 percent (table 6) compared with 1.7 percent in 1980 (South and Davey 1983). The methodology used to calculate soil organic matter, however, was not queried in either survey. The traditional Walkley and Black or Modified Walkley and Black methods will generally return a lower measure of soil organic matter than the loss on ignition method for soils in the coastal plain region (Tuffour et al. 2014).

In 2012, most managers (85 percent) reported that they have a regular program to increase soil organic matter other than the use of a cover crop as compared with 66 percent in 1980 (Boyer and South 1984). Although many organic amendments are available, 48 percent of the 27 managers responding in 2012 applied sawdust to the production units before fumigation to increase soil organic matter. The median amount of sawdust applied in 2012 was 61 yd^3/ac (115 m^3/ha). Bark was the second most common amendment (table 7).

The level of soil organic matter has become more of an issue because of recent changes in soil fumigation rules. The area of land that can be fumigated at any one time is now determined by "buffer zones" that must surround the fumigated land and cannot be entered for 3 days. Factors such as proximity of neighbors, ownership of adjoining land, and location of nursery buildings dictate the maximum acreage that can be fumigated daily. According to the Environmental Protection Agency (EPA) regulations, these buffer zones can be reduced with the use of new high-barrier plastic tarps such as totally impermeable film and by increasing the level of soil organic matter in the soil. Nurseries with 1 to 2 percent soil organic matter receive a 10-percent reduction credit, those with 2 to 3 percent receive a 20-percent reduction credit, and those with more than 3 percent receive a 30-percent reduction credit.

Table 6. Percent organic matter for southern bareroot forest nurseries in 2012.

Percent organic matter	Percent of nurseries (n = 34)
Less than 1.0	6
1.0 to 1.4	32
1.5 to 2.0	21
2.1 to 2.4	21
2.5 to 2.9	15
More than 3	6

Table 7. Organic matter materials used by southern bareroot forest nurseries to increase soil organic levels. Some managers reported using more than one type of material.

Organic matter	Percent of nurseries in 1980 (n = 50)	Percent of nurseries in 2012 (n = 27)
Sawdust	54	38
Bark	24	32
Gin compost	0	6
Wood chips	12	6
Mill grit	0	3
Other	10	24
None	34	15

Source for 1980 data: Boyer and South (1984)

Cover Crop/Fallow

Nurseries rotate their land with fallow and cover crop for many reasons including improving soil structure, addressing soil microbiology issues, and managing weed or nematode problems. In 2012, nursery land in cover crop or fallow was 53 percent (of the total cropland), which was similar to that in 1980 (Boyer and South 1984). By ownership class, the amount of land in cover crop or fallow in 2012 was 65 percent for State nurseries, 65 percent for private nurseries, and 35 percent for industry nurseries. Industry and larger private nurseries have less land in fallow or cover crop because of changes in production rotation. In 1980, 56 percent of industry nurseries followed a 1:1 seedlings:cover crop rotation while, in 2012, they used either a 2:1 or 3:1 rotation (2 to 3 years of seedling production followed by 1 year of cover crop/fallow). Extending the rotation length reduces fumigation costs and keeps land in production longer. This shift in rotation for industry and larger private nurseries might also help explain why soil organic matter has not increased from 1980 to 2012. In 1980, managers applied organic matter to nonproduction units every other year before fumigation. With a rotation shift to 2:1 or 3:1, organic matter is applied only every 3 to 4 years, which might have decreased the total amount of organic matter added to a field over time (assuming application amounts were not adjusted).

In 2012, 78 percent of nurseries used either millet (*Panicum ramosum* L.) or *Sorghum* spp. as a summer cover crop, which has not changed from the cover crops used in 1980. The application of fertilizer to the summer crop was done regularly in 2012 by more than 90 percent of the nurseries. In both 2012 and 1980 (Boyer and South 1984), a winter cover crop of rye (*Lolium* spp.) was the most popular used by nursery managers. In 2006, a strong relationship between cover crop type and stunt nematode (*Tylenchorhynchus claytoni*) and stubby-root nematode (*Paratrichodorus minor*) populations was reported (Cram and Fraedrich 2009). Since this report, nurseries that traditionally have nematode problems use cover crops other than corn or sorghum, which are hosts for these nematodes. Leaving production land fallow is a method that

45 percent of nurseries in 2012 reported using. The most common reason nurseries use fallow land is the ability to aggressively address weed problems using glyphosate.

Cultural Practices

Sowing

Before 1980, most managers used gravity-drop seed sowers such as Whitfield®, Love Oyjord®, Stanhay®, or Planet Junior® (Boyer and South 1984). Soon afterward, precision vacuum drum sowers became available and several were put into use in nurseries throughout the Southern United States. In the 2012 survey, gravity sowers were the most frequently used method for sowing seed (table 8, figure 2). A study by Boyer et al. (1985) found that a vacuum sower was more precise in seed placement and resulted in less seedling culls relative to gravity sowers. Slower speed and higher maintenance are two reasons vacuum sowers are not more commonly used today, however.

