Copper Root Pruning and Container Cavity Size Influence Longleaf Pine Growth through Five Growing Seasons

James D. Haywood, Shi-Jean Susana Sung, and Mary Anne Sword Sayer

ABSTRACT

Restoring longleaf pine (*Pinus palustris* Mill.) over much of its historic range requires artificial regeneration, and most often, container-grown seedlings are used. However, type and size of container can influence field performance. In this study, longleaf pine seedlings were grown in Beaver Plastics Styroblocks either without a copper treatment (Superblock) or with a copper oxychloride coating (Copperblock) and with three sizes of cavities that were 60, 108, and 164 ml. Seedlings from the six container types (two types of Styroblocks with three cavity sizes) were planted in central Louisiana in a 2 by 3 randomized complete block factorial design. Emergence from the grass stage was quickest for seedlings outplanted from either Copperblocks or large cavities (164 ml), but 99.3% of all seedlings had emerged after five growing seasons. Five-year-old trees outplanted from Copperblocks were significantly taller and had greater volume index (VI = [groundline diameter]^2 × [total height]) than trees outplanted from Superblocks (2.0 m tall and 114 VI versus 1.7 m tall and 87 VI). Trees outplanted from small cavities (60 ml) were shorter and had a smaller VI (1.5 m tall and 73 VI) than trees outplanted from the other two cavity sizes (average of 2.0 m tall and 114 VI).

Keywords: Copperblocks, copper oxychloride, *Pinus palustris* Mill., regeneration, Superblocks

Of the more than 1 billion conifer seedlings produced yearly since 1996 in nurseries in the US South for outplanting on forest sites (McNabb and Enebak 2008, Barnard and Mayfield 2009), 96% are bareroot seedlings and 4% are container stock (McNabb and Enebak 2008). An exception to this trend occurs for longleaf pine (*Pinus palustris* Mill.), with 30% of the 33 to 69 million seedlings produced annually through 2007 being bareroot seedlings and 70% being container stock (South et al. 2005, McNabb and Enebak 2008). Nearly 90% of the longleaf pine seedlings planted in 2008 were container stock (Barnard and Mayfield 2009).

With the preference for longleaf pine container stock, research on the suitability of container seedlings continues across the South to compare types of containers and cavity sizes both in the nursery and after outplanting (e.g., Barnett and McGilvray 2002, South et al. 2005, Sword Sayer et al. 2009). An evaluation of seedling root systems before planting often finds lateral roots growing downward on the outside of the root plug to the bottom of the container cavity because they were deflected by contact with the container wall (Burdett 1978), a condition referred to as caging. This weblike, stiff structure and lateral root deformity may persist after outplanting (Sung et al. 2009).

It has been suggested that downward-growing laterals of longleaf pine seedlings can potentially result in root system failures in high sustained winds (Sword Sayer et al. 2009, Sung et al. 2009). For example, we observed that many longleaf pine saplings outplanted from containers over the past decade in central Louisiana developed a severe lean or toppled following wind accompanying tropical storms or severe thunderstorms once trees reach sufficient crown size to catch enough wind to overcome the root system's capability for anchorage. This type of wind injury was also observed in the current study at age 4 years immediately after Hurricane Gustav (Sung et al. 2009). The entire stand is not lost in any one event; rather, toppling is scattered. We excavated and examined the root ball of several injured and noninjured trees and believe that resulting root system failure was principally due to poor root system architecture (Susana Sung, unpublished observations, 2010). Most of the leaning trees regained a vertical position in the next growing season, with the righted stem often having a sinuous form (Sung et al. 2009). Some trees remained downed. If prescribed fire is used, the downed saplings are killed and their tops consumed. Thus, the eventual loss or degradation of many trees is subtle and overlooked by the casual viewer.

