2008 Interim Guidelines for Growing Longleaf Pine Seedlings in Container Nurseries

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Abstract: Production of container longleaf pine (*Pinus palustris*) seedlings for reforestation and restoration plantings exceeds that of bareroot production, but information on container production techniques has been slow to develop. Because success of those outplantings requires quality seedlings, interim guidelines were proposed in 2002 to assist nursery managers and tree planters in developing and using the best stock possible. The guidelines were intended to be updated as new information was generated. During the past 6 years, additional studies have confirmed most provisions of the interim guidelines, except that presence of buds (number and color) as originally described in the guidelines does not appear to be a useful metric. In addition, some new parameters have been added. This report synthesizes that new information and revised guidelines are presented.

Keywords: root-collar diameter, clipping, root development

Introduction

Longleaf pine (*Pinus palustris*) forests once were a dominant ecosystem across the southeastern United States, but intense harvesting during the past century reduced this forest type from nearly 36 million ha (90 million ac) to about 800,000 ha (2 million ac) (Noss and others 1995; Outcalt 2000; Barnett 2002; Shibu and others 2006). Restoration of this forest type has been encouraged by federal incentive programs (Hainds 2002) and because survival and growth of container longleaf pine is often better after outplanting (Boyer 1989; Barnett and McGilvray 1997; South and others 2005), use of this stocktype has increased dramatically. In 2008, about 64 million container seedlings were produced compared to about 12 million bareroot seedlings (Longleaf Alliance data).

Despite demand for container longleaf pine, very little detailed research exists concerning the production of this relatively new stocktype. This information gap led to a major problem, that is, an absence of container seedling standards and subsequent variation in stock quality (Hainds 2004). Although stock quality can be described in the nursery, what really matters is how well it performs on the outplanting site (Landis and Dumroese 2006). Plants characterized as "poor" in the nursery may perform well in the field if site factors are favorable (for example, proper site preparation, planting techniques, weed control, and/or ample precipitation). On the other hand, "high" quality plants may do poorly if those same factors are poorly done or precipitation is below normal. Even with the existing information gaps, Barnett and others (2002a,b) published interim guidelines to help growers "zero-in" on container types and seedling quality attributes for growing longleaf pine seedlings in containers. These guidelines were generated based on the limited research results, experience of growers, and the expertise of regional specialists with the intention that they would be revised as new information became available.

Since 2002, some additional studies have been completed or are in the final stages of completion. Although most of these projects have not yet been vetted by the scientific community through refereed journal publications, we feel that some of the

information gleaned from them can be used to update the interim guidelines. Some preliminary results of this work include Dumroese and others (2005), Hainds and Barnett (2006), Jackson (2006), Jackson and others (2007), and Jackson and others (forthcoming).

2002 Interim Guidelines

The 2002 interim guidelines focused on needles, roots, root-collar diameter (RCD), buds, container size, and other important attributes, such as presence of "sondereggers" (Barnett and others 2002a,b). For each parameter, we summarize the "2002 interim guideline" as published in Barnett and others (2002a), describe the "rationale" behind each original guideline, and provide a "2008 update" that synthesizes new information that collaborates or refines the 2002 guidelines.

Needles

2002 Interim Guideline—If clipped, needles should be 15 to 25 cm (6 to 10 in) long, but not less than 10 cm (4 in). If not clipped, needles should be 20 to 30 cm (8 to 12 in) long. The appearance of many fascicles is preferred, and needles should have a pale to dark green color.