Nursery managers strive to complete sowing in a minimum number of days because uniformity in germination across a nursery greatly facilitates seedling management during the growing season. In 2012, nurseries that produced more than 20 million seedlings sowed an average of 5.4 million seeds per day to complete sowing in an average of 8 days. Nurseries that used a gravity sower sowed 700,000 more seeds per day than those nurseries that used a vacuum sower. Larger nurseries using a vacuum sower will frequently use more than one vacuum sower to complete the sowing operation in a shorter timeframe. Smaller nurseries that produced less than 20 million seedlings sowed an average of 1.8 million seeds per day to complete sowing in an average of 4 days.

Table 8. Sowing machines used in southern bareroot forest nurseries in 2012 to sow conifers. Some managers reported using more than one type of machine.

Machine	Mode of operation	Percent of nurseries (n = 34)
Love/Oyjord®	Gravity	50
Whitfield®	Gravity	38
Summit®	Vacuum	32
Love Vacuum®	Vacuum	6
Silver Mountain®	Vacuum	3

Approximately 60 percent of managers queried in 2012 began sowing in mid-April (table 9). Nurseries with coarse-textured soils tend to sow earlier than nurseries with finer textured soils that tend to warm up later in the spring. Before sowing, seed preparation such as stratification, is done on site at 62 percent of the nurseries in 2012. The remaining nurseries obtained stratified seed from a seed facility operated within their organization or from another nursery. Seed treatments that include fungicides for control of fusiform rust (*Cronartium querccum* f. sp. *fusiforme*) and/or bird or animal repellants were used by 82 percent of nurseries. In addition, 80 percent of nurseries used latex as a chemical sticker. The type of latex used ranged from store-purchased paint to latex from Dow Chemical.

Seedling root collar diameter (RCD) increases as seedbed density decreases. In 2012, the average seedbed density for loblolly and slash pines was 24 seedlings/ft^2 (258 seedlings/m^2)

Table 9. Starting date for sowing conifers in southern bareroot forest nurseries.

Date	Percent of nurseries (n = 31)
Late March	3
Early April	23
Mid April	60
Late April	13

Figure 2. Machines used to sow a bareroot nursery (A) Vacuum precision drum sower (Silver Mountain Equipment®) and (B) Gravity drop sower (Love®). (Photos by Tom Starkey, 2009 and 2014)

and for longleaf pine was 13 seedlings/ft^2 (140 seedlings/m^2). These densities have changed little during the past 32 years in southern bareroot forest nurseries.

Since the 1980 survey, synthetic soil stabilizers (e.g., Agrilock®) have been introduced to reduce bed washout and seed losses soon after sowing. Effective stabilizers also maintain seedbed integrity over most of the growing season. In 2012, 72 percent of nurseries reported using synthetic soil stabilizers. At three nurseries, bark mulch and a soil stabilizer were used either on all production units or on nursery beds adjacent to riser lines to prevent washout from the irrigation system. The use of synthetic soil stabilizers is a major change from 32 years ago. In 1980, hydromulch was a common choice in industrial nurseries whereas other nurseries favored pinestraw, sawdust, or bark (Boyer and South 1984). In 2012, the only mulch reported used to cover seedbeds was bark mulch, although it did little to keep seed in place or maintain seedbed integrity during heavy rainfall events.

Irrigation

In 1980, less than 33 percent of southern bareroot forest nursery managers monitored soil moisture as compared with 100 percent in 2012. In 2012, more than 75 percent used a subjective visual and tactile soil assessment, while 8 percent used objective methods such as tensiometers or electronic soil moisture devices. One manager asserts that an objective method reduces over-watering and increases development of fibrous seedling root systems (Weatherly 2014).

Managers reporting satisfaction with their irrigation systems (70 percent) remained the same for both surveys. In 1980 and in 2012, impact head irrigation systems were the predominant irrigation method. In 2012, one manager reported using a center pivot irrigation system exclusively and another reported using both the center pivot and the impact head systems (figure 3). The riser/nozzle layout for impact head irrigation systems are designed in square/rectangular patterns (62 percent) or a rhomboid pattern (in which nozzles on adjacent riser lines are staggered). In 2012, 55 percent of nurseries used well water for irrigation. Other sources of irrigation water included surface ponds, streams, and rivers. Some nurseries (15 percent) used other water sources, providing a backup in case the primary source runs into problems during the growing season.