Most of the research to lessen caging has focused on modifying the containers themselves and on applying a copper coating to the interior wall of the container cavity to inhibit root elongation at the interface between the roots and the container wall and stimulate secondary lateral root formation (Sword Sayer et al. 2009, 2011). Copper-coated containers result in more new roots egressing along the circumference of the top one third of the root plug after a 28-day root growth potential test and up to 3 years in the field (Sung et al. 2009, Sword Sayer et al. 2009, 2011). South et

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This article uses metric units; the applicable conversion factors are: millimeter (mm): 1 mm = 0.039 in.; centimeters (cm): 1 cm = 0.39 in.; meters (m): 1 m = 3.3 ft; square meters (m^2): 1 m^2 = 10.8 ft^2; cubic meters (m^3): 1 m^3 = 35.3 ft^3; kilograms (kg): 1 kg = 2.2 lb; milliliter (mL): 1 mL = 0.061 in.^{3} (dry), = 0.27 fluid dram (liquid).

al. (2005) also reported an increase in root growth potential by copper.

There is a need to evaluate the effects of container modification with copper oxychloride and container cavity size on the long-term field performance of planted longleaf pine seedlings. For this study, seedling development in the nursery, subsequent root growth potential testing, and first-year root system and shoot development and growth were reported by Sword Sayer et al. (2009, 2011). Sung et al. (2010) reported on field performance in the first 2 years and photosynthetic rates in the second growing season. Sung et al. (2009) reported on the root and shoot growth of several seedlings excavated in the third growing season and on tree toppling in the fourth growing season. Herein, we report on the 5-year field performance of longleaf pine trees originating from six container types that differ by copper treatment and cavity size—Superblock (no copper treatment) or Copperblock in combination with small (60 ml), medium (108 ml), or large (164 ml) cavities. Our objectives were to (1) to determine whether cavity size and copper coating of the inner wall of the container cavities before they are filled with medium affect longleaf pine survival, emergence from the grass stage, and subsequent aboveground growth; and (2) evaluate whether there are interactions between type of Styroblock used and cavity size.

Methods

Container Types and Nursery Practices

Longleaf pine seedlings were grown in two types of Beaver Plastics Styroblocks (Beaver Plastics, Ltd., Acheson, Alberta, Canada): Superblock, with no copper treatment applied to the cavity walls, and Copperblock, with the inner cavity walls treated with Root Trim, which contains copper oxychloride (Beaver Plastics). The Styroblock cavity sizes were small (cavities were 60 ml, 13.3 cm deep, with a 2.8-cm top diameter and 936 cavities per m^2), medium (cavities were 108 ml, 15.0 cm deep, with a 3.6-cm top diameter and 530 cavities per m^2), and large (cavities were 164 ml, 15.2 cm deep, with a 4.2 cm top diameter and 364 cavities per m^2). Therefore, there were six container types—Superblock with small, medium, and large cavities and Copperblock with small, medium, and large cavities.

Mixed seedlots of longleaf pine seeds from Florida were sown in the six container types at Pineville, Louisiana, in April 2004. Approximately 700 longleaf pine seedlings were grown in each of the six container types using standard cultural practices (Barnett and McGilvray 1997, 2000). Briefly, the growing medium was a 1:2 mixture of commercial peat moss and vermiculite. Sown containers were randomly placed on greenhouse benches. The growing medium contained Osmocote 19-6-12 slow release fertilizer (Scotts Miracle-Gro Company, Marysville, OH) at a rate of 3.6 kg/m^3. Between early June and the end of September 2004, a 0.05–0.06% solution of Peter's Professional 20-19-18 water-soluble fertilizer (J.R. Peters, Inc., Allentown, PA) was applied five times to root plug saturation. Between July and mid-October 2004, a 3% solution of benomyl fungicide was applied five times to root plug saturation. Between fertilizer and fungicide applications, seedlings were watered to root plug saturation as needed to maintain vigor, and the smaller seedlings were irrigated more frequently than larger ones because they dried out faster. Seedlings were grown for 27 weeks under ambient light in a greenhouse where air temperature was maintained at 20–25°C. Six weeks before planting, fertilization was stopped, and watering was reduced to encourage bud set. Seedlings were top-pruned 18 days before planting to reduce water stress after outplanting. At the end of the 27 weeks, root-bound index was acceptable for all six container types (less than 14%) on the basis of work by South et al. (2005).