Rationale—Barnett (1984) showed that repeated clipping of longleaf needles to maintain a length of 5 cm (2 in) reduced RCD, shoot weight, and root weight during nursery production, but seedlings given single or multiple clippings to maintain a needle length of 25 cm (10 in) were similar to their non-clipped cohorts. In addition, survival of seedlings clipped to maintain the 5-cm (2-in) length was poorer under higher levels of moisture stress than seedlings with longer needles. Barnett (1984) also reported that seedlings clipped once to 25 cm (10 in) immediately before outplanting under severe moisture stress conditions survived better than control seedlings and seedlings clipped too frequently. These results are similar to the conclusions of South (1998) who noted that clipping needles of bareroot seedlings improved survival, presumably because of reduced transpiration on sites where seedlings are under significant moisture stress. Clipping needles in the nursery can prevent their lodging and reduce subsequent susceptibility to disease by improving air circulation, reducing humidity levels, and allowing more uniform irrigation. Poor irrigation uniformity leads to overwatering and can increase root disease (Enebak and Carey 2002). Barnett (1989) found that seedlings grown in shade during nursery production were much smaller and suggested that clipping could allow more uniform light exposure (Barnett 1984). Seedlings with fascicles are preferred; Wakeley (1954) and Barnett (1980) reported that seedlings with fascicles perform better after outplanting. A healthy "green" color is indicative of proper nutrient status, rather than the "yellow" (chlorotic) foliage resulting from nutrient deficiencies.

2008 Update—To our knowledge, no new work has been published on clipping. However, we found that needle length of container seedlings is a function of nitrogen fertilizer rate (Jackson 2006; Jackson and others 2007). We also determined that a rate of 2 to 3 mg nitrogen/seedling/week for 20 weeks produced seedlings in Ropak® Multipot #3-96® containers (depth = 12 cm [4.8 in]; volume = 98 cm^3 [6 in^3]; density = 441 per m^2 [41 per ft^2]) with needles within the original interim guidelines without the need for clipping. After outplanting, these seedlings survived and grew well (Jackson 2006; Jackson and others 2007). Seedlings given 4 mg nitrogen/week for 20 weeks had needles that would have required clipping under operational conditions to prevent lodging (we did not clip them, however, in the experiment); no additional benefit in terms of seedling survival or growth was noted for this stocktype. It should be noted that many other fertilizer regimes appear to produce longleaf seedlings without the need for clipping (Dumroese and others 2005). It may be, however, that nutrient loading longleaf pine seedlings in the nursery (Hinesley and Maki 1980; Dumroese 2003) in concert with clipping may improve outplanting performance, particularly because of unpublished work conducted at Auburn University. Researchers there found that clipping longleaf pine seedlings to 20 cm (8 in) reduced water loss in a greenhouse during the first 4 days after clipping (South 2008). This short-term affect may be beneficial to outplanting performance.

Roots

2002 Interim Guideline—RCD, measured at the base of the needles, should be 6.35 mm (0.25 in) or more, and no less than 4.75 mm (0.19 in). Roots should be light brown in color with white root tips, free of disease symptoms, and without circling. Presence of mycorrhizae is encouraged.

Rationale—Because longleaf pine seedlings generally exit the grass stage when their RCDs are about 25 mm (1 in) (Wahlenberg 1946), obtaining large RCDs in the nursery could shorten the grass stage after outplanting. In addition, larger RCDs are associated with better survival of bareroot stock (White 1981). The minimum value was based on observations that seedlings with less than 4.75 mm (0.19 in) diameter grown in Ropak® Multipot #6-45® containers (described below) were "floppy" and had reduced survival. ("Floppy" seedlings, when held horizontally by the terminal bud, "flopped" over because of insufficient development of roots within the root plug [Hainds and Barnett 2004, 2006]). Light brown roots with white root tips indicate a healthy root system and show potential for new root development. Black roots require close scrutiny, particularly if a large portion of the root system is black, because they are likely diseased. Presence of mycorrhizae indicates a healthy root system, but applying inoculant is usually unnecessary because windborne spores typically inoculate seedlings naturally (Barnett and Brissette 1986).