The amount of water applied during a growing season varies with soil texture and seedling growing phase. Depending on rainfall, the median amount of water applied in 2012 during germination and seedling growth was 1 in/wk (2.5 cm/wk). As seedlings are hardened off in preparation for lifting, the median amount of water applied per week dropped to 0.5 in/wk (1.3 cm/wk). Many nurseries (88 percent) also used irrigation to cool the seedlings during the summer to avoid heat problems. Short periods of irrigation can reduce bed temperatures by 20 °F (11.1 °C) and ambient air temperatures by 10 to 15 °F (5.6 to 8.3 °C) (May 1984). When air temperatures exceed 93 °F (34 °C) in 2012, most nurseries applied irrigation to reduce bed temperatures regardless of recent precipitation. Despite measures to cool nursery beds and seedlings, 83 percent of responding southern bareroot forest nursery managers indicated they have experienced heat-related problems in seedling growth.

Figure 3. Oscillating impact head irrigation system used by nearly all bareroot nurseries in Southeast. (Photo by Tom Starkey 2014)

Four nurseries (12 percent) regularly irrigated at night in 2012, and 50 percent have considered night irrigation as an option for their production system. In 2012, lack of labor was listed as the primary concern about night watering and reduced ability to spot problems was the primary concern in 1980 (Boyer and South 1984). Managers also had concerns about disease increases in 2012, but this concern may not be based on scientific data because plants are commonly wet at night from rainfall or heat loss to the atmosphere. Seedling surface moisture (dew) quickly evaporates when the sun rises. In the 1930s, night irrigation was preferable because of reduced evaporative loss, thereby resulting in increasing water penetration into the soil (Wakeley 1935).

Fertilization

In 2012, more than 50 percent of managers used a private consultant for fertilization recommendations of bareroot seedbeds and 25 percent used personnel within their company to determine fertilizer needs. In 2012, both granular and liquid inorganic fertilizers were used. More than 70 percent of managers purchased granular fertilizer by the bag rather than bulk whereas 83 percent use bulk liquid fertilizers. Nearly 60 percent of nurseries used some form of urea as their primary nitrogen source (figure 4). Iron was the most frequent micronutrient used to treat nutrient problems. In 2012, 29 different fertilizers formulations were listed for growing loblolly pine. In 1980, potassium was "often applied" (Boyer and South 1984) to encourage seedling hardening-off; however, little research data support this practice (Boyer and South 1984). In 2012, 55 percent of nurseries continued to apply potassium in late summer to early fall.

Figure 4. Application of liquid fertilizer while irrigating using a nine-bed sprayer to reduce fertilizer burn to seedlings. (Photo by Scott Enebak 2002)

Pruning

Seedling shoot (top) and root pruning are cultural tools commonly used by southern bareroot nurseries in an effort to achieve seedling target specifications, improve shoot:root ratio, increase crop uniformity, control shoot height, and prepare the seedling for shipping (South and Donald 2002). Although commonly used today (2012), these practices were operationally used at several nurseries in 1980 (exact number of nurseries not reported) and were nonexistent in the 1930s (Boyer and South 1984).

In 2012, 91 percent of southern bareroot nurseries top pruned seedlings; the State-operated nurseries were the only respondents that did not top prune. The first top pruning is usually done in July, with 76 percent of nurseries top pruning again two or three times during the summer.

Root pruning is accomplished by (1) undercutting, which cuts the tap root; (2) root wrenching, which tears the roots and improves bed drainage; and (3) lateral pruning, which separates seedlings in adjacent drills to facilitate lifting with mechanical lifters. Undercutting and lateral root pruning are typically done before lifting. Root wrenching is done to encourage root growth, improve bed drainage, and occasionally to loosen seedlings before lifting. In 2012, 89 percent of responding managers root pruned their crop (53 percent undercut, 26 percent undercut and root wrenched, and 82 percent lateral pruned). State nurseries were the only nurseries that did not root prune.

Undercutting is done with either a horizontal fixed or reciprocating blade that cuts the tap root at 6 to 8 in (15 to 20 cm) below the ground line. Root wrenching uses a fixed blade at a slight angle that tends to tear the roots and breakup the bed's soil profile. Managers who do not lateral root prune must hand lift their seedlings using either a Frobro® or similar seedling harvester that undercuts, lifts, and vibrates the seedling bed while minimizing root damage. In 2012, most managers reported that they initiated root pruning in July or October. Those who indicated July were most likely root wrenching, not undercutting. Those who reported root pruning in October were undercutting their tap roots to help meet target seedling specifications in preparation for lifting.

Integrated Pest Management

Mortality

More than two-thirds of nursery managers in 2012 estimated crop mortality of less than 3 percent caused by factors other than weeds, with an average of 2 percent for all nurseries (table 10). This rate is a significant decrease from the 1980 survey where the average mortality was 11 percent (Boyer and South 1984). Average loss because of bird predation in 2012 was 0.21 percent, which was up slightly from 1980 (Boyer and South 1984). Nurseries reporting seedling loss because of bed washout from early spring rains was significantly lower in 2012 (0.02 percent) compared with 2.6 percent in 1980 (table 10). This reduced loss is most likely because of the widespread use of soil stabilizers applied at sowing, which were not available in 1980. The use of soils stabilizers probably also explain the reduction in losses because of rain splash since 1980.