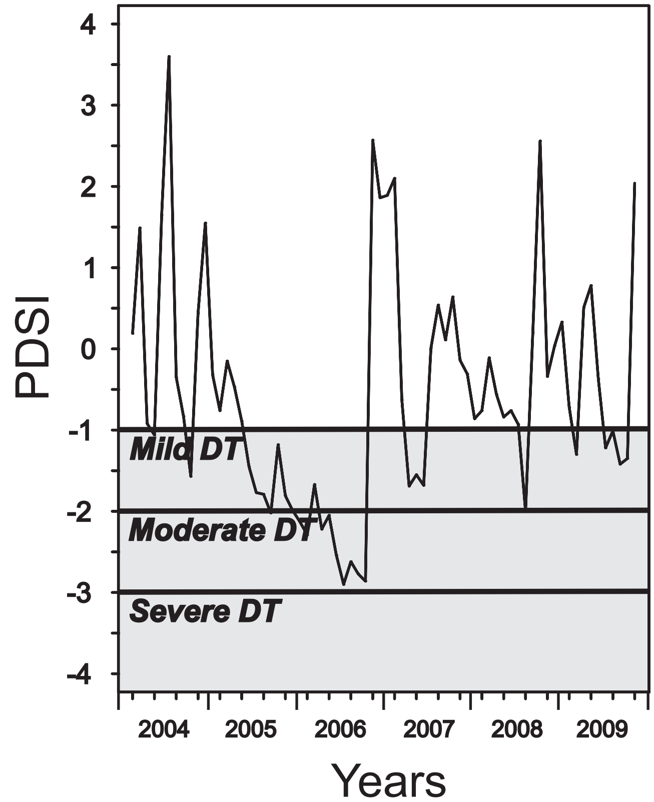

Figure 1. Palmer Drought Severity Index (PDSI) values for central Louisiana in 2004 through 2009. DT, drought.

Field Establishment and Measurements

The field study site is on the Palustris Experimental Forest within the Kisatchie National Forest in central Louisiana (31° 10′ N latitude, 92° 41′ W longitude) at 75 m above sea level. The soils are Beauregard silt loam (fine-silty, siliceous, superactive, thermic Plinthaquic Paleudults) and Malbis fine sandy loam (fine-loamy, siliceous, subactive, thermic Plinthic Paleudults), and both soils are well suited for growing trees (Kerr et al. 1980). Vegetation is mostly grasses, forbs, and scattered hardwood and pine brush.

The study site was prescribed burned in May 2004. The fire cleared the accumulated litter (mostly grass stubble) and much of the live vegetation. The site was rotary mowed in June 2004. After rotary mowing, the woody vegetation too large to mow was hand-felled and removed.

After the vegetation was cleared, four blocks of six plots each were established. Blocking was based on apparent soil drainage using depth to mottles with a chroma of 2 or less as a drainage indicator. The six container types were randomly assigned to one of six plots per block and were laid out in a 2 by 3 randomized complete block factorial design (Steel and Torrie 1980). Each 24- by 24-m (0.0576 hectare) plot was 12 rows of 12 longleaf pine seedlings planted at 2- by 2-m spacing.

The 144 planting spots per plot were planted with 27-week-old longleaf pine seedlings in November 2004 using a container dibble of the correct size for each of the three cavity sizes. Root plugs were moist at planting, as recommended by Dumroese et al. (2009).

Table 1. Longleaf pine survival, total height (TH), diameter at groundline (gld) and breast height (dbh), and volume index (VI) after the fifth growing season.

Styroblock types, cavity sizes, and analysis		Adjusted survival (%)[a]	TH (m)	gld	dbh	VI ($gld^2 \cdot TH$)
				. . . .(cm)	. . . .	
Styroblock types						
Copperblock		94[b]	2.0[b]	7.0[b]	3.5[b]	114[b]
Superblock		91[b]	1.7[c]	6.5[c]	3.2[c]	87[c]
Cavity sizes						
Small		88[c]	1.5[c]	6.3[d]	3.1[c]	73[c]
Medium		95[b]	1.9[b]	6.7[c]	3.4[b]	103[b]
Large		96[b]	2.1[b]	7.2[b]	3.5[b]	125[b]
Analysis of variance	df[b]			Probability > *F*-value		
Block	3	0.7479[b]	0.0043	0.0089	0.0035	0.0102
Styroblock types	1	0.0683	0.0050	0.0049	0.0332	0.0087
Cavity sizes	2	0.0093	0.0004	0.0006	0.0221	0.0011
Type × size interaction	2	0.8112	0.4911	0.2699	0.3661	0.3196
Error mean square	15	22.36631	0.05158	0.12716	0.06639	489.86702