2008 Update—In general, the recommendation for RCDs greater than 4.75 mm (0.19 in) for typical 100 cm^3 (6 in^3) containers seems acceptable. In this stocktype, we note that most fertilizer regimes produce seedlings above this threshold (Jackson 2006; Jackson and others 2007). Seedlings below this threshold have reduced survival (Hainds and Barnett 2004, 2006), and it appears that seedlings with increasing RCDs have increasingly better performance in terms of reduced time in the grass stage (Jackson and others 2007, forthcoming). South and others (2005) report a critical threshold of 5.5 mm (0.22 in); seedlings with lower RCDs

had poorer survival across a variety of sites than those with greater RCDs. Recent work shows, however, that RCD cannot be increased indefinitely without a decline in survival and growth—when the ratio of RCD to the diameter of the growing container (the Root Bound Index [RBI]) was greater than 27%, seedling survival was compromised (fig. 1) (South and others 2005; South and Mitchell 2006). Our observation is that this critical threshold may be difficult to achieve in a 20- to 30-week growing cycle for seedlings in Ropak® Multipot #3-96® containers, but, as Salonius and others (2002) point out, could be easily achieved when seedlings are grown too long in the containers, or "held over" in the nursery in anticipation of being sold the following year.

Most typical, commercially available containers used for reforestation have design features to prevent root circling. Some containers are treated with copper to prevent root spiraling, which also prevents lateral roots from growing downward on the exterior of the plug and forming a "birdcage," and this treatment was associated with changes in root system morphology, shoot and root biomass (Barnett and McGilvray 2002), and root growth potential (South and others 2005). In general, these seedlings are easier to extract from containers, especially those made of Styrofoam™, and fresh copper on container walls decreases the level of potential disease inoculum (Dumroese and others 2002). Copper-coated containers yield seedlings with better, more uniform root distribution higher on the initial root plug, which is believed to improve resistance to windthrow (Burdett 1978; Burdett and others 1986). Neither South and others (2005) nor Sung and others (forthcoming) noted any short-term benefit, in terms of survival or growth, from growing seedlings in copper-treated containers.

Tinus and others (2002) determined that exposing longleaf roots to temperatures below –4 °C (25 °F) caused significant damage. South (2006) reports damage is more severe if that temperature is achieved before seedlings have acclimated to cold temperatures (early winter), or the frost is preceded by warm temperatures that cause deacclimation of seedling tissues to cold.

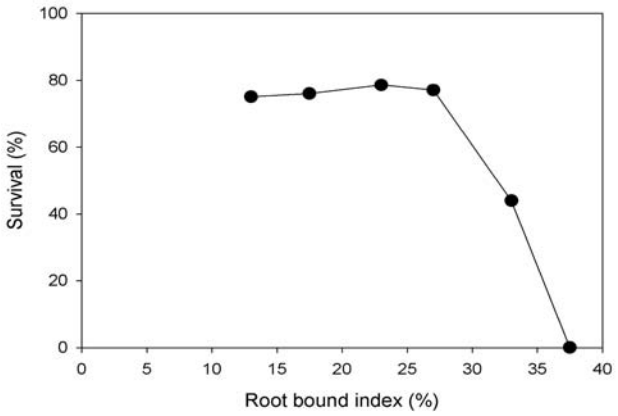

Figure 1. Effect of the root bound index (RCD/cell diameter) on second-year survival of container longleaf pine seedlings (South and others 2005).

Buds

2002 Interim Guideline—Buds should be present on 90% of the crop. Seedlings outplanted in late October or early November are more likely to have green buds, whereas seedlings outplanted in late December or January are more likely to have brown buds. Brown buds are thought to be more mature, but outplanting should not be delayed to obtain better bud development.

Rationale—Personal observations of quality seedling crops grown during a variety of research projects indicated that seedlings at the end of the growing cycle in late fall had a cessation of needle growth, hardening of tissue, and formation of notable, green, terminal buds, which then became brown during winter.

