

INFLUENCE OF PLANTING STOCKS ON THE SURVIVAL AND GROWTH OF NUTTALL AND CHERRYBARK OAK PLANTED ON LANDS DAMAGED BY HURRICANE KATRINA

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Abstract.—Bare-root, container, and root production method (RPM™) seedlings of Nuttall oak (*Quercus texana* Buckley) and cherrybark oak (*Q. pagoda* Ell.) were planted on lands damaged by Hurricane Katrina in southern Mississippi to compare the height growth, groundline diameter (GLD) growth, and survival of the different planting stocks. Two study areas were divided into three replicates containing six treatment combinations with 100 seedlings per replicate. Tree shelters were used on half of the bare-root seedlings to determine their effect on height, GLD growth, and survival of the seedlings. Height and GLD growth were greater in RPM™ seedlings compared to bare-root or container seedlings after one growing season. Bare-root seedlings exhibited greater height and GLD growth than container seedlings. Tree shelters increased height growth of bare-root seedlings; however, sheltered bare-root seedlings exhibited less GLD growth than unsheltered seedlings. Cherrybark oak exhibited greater height growth than Nuttall oak, whereas Nuttall oak exhibited greater GLD growth than cherrybark oak across all planting stocks. There was no significant difference among the planting stocks after the first growing season.

INTRODUCTION

Among the many benefits of bottomland hardwood forests are flood protection, increased groundwater storage, increased soil productivity, and reduced nutrient runoff (Sparks 1995). However, oak regeneration on these mesic bottomland hardwood sites has proven to be problematic (Clatterbuck and Meadows 1993, Janzen and Hodges 1987, Johnson et al. 2002, Loftis and McGee 1993, Lorimer 1993). Failure can be attributed to inadequate regeneration before harvest, predation, herbivory, and the inability of seedlings to compete with other vegetation for resources such as light and water (Allen et al. 2001, Loftis 1983, Lorimer 1989, Stanturf et al. 2001). Environmental factors such as extended drought and flooding also contribute greatly to poor seedling survival and growth (Allen and Burkett 1996, Gardiner et al. 2004, Kennedy and Johnson 1984). Bottomlands commonly have an adequate supply of nutrients and water, which generally favors species with rapid growth rates and thus compounds the problem of inadequate oak regeneration (Hicks 1998).

To solve the problem of inadequate oak regeneration, many private landowners have elected to use artificial regeneration. The goal of planting seedlings on previously forested areas is to accelerate natural succession (Stange and Shea 1998). However, in large-scale plantings of seedlings in bottomland hardwoods, mortality is often high after planting (Cleveland and Kjelgren 1994, Schweitzer and Stanturf 1997), resulting in planting failures (Patterson and Adams 2003). Poor survival of oaks has been linked to factors such as slow growth, rapid growth of competing vegetation, poor planting, and poor seedling quality (Johnson et al. 1986, McGee and Loftis 1986, Pope 1993,

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Russell 1971). Potentially high mortality rates underscore the importance of matching species with site, planting vigorous seedlings, and using proper planting methods.

In 2005, Hurricane Katrina destroyed thousands of hectares of bottomland hardwood forest in Mississippi. Natural regeneration on hurricane-disturbed lands, like that on harvest-disturbed lands, may result in site-dominating species that are undesirable for landowner objectives (Aust et al. 2006, Battaglia et al. 1999, Peterson and Pickett 1995). The bulk of these undesirable species may be light-seeded species such as sweetgum (*Liquidambar styraciflua* L.) and American elm (*Ulmus americana* L.) (Allen 1990). Desirable species such as oaks have been shown to make up less than 10 percent of regeneration when a stand is allowed to regenerate naturally (Johnson 1984). Thus, due to the potential lack of desirable heavy-seeded species such as oaks (*Quercus* spp.), seedlings must often be planted to achieve reforestation objectives (Allen 1990).