[a] Survival percentages were adjusted to account for seedlings that were excavated in other research by removing the trees from the data set.
[b,c,d] Within columns, Styroblock types or cavity sizes followed by a different letter are significantly different based on the analysis of variance and Duncan's multiple range tests at $\alpha = 0.05$. df, degrees of freedom. Percentages were arcsine transformed before analysis.

The entire site was again prescribed burned in February 2006, 15 months after planting, and nearly 95% of the longleaf pine foliage was scorched. In summer 2008, all plots were rotary mowed between rows to improve access. The entire site was prescribed burned in May 2009, and significant foliar scorch again occurred.

Measurements were made on the center eight rows of eight longleaf pine seedlings per plot, which included total height (TH) taken annually with a meter stick and later with a calibrated pole, groundline diameter (gld) after the second through fifth growing seasons, and dbh after the fifth growing season. Diameter measurements were taken with calipers. Total height and gld were used to calculate volume index ($VI = gld^2 \times TH$). The grass stage and hardy growing stage (i.e., height growth initiation) were distinguished by a TH of 12 cm.

Meteorological Conditions

Mean January and July temperatures were 11 and 28°C, respectively, in 2005 through 2009 for central Louisiana (National Climatic Data Center 2010). Annual precipitation averaged 1,430 mm, and growing season precipitation (March through November) averaged 1,017 mm per year. June was the driest month (74 mm/year), and September was the wettest month (172 mm/year) during the 5-year period.

Palmer Drought Severity Index (PDSI) values for central Louisiana between 2004 and 2009 were obtained from the National Climatic Data Center (2010), and PDSI classifications were from Strzepek et al. (2010). Accordingly, soil moisture was good when the seedlings were planted in November 2004 (Figure 1). Within the 2-year period after planting, however, a prolonged mild to moderate 17-month drought spanned from May 2005 through September 2006. A mild 3-month drought developed in 2007, and 2008 was relatively drought-free. Two mild droughts that lasted 1 to 4 months each developed in 2009. Overall, drought conditions developed 43% of the time in central Louisiana in 2005 through 2009. The drought conditions were above normal because in the 115-year period from 1895 to 2009, drought developed only 36% of the time in central Louisiana (Strzepek et al. 2010, National Climatic Data Center 2010).

Data Analysis

Before statistical analysis, it was determined that TH, gld, and dbh were normally distributed with the univariate procedure (SAS Institute, Inc., 1985), and plot survival percentages were adjusted to account for seedlings that were excavated in other research (e.g., Sung et al. 2009). Additionally, all percentages were arcsine transformed before analysis to equalize variances (Steel and Torrie 1980).

Annual percent survival, percent of longleaf pine emerged from the grass stage (seedling was at least 12 cm tall), TH, gld, and VI were evaluated using a randomized complete block factorial model at a significance level of $\alpha = 0.05$ (Steel and Torrie 1980, SAS Institute, Inc., 1985). In the analyses, Styroblock type (Superblock or Copperblock) and cavity size (small, medium, or large) were the main effects, and their interaction was also tested. If there was a significant difference among cavity sizes, mean comparisons were made with Duncan multiple range tests at $\alpha = 0.05$. Other variables were tested with the previous model: seedling gld and TH for the year before emergence from the grass stage, seedling gld and TH for the year the seedling emerged from the grass stage, and fifth-year dbh.

Results and Discussion

Percent survival after five growing seasons was not significantly affected by the type of Styroblock used (Table 1), and South et al. (2005) also reported that copper treatment did not affect the survival of planted longleaf pine seedlings. Cavity size, however, affected percent survival by the end of the third ($P > F = 0.027$) through fifth growing seasons with survival being less on the small-cavity plots than on the other two cavity sizes (Figure 2, Table 1). One explanation for poorer survival of seedlings grown in smaller cavities is that these seedlings were not as large as the other seedlings in either shoot or root biomass when outplanted (Sword Sayer et al. 2009). Fewer needle fascicles on small seedlings provided a smaller total amount of photosynthate for root growth than seedlings from larger cavities that had more needle fascicles. Under these conditions, the root system of seedlings grown in small cavities may have eventually failed to meet the growing shoot's demand for soil resources, leading to greater seedling mortality compared with the other two cavity sizes starting in the third growing season.