2008 Update—Early researchers noted that longleaf pine seedlings in the grass stage exhibit a progression of bud types (Pessin 1939; Wahlenberg 1946). Wakeley (1954) noted that bud status during a single growing season changed as terminal buds formed, opened, re-formed, and re-opened. We have observed development of the apex during several studies and have attempted some quantification. Attempting to use the bud descriptions (pincushion, round, and elongated) of Pessin (1939), Wahlenberg (1946), and Wakeley (1954) during nursery production has been problematic, as nursery stock shows a wide variation in apex characters not necessarily meeting those descriptions. Jackson (2006) found that increasing rates of fertilizer resulted in larger, more robust buds. At deficient nitrogen rates, buds were small and brownish, whereas seedlings given high doses of nitrogen had larger, green buds. In another trial, we observed that frequency of terminal buds varied by month, generally increasing from September through December and then decreasing dramatically in January (fig. 2). In another study, more than 90% of the crop still had firm terminal buds in January. Larson (2002) points out that dormant buds may be difficult to see. Therefore, additional quantification, and perhaps a new framework for describing/measuring bud development during nursery culture, would help identify if, and what, the effect of differing bud/apex condition on longleaf pine seedling quality might be. Because we have outplanted groups of longleaf pine seedlings with wide variation in the presence of terminal buds (ranging from 20% [Jackson and others 2007] to 100% [fig. 2]), and survival and growth have been similar, it appears that the bud criteria in the 2002 guidelines does not appear to be useful.

Container Size

2002 Interim Guideline—Container diameter should be no less than 25 mm (1 in), with 38 mm (1.5 in) or greater desired. Container depth should be no less than 9 cm (3.5 in), with 11.5 cm (4.5 in) or more preferred. Container volume should be no less than 90 cm^3 (5.5 in^3), with 100 cm^3 (6 in^3) or more recommended.

Rationale—The guidelines were based on observations from a variety of studies (Barnett 1974, 1984, 1988, 1991; Amidon and others 1982; Barnett and McGilvray 1997).

2008 Update—Since the interim guidelines were published, most of our work has focused on seedlings grown in

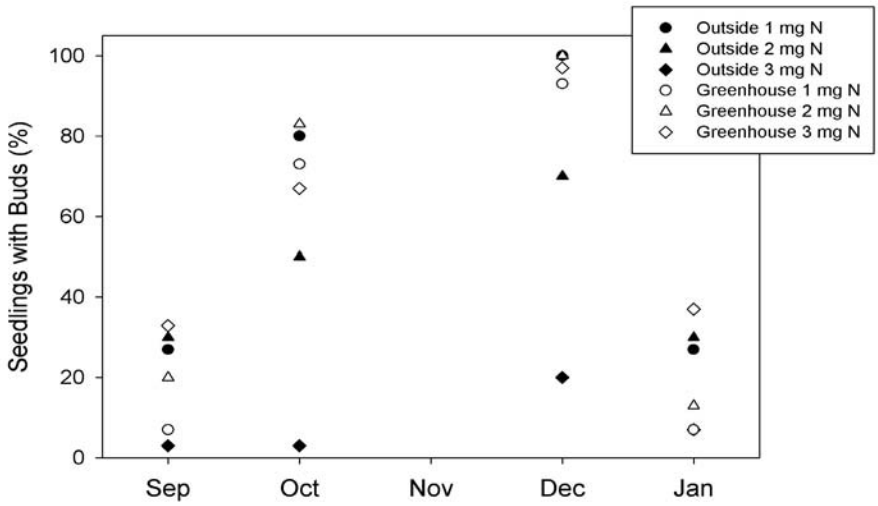

Figure 2. Bud occurrence from September through January for longleaf pine seedlings in a recent fertilizer trial completed by the authors. Although no pattern was observed between seedlings grown in a greenhouse or outside, or among three levels of nitrogen fertilizer, pooled data showed that buds formed from September, with most of the crop having discernable terminal buds in December, followed by an opening of terminal buds in January.

Ropak® Multipot #3-96® (Jackson 2006; Jackson and others 2007, forthcoming) or Ropak® Multipot #6-45® (Dumroese and others 2005) containers. The Multipot #6-45® is the same as the Multipot #3-96® described above except seedlings are grown at a higher density (581 per m^2 [54 per ft^2]). Seedlings grown in Ropak® Multipot #3-96® containers have been evaluated up to 3 years in the field; preliminary data shows excellent survival and growth (Jackson and others 2007, forthcoming). South and others (2005) evaluated six different container types of various materials, ranging in depth from 6.5 to 15 cm (2.6 to 6 in) and volume from 60 to 120 cm^3 (4 to 6 in^3), outplanted on four field sites. They concluded that container type (Styrofoam™, hard plastic, or mesh) may not affect survival on easy-to-regenerate sites, but mesh-type containers (such as Jiffy pellets) performed poorer than Styrofoam™ and hard plastic containers, which had characteristics consistent with the original guidelines. Sung and others (forthcoming) found reduced survival, height growth, and exit from the grass stage for seedlings grown in small volume (54 cm^3 [4 in^3]) containers compared to larger cohorts. A study examining a wider range of container sizes (60 to 340 cm^3 [4 to 20 in^3]) was outplanted on the USDA Forest Service Palustris Experimental Forest (Louisiana) in December 2008.