Fumigation

Integrated pest management begins in all bareroot nurseries with soil fumigation (figure 5). The goal of which is to provide broad control of soil borne diseases, insects, weeds, and nematodes without lasting injury to beneficial organisms. Methyl bromide was the most commonly used soil fumigant in both 1980 (Boyer and South 1984) and 2012. A significant effect on the use of methyl bromide occurred in 1993 when

Table 10. Factors contributing to seedling mortality in southern bareroot forest nurseries in 1980 and in 2012.

Factor	Percent of nurseries in 1980 (n = 51)	Percent loss in 1980 (n = 51)	Percent of nurseries in 2012 (n = 31)	Percent loss in 2012 (n = 31)
Pre-emergent damping off	14	0.58	39	0.23
Post-emergent damping off	33	1.00	71	0.42
Fusiform rust	14	0.16	3	0.01
Rhizoctonia foliar blight	—	—	29	0.12
Nematode	4	0.11	13	0.06
Animals	—	—	61	0.25
Herbicide	24	0.52	42	0.30
Insect	10	0.38	48	0.11
Birds	12	0.16	48	0.21
Hail	—	—	13	0.01
Rain splash	22	0.44	42	0.19
Nutrient deficiency	18	0.20	13	0.04
Wind	12	0.40	3	0.01
Bed washout	59	2.60	3	0.02
Drought	18	0.72	3	0.02

Source for 1980 data: Boyer and South (1984)

Figure 5. Fumigation of bareroot nursery with methyl bromide/chloropicrin under plastic. (Photo by Tom Starkey 2008)

the EPA began an incremental phaseout of methyl bromide (EPA 2014). Although the initial goal was a phaseout by 2005, allowable exemptions using the Critical Use Exemption and the Quarantine and Preshipment permitted continued use in tree nurseries. Since its beginning in the 1970s, the Nursery Cooperative researched alternatives that could be effectively substituted for methyl bromide (Starkey 2012). Although many Nursery Cooperative nurseries have participated in alternative fumigant trials, as of 2012, only 16 percent of responding managers have operationally tried an alternative fumigant.

Use of methyl bromide as the primary fumigant rose from 88 percent in 1980 to 97 percent in 2012 (Boyer and South 1984). Chloropicrin is commonly mixed with methyl bromide to act as a warning agent and to increase efficacy on soil fungi. In 1980, the most common mixture ratio was 98:2 methyl bromide:chloropicrin at an average rate of 357 lb/ac (400 kg/ha) and in 2012, 80:20 was the most common ratio applied at 364 lb/ac (408 kg/ha). During the past 32 years, the amount of methyl bromide (active ingredient) applied per nursery-acre has decreased by 17 percent. This reduction is even greater when changes in crop rotation since 1980 are considered. In addition, the total amount of methyl bromide applied on all nursery land has decreased since 1980 because of nursery closures and mergers. The net seedling loss of 480 million seedlings, discussed previously, represents approximately 775 ac (334 ha) of nursery land no longer needing fumigation. The cost of fumigation (including tarp removal), accounting for inflation, has stayed constant during the past 32 years with a 2012 cost of approximately \$2,032/ ac (\$5,021/ha). Because of changes in crop rotations, the 2012 cost per thousand seedlings is less than 1980 costs because it is now prorated across three to four crops.

Season and frequency of soil fumigation has changed during the past 32 years. In 1980, one-half of nurseries fumigated their soils after February and one-half fumigated in the fall (Boyer and South 1984). In 2012, 68 percent of southern bareroot nurseries fumigated in the fall. Fall fumigation provides a broader biological window in which fumigation can occur. During October and November, nurseries have more days in which to fumigate before the labor-intensive lifting season begins in December. Also, achieving proper soil temperatures is easier in the fall than the spring, which can be a problem in nurseries located in cooler regions. In 1980, 60 percent of nurseries fumigated a production unit every other year (Boyer and South 1984). In 2012, only 17 percent fumigated every other year, 56 percent fumigated the same production area after two seedling crops, and 27 percent fumigated after three or more seedling crops. With the cost of soil fumigation increasing, more nursery managers are considering the option of fumigating after 3 crop years.

Disease Control

Post-emergent damping off caused the greatest mortality loss in nurseries in 2012 (table 10). The percentage of nurseries reporting damping off as a major cause of mortality was nearly double for 2012 compared with 1980 yet the percent loss decreased by 58 percent from 1980 to 2012. The development of more efficacious fungicides is a primary reason for the decrease in seedling loss because of diseases since 1980.