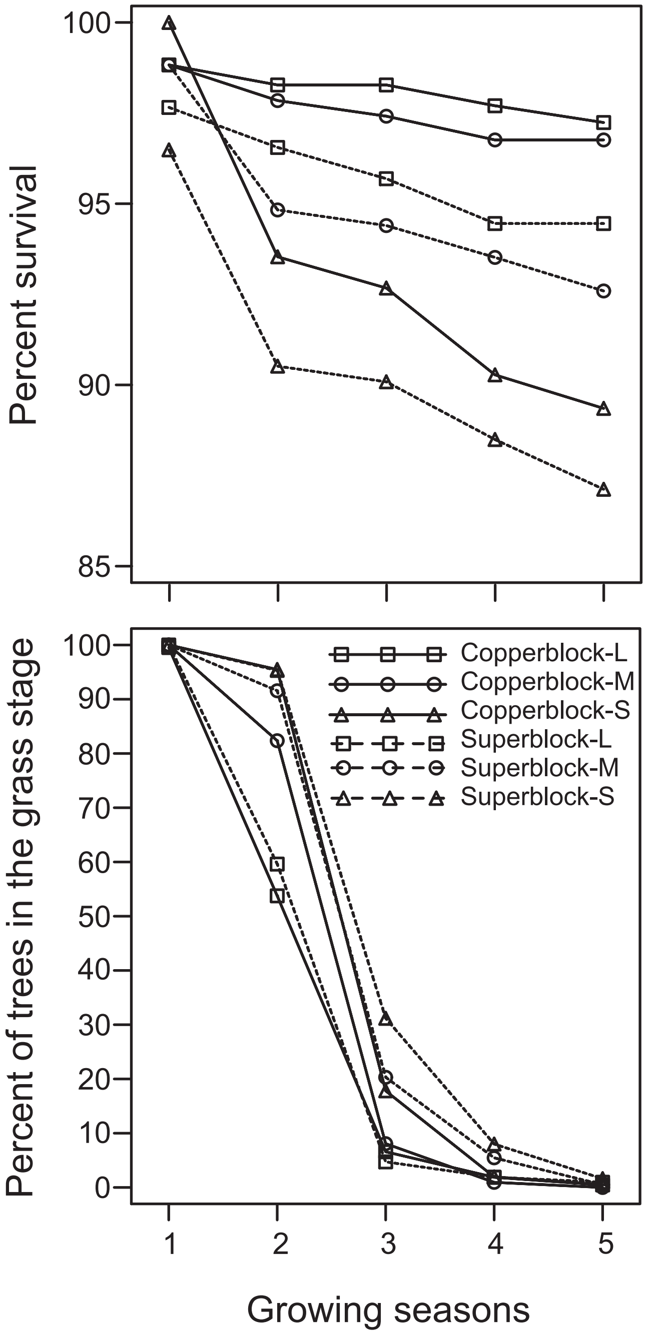

Figure 2. Percent longleaf pine survival and seedlings in the grass stage after the first through fifth growing seasons for Copperblock and Superblock containers with large (L), medium (M), and small (S) cavities. Survival percentages were adjusted to account for seedlings that were excavated in other research.