Other Important Attributes

2002 Interim Guideline—Root plugs should remain intact (no loss of medium) when extracted and during handling, and they should always be moist. Seedlings should lack competing weeds and insect pests. The nursery manager and the buyer should agree whether to cull sonderegger seedlings.

Rationale—Firm root plugs indicate good root development and seedlings with firm plugs and appropriate RCD for the container diameter are not "floppy," as described in the "roots" section. Furthermore, firm plugs facilitate handling in the nursery and outplanting because they do not fall apart, and losing a portion of the root plug during the process of extraction through outplanting was associated with a decrease in survival and subsequent growth in a conifer species (Tinus 1974). Moisture held in the growing medium prevents root desiccation. A seedling sharing its container with a competing weed has less access to nutrients and water, resulting in reduced growth (Pessin and Chapman 1944). Seedlings that begin height growth during nursery production are usually sonderegger pines (*Pinus* X *sondereggeri*), a naturally occurring hybrid of longleaf and loblolly (*P. taeda*) pines (Little 1979). These seedlings produce poorly formed trees in plantations and are less desirable than longleaf pine.

2008 Update—Many growers irrigate their seedlings just prior to extraction (Dumroese and Barnett 2004). Seedlings may be hot-planted (no or very limited storage) or cooler stored for a week to a few months (Dumroese and Barnett 2004). Regardless, having moist plugs when shipped to the field is important. This may be especially true for seedlings hot-planted during the April through October planting window because these seedlings likely have more exposure to greater vapor pressure deficits than seedlings hot-planted, or outplanted after cooler storage, during the relatively mild "winter" season. Luoranen and others (2004) found that mortality of silver birch (*Betula pendula*) increased with decreasing plug moisture content; rate of mortality with decreasing plug moisture was greatest on dry sites. More detailed observations by Hainds and Barnett (2006) suggest that seedlings with as much as 10 cm (4 in) of height growth in the nursery may not necessarily be sonderegger pines. This may complicate identification of hybrid seedlings in the nursery; as always, the best solution is for the grower and the buyer to communicate about this beforehand.

Not discussed in the original guidelines were "double seedlings," two seedlings growing in a single container. During nursery production, a "single" seedling can have twice the dry weight of a "double" seedling (Brissette and Barnett 1989), which affects outplanting performance. After outplanting, Brissette and Barnett (1989) showed that survival was greatly reduced when two or three seedlings occupied the same container (fig. 3A), and Hainds and Barnett (2006) report that height growth was also diminished (fig. 3B).

Summary

Results from recent studies confirm that most of the recommendations made when the 2002 interim guidelines were developed are still sound (table 1). The main exception is related to the presence of terminal buds and its effect on outplanting performance. Additional information regarding "floppy" seedlings, double seedlings, and classification of sonderegger pines has also been included.