Fusiform rust is the primary stem disease that managers in southern nurseries must address. The fungus is commonly found within a 150-mi (241-km) wide band extending from South Carolina to Texas (Enebak and Starkey 2012). Basidiospores from the rust fungus are produced in early spring to early summer, coinciding with susceptible seedling germination in the nursery. A notable change from the 1980 survey is the class of fungicides available to control fusiform rust. In 1980, 75 percent of southern nurseries applied Fermate® (ferbam). Because of its lack of rain-fastness, nurseries reportedly made up to 54 applications of Fermate® per season to control fusiform rust (Boyer and South 1984). Bayleton® (triadimefon), a relatively new fungicide in 1980 was reported to be as effective or more effective for the control of fusiform rust (Boyer and South 1984) with only four to five applications per season. In the 2012 survey, 71 percent of nurseries used Bayleton® and 29 percent used Proline® (prothioconazole), a fungicide registered in 2011, which also requires four to five applications per season (Starkey and Enebak 2011). The amount of active ingredient applied in 1980 with Fermate® was more than 4 lb/ac/yr (4.4 kg/ha/yr). With the introduction of Bayleton® the rate dropped to less than 1 lb/ac/yr (1.1 kg/ha/yr) active ingredient and 10 oz/ac/yr (0.7 kg/ha/yr) of Proline®. More efficacious fungicides have resulted in a reduction of seedling losses because of fusiform rust (table10). For example, in 1980, a nursery growing 30 million seedlings may have lost 4.8 million seedlings to fusiform rust whereas in 2012, that same nursery, using better fungicides, may have reduced the loss to 300,000 seedlings.

Other diseases addressed less frequently in nurseries are *Rhizoctonia* foliar blight, pitch canker, and tip blight. A total of 27 fungicides were used to control various seedling foliage, stem, and root diseases in 2012 including Cleary 3336F®, (thiophanate-methyl), Bravo® (chlorothalonil), Chipco 26019® (iprodione), and Banner Maxx® (propiconazole).

Insect Control

Nurseries reported annual losses because of insects to be less than 1 percent in 2012, which is less than the 1 to 2 percent reported in the 1980 survey (Boyer and South 1984). Most of the seedlings reported damaged by insects in 2012 (25 percent) were attributed to the tarnished plant bug (*Lygus lineolaris* Miridae and/or *Taylorilygus* spp.). Losses from these insects were not recognized as a problem before 1982 (South 1991). Southern bareroot forest nurseries commonly use Asana® (esfenvalerate) and permethrin-based insecticides to control insects.

Weed Control

Many of the same troublesome weeds appear on the 1980 and 2012 surveys (table 11). The prevalence of certain weed species, however, has changed dramatically during the past 32 years. In 1980, only one nursery mentioned spurge (*Euphorbia* spp.) as a troublesome weed (Boyer and South 1984). In 2012, spurge was mentioned by 22 nurseries (65 percent) (table 11) and considered the most troublesome weed by 19 percent of managers. Managers listed yellow nutsedge (*Cyperus esculentus* L.) and purple nutsedge (*C. rotundus* L.) as troublesome weeds in both 1980 and 2012, although the percentage that indicated nutsedge was the most troublesome weed has decreased since 1980 (table 11). This decrease in "troublesomeness" may be attributed to aggressive weed control during the crop and cover/fallow periods. This approach has been called the "24/7 weed management program" (South 2009).

Table 11. Most troublesome weeds in southern bareroot forest nurseries reported in 1980 and 2012. Some managers listed more than one species.

Weed	Scientific name (genera)	Percent of nurseries in 1980 (n = 47)	Percent of nurseries in 2012 (n = 31)
Crabgrass	*Digitaria*	64	12
Nutsedge	*Cyperus*	62	44
Bermuda grass	*Cynodon*	36	6
Purslane	*Portulaca*	30	—
Morning glory	*Ipomoea*	28	35
Sicklepod	*Arabis*	23	18
Goose grass	*Acrachne*	23	3
Carpetweed	*Mollugo*	17	
Fennel	*Eupatorium*	13	3
Clover	*Dalea* spp.	6	3
Barnyardgrass	*Echinochloa*	6	—
Florida pusley	*Richardia*	4	—
Broomsedge	*Carex; Andropogon*	4	—
Cocklebur	*Xanthium*	4	—
Crowfoot grass	*Dactyloctenium*	4	—
Flathead sedge	*Cyperus*	4	12
Spurge	*Euphorbia*	2	65
Coffee weed	*Senna*	—	15
Water weed	*Eclipta*	—	6
Willow	*Salix*	—	9
Other	—	40	32

Source for 1980 data: Boyer and South (1984)