It was expected that prescribed fire would play a role in seedling mortality among container types because fire disproportionately kills smaller rather than larger longleaf pines (Haywood 2011). Although all of the seedlings in our study were small after the first growing season, with an average height of 4 cm across all treatments, the fire in February 2006 was associated with greater mortality during the second growing season for small containers (6%) than for the other two cavity sizes (average of 2%) at $P > F = 0.006$ (Figure 2). At the end of the second growing season, however, this fire did not significantly affect survival among cavity sizes ($P > F = 0.059$). The prescribed fire in May of the fifth growing season had little effect on

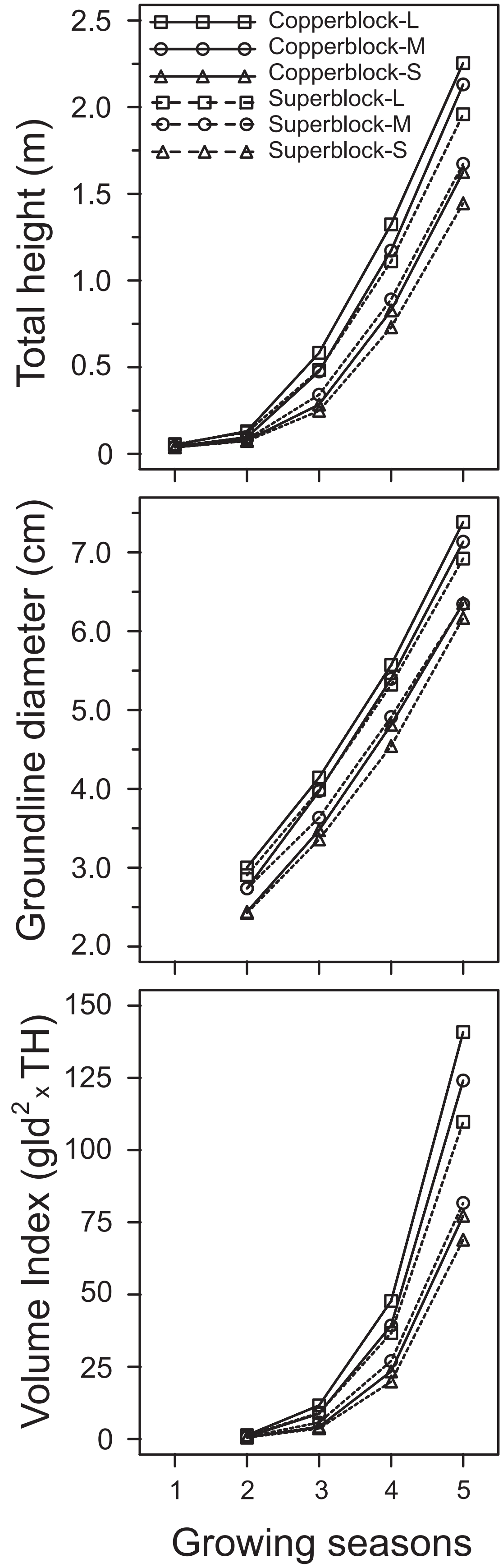

Figure 3. Longleaf pine total height (TH), groundline diameter (gld), and volume index (gld^2 × TH) after the first through fifth growing seasons for Copperblock and Superblock containers with large (L), medium (M), and small (S) cavities.

longleaf pine survival regardless of cavity size or seedling stature (Figure 3), because at this time nearly all seedlings were in the hardy growing stage of development, with terminal shoots above the height of the most damaging heat (Bruce 1951).

Relatively low but chronic mortality during the first 5 or 6 years after planting longleaf pine has been reported elsewhere (e.g., Haywood 2000, 2005, 2007). After five growing seasons, survival averaged 93% (Table 1) and ranged from 87 to 97% (Figure 2), which is considered good for longleaf pine planted in native grass cover. There were no significant interactions between Styroblock type and cavity size influencing survival.

After two growing seasons, large-cavity plots had fewer seedlings in the grass stage (57%) than plots of the other two cavity sizes, and the medium-cavity plots had fewer seedlings in the grass stage (87%) than the small-cavity plots (95%) at $P > F < 0.0001$ (Figure 2). In the third growing season, emergence from the grass stage was affected by an interaction between Styroblock type and cavity size ($P > F = 0.045$), in which the medium-cavity Copperblock plots had as few seedlings in the grass stage as large-cavity plots regardless of Styroblock type (an average of 6%). At the same time, the Superblock medium-cavity and Superblock and Copperblock small-cavity plots averaged 23% of trees in the grass stage. After five growing seasons, however, there were no significant differences in emergence from the grass stage between the two Styroblock types or among cavity sizes, with 99.3% of longleaf pine seedlings in height growth across all plots.