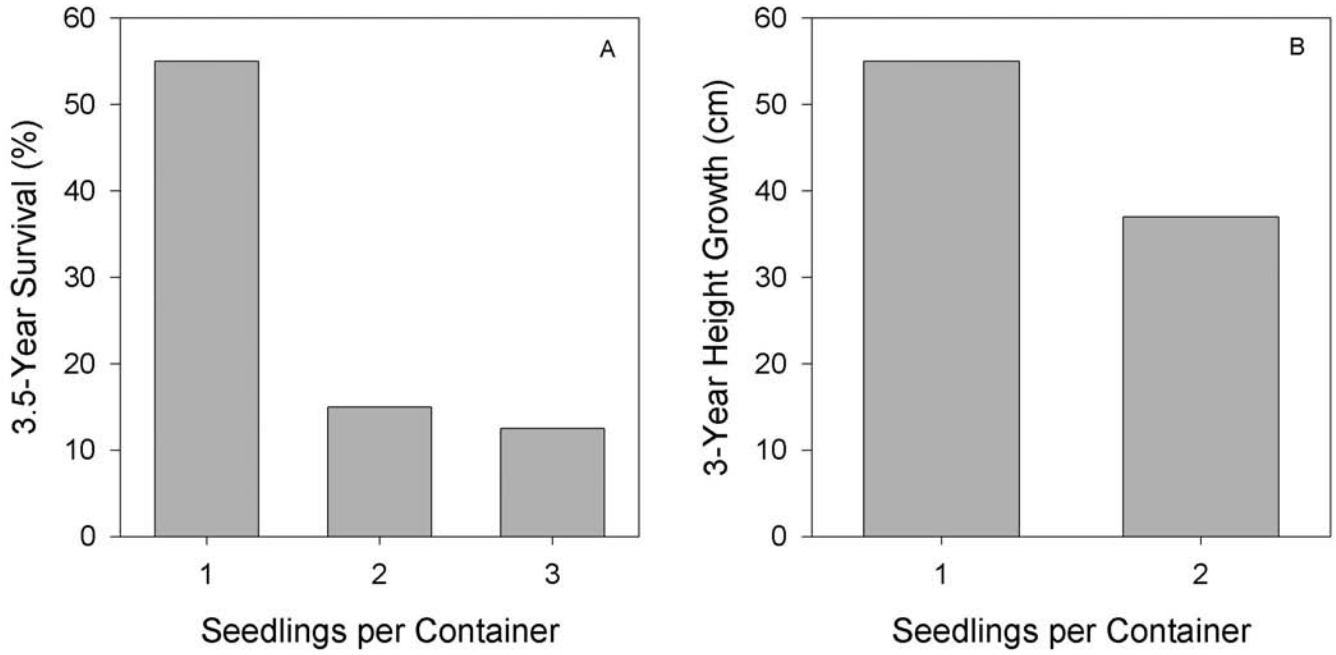

Figure 3. (A) Survival of longleaf pine seedlings decreases when multiple seedlings exist within a single container (Brissette and Barnett 1989). (B) Height growth of seedlings at Samson Site Alabama (see Hainds and Barnett 2006 for more details). "Double" had 2 seedlings growing within the same container. Note: This figure was presented incorrectly in Hainds and Barnett (2006).

Table 1. The 2008 interim guidelines for nursery production of longleaf pine seedlings.

Needles	Needles should be 15 to 30 cm (6 to 12 in) long, and not less than 10 cm (4 in). Needles should have a "medium to dark" green color. Avoid yellow or brown seedlings.
Roots	Root-collar diameter, measured at the base of the needles, should be no less than 4.75 mm (0.19 in). Larger RCDs are encouraged as long as the ratio of seedling RCD to container diameter is less than 27% to avoid root binding. Roots should be light brown in color with white root tips, free of disease symptoms, and without circling. Cambium at or near the root-collar should be whitish or greenish, never orange or brown. Plugs should be firm and moist and stay intact during extraction and outplanting. Avoid "floppy" seedlings—these seedlings, when held by the terminal horizontally, bend or flop, unable to maintain a straight horizontal alignment.
Buds	May or may not be present.
Container size	Diameter ≥ 25 mm (1 in), with 38 mm (1.5 in) or greater desired. Depth ≥ 9 cm (3.5 in), with 11.5 cm (4.5 in) or more preferred. Volume ≥ 90 cm^3 (5.5 in^3), with 100 cm^3 (6 in^3) or more recommended.
Other important attributes	Seedlings should be free of weeds and insects. Avoid multiple seedlings within a single container. Sonderegger pines retained or removed pending decision by grower and buyer in agreement.

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