The most common source of weed seed in 1980 was windblown seed from adjacent areas and mulch used to cover recently sown nursery beds (Boyer and South 1984). In 2012, 82 percent of nurseries reported windblown seed as the most common source of weed seeds followed by irrigation water and mulch. Nursery Cooperative members also cite "lack of chemical efficacy" as a common weed control issue. The lack of chemical efficacy can sometimes be attributed to mixing chemicals with hard water that can tie-up the active ingredients in some herbicides or the use of off-patent chemicals. In 1980, nurseries were still transitioning from the widespread use of mineral spirits to herbicides such as Goal® (oxyfluorfen) and Roundup® (glyphosate). The availability of off-patent herbicides was minimal in 1980. Manufacturers of off-patent pesticides must formulate the inert-ingredient composition resulting in variation among companies and differences in efficacy compared with the original chemical formulation (Capuzzi 2010).

In 1980, 73 percent of nurseries surveyed used Goal® (oxyfluorfen) (table 12) (Boyer and South 1984) and in 2012, 100 percent nurseries used Goal 2XL® (oxyfluorfen). GoalTender® (oxyfluorfen) is a different formulation than Goal 2XL® and allows its application to seedlings earlier after sowing than Goal 2XL®. The Nursery Cooperative has encouraged the use of GoalTender® among members to control weeds early in the growing season before they become established (South et al. 2004). In the 2012 survey, only Nursery Cooperative members used GoalTender®. In 2012, more than one-half (55 percent) of nurseries used shielded sprayers to apply herbicides (primarily in hardwood weed control) and 29 percent used wick-wiper herbicide applicators.

Table 12. Herbicides used in southern barefoot forest nurseries in 2012. Managers listed more than one herbicide.

Herbicide	Percent of nurseries (n = 33)
Goal®	100
GoalTender®	36
Cobra®	58
Sethoxydin	45
Reflex®	29
Fusilade®	21
Others	42

Lift, Pack, and Ship

In 2012, 62 percent of nursery respondents machine lifted their seedlings and 38 percent hand lifted their seedlings (figure 6). In 1980, only 38 percent of nurseries used machine lifting (Boyer and South 1984). The J.E Love Company's (Garfield, WA) full-bed belt lifter is used by more than three-fourths of southern bareroot forest nurseries that use a full-bed belt lifter. More than 75 percent of managers pack their seedling in a packing shed while the rest pack their seedlings in the field. Managers who use a packing shed cull large, small, or deformed seedlings before packing. It is more difficult to cull seedlings during field packing and therefore managers strive to produce a uniform seedling crop to minimize the cull percentage.

Although not specified in the 1980 survey, clay slurries were frequently used to coat seedling roots before shipping. This practice reportedly protected seedling roots before planting (Hamner and Broerman 1967). During the 1980s, managers adopted the operational use of polyacrylamide gels to protect roots because of (1) lower cost, (2) less storage space, and (3) less mess compared with clay. In 2012, 70 percent of managers used polyacrylamide gels while 24 percent still used clay slurries. In 1980, nursery managers most frequently packed

Figure 6. Methods used to lift seedlings for shipping in southern bareroot nurseries include (A) hand lifting seedlings that have been loosened using a Fobro® seedling lifter and (B) machine lifting with a Love® full-bed belt lifter and seedling transport wagon. (Photos by Tom Starkey 2014 and 2011)

seedlings in bundles—seedling root systems were placed on a large piece of wax-coated Kraft paper, rolled, and strapped with a stick to facilitate carrying and lifting. This packing method kept seedling roots protected, but left foliage exposed. In 2012, only 21 percent of nurseries packed seedlings exclusively in bundles while 44 percent packed seedlings in closed bags exclusively, 6 percent used boxes exclusively, and 29 percent packed seedlings in boxes or bags depending on customer requests.

In the Southern United States, most seedlings are lifted from December to February. The accumulated chilling hours is commonly monitored by nursery managers. Although chilling is directly related to freeze tolerance, the relationship between chilling hours and long-term storability of seedlings has not been established (South 2013). In 2012, 67 percent of nursery respondents monitored chilling hours (32 to 46 ° F [0 to 8 ºC]). The minimum chilling reported for storing bareroot pine seedlings for less than 1 week was 182 hours. Many managers desire about 400 chilling hours when storing loblolly pine seedlings for 4 weeks or more. When lifting seedlings before the end of December, 54 percent of managers hold seedlings less than 1 week in cool storage and 46 percent store for less than 2 weeks. When seedlings are lifted after December 31, nearly 35 percent of managers are comfortable storing them longer than 3 weeks and the remaining 65 percent try to ship seedlings as soon after lifting as possible.

In the Southern United States, seedlings in the nursery bed continue to grow during the winter months (December to February), increasing in both RCD and root biomass. Seedling shoot height does not change during the winter months and remains relatively constant until bud break in late winter. In 2012, the average reported target RCD for loblolly pine shipped in late November is 0.18 in (4.6 mm) while a loblolly pine shipped in February has a target RCD of 0.22 in (5.5 mm). Target seedling size was not reported in the 1980 survey.