In this and other studies in central Louisiana (Haywood 2000, 2005, 2007) where grasses dominated the understory, emergence from the grass stage began in the second growing season and continued through six or more growing seasons. In these settings, the majority of seedlings were released by the third through fifth growing seasons. In contrast, on similar soils where forbs and woody plants dominated the understory, emergence from the grass stage was more rapid, with more than 80% of seedlings emerging after two growing seasons (Haywood 2005, 2007). In the absence of postplant vegetation control, rapid emergence allows planted longleaf pine seedlings to be competitive for light on sites with significant woody competition (Haywood 2000, 2011).

Generally, once longleaf pine seedlings develop a rootcollar of at least 2.5 cm, they emerge from the grass stage (Wahlenberg 1946). In this study, 1 year before emergence, seedlings had an average gld of 2.5 cm on small-cavity plots and 2.8 cm on medium- and large-cavity plots, results that support Wahlenberg (1946). The year before emergence from the grass stage, we found that seedlings averaged 8 cm tall but grew to an average height of 27 cm the year they bolted, and Copperblock seedlings (28 cm) were taller than Superblock seedlings (25 cm) ($P > F = 0.033$).

Total height of longleaf pine trees was greater on large-cavity plots than on small-cavity plots after all five growing seasons (Figure 3 and Table 1). Total height of trees was also greater on large-cavity plots than on medium-cavity plots after the second through fourth growing seasons, but after 5 years, TH values on the large- and medium-cavity plots were no longer significantly different. The loss of a treatment difference between large- and medium cavities might have developed because of the quickened emergence of seedlings from the grass stage on the Copperblock medium-cavity plots in the third growing season (Figure 2). As reported by South et al. (2005), copper treatment did not increase tree height in the first two field seasons, but trees on Copperblock plots were taller than trees on Superblock plots after the third through fifth growing seasons. Nevertheless, a significant interaction effect on TH between Styroblock type and cavity size was not detected.

Groundline diameter and VI of longleaf pine trees were greater on large-cavity plots than on small-cavity plots after each growing season (Figure 3 and Table 1). Trees also had greater VI on large-cavity plots than on medium-cavity plots after the second through fourth growing seasons, but after 5 years, VI values on the large- and medium-cavity plots were no longer significantly different. Therefore, the pattern of cavity-size responses for both TH and VI were similar. Groundline diameter remained significantly greater on large-cavity plots than on medium-cavity plots through five growing seasons.

Copperblock plots had greater gld and VI after the third through fifth growing seasons than Superblock plots (Figure 3 and Table 1). After 5 years, dbh was greater on Copperblock plots than on Superblock plots, and medium- and large-cavity trees had greater dbh than small-cavity trees. However, we failed to detect significant interactions between Styroblock type and cavity size influencing gld, VI, or dbh.

Conclusions

Copperblock plantings did not have greater survival than the Superblock plantings after 5 years in the field. Sung et al. (2009) and Sword Sayer et al. (2009) reported that use of Copperblocks caused more root egression from the root plug into the upper 5 cm of soil and the seedlings presumably would be more competitive with native grasses and forbs for soil moisture. However, a 17-month mild to moderate drought spanning the first and second growing seasons had no effect on survival (Figure 1). Drought conditions were probably not severe enough to influence seedling survival between the Copperblock and Superblock plots, and once container-grown longleaf pine seedlings of good quality are established among native vegetation, they are able to endure even extreme drought conditions (Haywood 2005, 2007).

The use of Copperblocks and large cavities increased the early emergence of seedlings from the grass stage, but nearly all seedlings were in height growth after five growing seasons. Trees in Copperblock plantings were larger in stature than trees in Superblock plantings after 5 years. The Copperblock-medium cavities might be a good substitute for Superblock-large cavities in terms of tree growth (Figure 3) partly because Copperblock medium-cavity trees were in height growth as quickly as large-cavity trees by the third growing season (Figure 2). To get seedlings out of the grass stage quickly and into height growth, we recommend that forest managers take the following steps: (1) plant large-cavity seedlings if not using copper; (2) if planting medium-size seedlings, grow them in copper cavities; and (3) on a grassy site, plant large seedlings grown in copper-treated cavities.

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