Labor

Although not part of the 1980 survey, most nonpermanent nursery labor in 1980 was local labor. In 2012, nursery managers reported that their current labor sources include (1) permanent employees; (2) part-time local labor, including U.S. nationals and legal foreign nationals; (3) migrant labor, including H1A and H2B workers; and (4) prison labor (table 13). Permanent employees were reported to be the primary source of labor for the sowing operation because of the precision and attention to detail required at this critical stage of seedling production and because a large labor force is not needed. Permanent labor is also the primary source of labor during the summer months (June to August) when hand weeding is the major activity. During the lifting season, migrant labor is the major labor source used to lift, sort, and package seedlings. Nurseries indicated that 75 percent of their total temporary labor budget is used during shipping season. This use of temporary labor has not changed during the past 3 years for 90 percent of the nurseries.

Table 13. Sources of labor used in southern bareroot forest nurseries in 2012.

Labor[1]	Nursery Activity (n = 34)		
	Percent of nurseries		
	Sowing	Summer	Lifting
Permanent	81	74	68
Local	55	61	61
Migrant	19	23	65
Prison	10	16	16

Permanent = full-time employees. Local = includes U.S. nationals and legal foreign nationals. Migrant = includes H1A and H2B labor, etc.
[1] More than one labor source was listed for most nurseries.

Managers' top concerns about temporary labor were (1) availability, (2) cost, and (3) consistent attendance. From 2008 to 2011, 48 percent of those surveyed reported labor cost increases of about 8 percent. These concerns, along with changes in labor laws, create uncertainty for nurseries as well as their customers.

Summary

Surveys of this type are important as they document changes in specific cultural activities and development of new equipment, technology, and pesticides. Documenting changes in government regulations can also explain shifts in nursery production. When Abbott (1956) began the first of several surveys of bareroot nursery practices, he established the importance of tracking seedling production and practices in the United States. The survey by Boyer and South (1984) was the most significant because it focused on the Southern Region of the United States where most seedlings are produced. Surveys such as the one presented in this paper and the 1984 survey should be conducted every 10 years.

When the Nursery Cooperative began in 1972, research efforts were directed toward pest management, especially weed control. Although great strides have occurred in this area, new pesticides are still a need. Registering new pesticides has become more difficult in recent years. Government regulations for new pesticides and the failure to reregister current pesticides have reduced the number of pesticides available to nursery managers. Furthermore, chemical companies are reluctant to register new products for a crop, which is grown regionwide on less than 2,000 ac (809 ha).

Advances in seedling production in the future will likely occur as a result of practices that improve seed efficiency and seedling quality. Opportunities exist for cultural activities and changes in the lifting operation that minimize loss of roots during lifting. Improvements in seedling quality uniformity and seedling nutrition at outplanting will help in establishment of seedling plantations. Opportunities exist for advances in seed treatment, seed stratification, and early seed establishment. Biological pesticides and fertilizers are finding widespread use in agronomy and horticulture and may also have applications in bareroot seedling production.

Address correspondence to—

Tom E. Starkey, Southern Forest Nursery Management Cooperative, Auburn University, School of Forestry and Wildlife Sciences, 602 Duncan Drive, Auburn, AL 36849; e-mail: tom.starkey@auburn.edu; phone: 334–844–8069.

Acknowledgments

The USDA Forest Service, Region 8 Cooperative Forestry, Atlanta, GA, provided funds for this survey. The authors thank Stan Bartkowiak, Jeff Chieppa, Joe Clark, Rachel Conley and Ferhat Kara for their assistance in summarizing the survey data.

REFERENCES

Abbott, H.G. 1956. Forestry tree nursery practices. American Nurseryman. 103(6): 17–18, 130–134.

Abbott, L.G.; Eliason, E.J. 1968. Forest tree nursery practices in the United States. Journal of Forestry. 66: 704–711.

Abbott, L.G.; Fitch, S.D. 1977. Forest tree nursery practices in the United States. Journal of Forestry. 75: 141–145.

Boyer, J.N.; South D.B. 1984. Forest nursery practices in the South. Southern Journal of Applied Forestry. 8: 67–75.

Boyer, J.N.; South, D.B.; Muller, C.A.; Vanderveer, H. 1985. A comparison of nursery sowers. Tree Planters' Notes. 36(3): 20–24.

Capuzzi, G. 2010. Not all pesticide formulations are created equal. Greenhouse Management and Production. 30(2): 30–31.

Cram, M.M.; Fraedrich, S.W. 2009 Stunt nematode (*Tylenchorhynchus claytoni*) impact on southern pine seedlings and response to a field test of cover crops. In Dumroese, R.K.; Riley, L.E., tech. coords. National proceedings, forest and conservation nursery associations—2008. Proc. RMRS-P-58. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 95–100.

Enebak, S.A. 2012. Forest tree seedling production in the South for the 2011–2012 planting season. Tech. Note 2012-01. Auburn University Southern Forest Nursery Management Cooperative. 10 p.

Enebak, S.A.; Starkey, T. 2012. Fusiform rust. In Cram, M.M.; Frank, M.S.; Mallams, K.M., tech. coords. Forest nursery pests, Agriculture Handbook 680. Washington, DC: U.S. Department of Agriculture, Forest Service: 41–44.

Environmental Protection Agency (EPA). 2014. The phaseout of methyl bromide. http://www.epa.gov/ozone/mbr. (May 2014).

Grossnickle, S.C.; Pait, J. 2008. Somatic embryogenesis tissue culture for applying varietal forestry to conifer species. In Dumroese, R.K.; Riley, L.E., tech. coords. National proceedings: forest and conservation nursery associations—2007. Proc. RMRS-P-57. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 135–139.

Hamner, J.C.; Broerman, F.S. 1967. A comparison of three packaging methods for slash pine. Tree Planters' Notes. 18(4): 3–4.

Harper, R.A.; Hernández, G.; Arseneault, J.; Bryntesen, M.; Enebak, S.; Overton, R.P. 2013. Forest nursery seedling production in the United States—fiscal year 2012. Tree Planters' Notes. 56(2): 72–75.

May, J.T. 1984. Soil moisture. In Lantz, C.W., ed. Southern pine nursery handbook. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region: Chapter 11. 19 p.

Sharp, D. 2014. Personal communication. Plum Creek, Brunswick, GA.

South, D.B. 1991. Lygus bugs: a worldwide problem in conifer nurseries. In Sutherland, J.R.; Glover, S.G., eds. Proc. 1st IUFRO workshop on diseases and insects in forest nurseries. Info. Rep. BC-X-331. Victoria, British Columbia, Canada: Forestry Canada: 215–222.

South, D.B. 2009. A century of progress in weed control in hardwood seedbeds. In Dumroese, R.K.; Riley, L.E., tech. coords. National proceedings: forest and conservation nursery associations—2008. Proc. RMRS-P-58. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 80–84.

South, D.B. 2013. Chilling hours: myths and facts. In Haase, D.L.; Pinto, J.R.; Wilkinson, K.M., tech. coords. National proceedings, forest and conservation nursery associations—2012. Proc. RMRS-P-69. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 3–10.

South, D.B. 2014. Personal communication. Pickens, SC.

South, D.B.; Davey, C.B. 1983. The southern forest nursery soil testing program. Circular 265. Auburn, AL: Auburn University, Alabama Agricultural Experiment Station. 38 p.

South, D.B.; Donald, G.M. 2002. Effect of nursery conditioning treatments and fall fertilization on survival and early growth of *Pinus taeda* seedlings in Alabama, U.S.A. Canadian Journal of Forest Research. 32(7): 1171–1179.

South, D.B.; VanderSchaaf, C.L.; Hill, T. 2004. Trials with a new formulation of oxyfluoren. Res. Rep. 2004-04. Auburn, AL: Auburn University, Southern Forest Nursery Management Cooperative. 5 p.

Starkey, T.E. 2012. The history and future of methyl bromide alternatives in the Southern United States. In Haase, D.L.; Pinto, J.R.; Riley, L.E., tech. coords. National proceedings, forest and conservation nursery associations—2011. Proc. RMRS-P-68. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 31–35.

Starkey, T.E.; Enebak, S.A. 2011. The use of Proline® (prothioconazole) to control pitch canker, Rhizoctonia foliage blight, and fusiform rust in forest seedling nurseries and efforts to acquire registration. In Riley, L.E.; Haase, D.L.; Pinto, J.R., tech. coords. National proceedings, forest and conservation nursery associations—2010. Proc. RMRS-P-65. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 49–57.

Tillotson, C.R. 1917. Nursery practice on the national forests. Bull. 479. Washington, DC: U.S. Department of Agriculture. 86 p.

Tuffour, H.O.; Yeboah, I.B.; Bonsu, M.; Adjei-Gyapong, T.; Khalid, A.A.; Abubakar, A.; Melenya, C.; Kpotor, P. 2014. Soil organic carbon: relating the Walkley-Black wet oxidation method to loss on ignition and clay content. International Journal of Scientific Research in Knowledge. 2(5): 249–256.

Wakeley, P.C. 1935. Artificial reforestation in the southern pine region. Tech. Bull. 492. Washington, DC: U. S. Department of Agriculture. 115 p.

Weatherly, C. 2014. Personal communication. Fred C. Gragg SuperTree Nursery, Bluff City, AR.