Costs associated with reforestation of these lands can be excessive for nonindustrial private landowners. Federal programs such as the Wetlands Reserve Program (WRP) and Conservation Reserve Program offer cost-share incentives to offset the expense of restoring bottomland hardwoods (Williams and Craft 1998). However, Schweitzer and Stanturf (1997) found that only 9 percent of the total reforested land in Mississippi planted in the WRP program met the Natural Resources Conservation Service requirement of at least 308 hard-mast stems per ha in 3-year-old stands. A possible explanation for the failures could be that the program uses direct seeding and bare-root seedlings. The use of different planting stocks may increase survival rates on these reforested lands. However, biological and economic outcomes of artificial regeneration are not fully understood in terms of which species or planting stocks will be most successful or cost-effective.

This study focused on reforestation of Hurricane Katrina-damaged lands and attempted to add to the body of knowledge about planting stock comparisons and proper stocking of oaks on a site. It was a valuable opportunity to study management practices following a major disturbance event and provide managers and private landowners with recommendations for future work. The overall objective of this study was to determine the effect of species, planting stock, and tree shelters on survival and growth of Nuttall (*Quercus texana* Buckley) and cherrybark (*Q. pagoda* Ell.) oak seedlings planted on hurricane-damaged lands. The planting stocks were: 1-0 bare-root, containerized (409.68 cm³ Nuttall, 331.84 cm³ cherrybark), and 11.356-L root production method (RPM™) (Forrest Keeling Nursery, Elsberry, MO) seedlings. Specific objectives were: (1) to compare overall height growth and groundline diameter (GLD) growth of Nuttall and cherrybark oak 1 year after planting, (2) to compare overall survival of the three different planting stocks for Nuttall and cherrybark oak 1 and 2 years after planting, and (3) to evaluate the effect of tree shelters on survival and growth rates of bare-root Nuttall and cherrybark oak seedlings.

STUDY AREA

Two study areas on bottomland hardwood sites damaged by Hurricane Katrina were chosen for reforestation and evaluation. The two sites were selected for uniformity of soil and terrain properties. One area, known as the Norris tract, is located in section 3, T3S R12W in Stone County, Mississippi. The area received a salvage harvest following Hurricane Katrina. Site preparation on the area included the use of a bush hog to mow down vegetation and a bulldozer to clear stumps. Dominant vegetative species on the site before the first growing season were blazing star (*Liatris spicata* Willd.), boneset (*Eupatorium* spp. L.), partridge pea (*Chamaecrista fasciculata* Michx.),

broomsedge (*Andropogon virginicus* L.), blackberry (*Rubus* L.), rush (*Juncus* L.), goldenrod (*Oligoneuron* Small), gallberry (*Ilex* Chapm.), and hoary mountain mint (*Pycnanthemum incanum* L.). Woody species present on the area before the salvage cut included blackgum (*Nyssa sylvatica* Marsh.), sweetgum, red maple (*Acer rubrum* L.), American beech (*Fagus grandifolia* Ehrh.), black cherry (*Prunus serotina* Ehrh.), persimmon (*Diospyros virginiana* L.), water oak (*Q. nigra* L.), winged sumac (*Rhus copallina* L.), loblolly pine (*Pinus taeda* L.), and swamp chestnut oak (*Q. michauxii* Nutt.). Based on soil samples, pH across the site averaged 4.7, which is within the desired pH range for cherrybark and Nuttall oak.

The second area, known as the Garretson tract, is located in section 12, T3N R6W in Greene County, Mississippi. Following Hurricane Katrina, a salvage cut was conducted on the area. Stumps too large to be moved by a bulldozer were left, and smaller stumps were removed. The dominant woody species on the area before the salvage cut was swamp chestnut oak. Other tree species present on the area prior to the salvage cut were cherrybark oak, willow oak (*Q. phellos* L.), water oak, hickory (*Carya* spp. Nutt.), white oak (*Q. alba* L.), American beech, red maple, elm (*Ulmus* spp. L.), American hornbeam (*Carpinus caroliniana* Walter), persimmon, sweetgum, and Chinese tallow tree (*Sapium sebiferum* L.). Vegetation on the area consisted of Carolina horsenettle (*Solanum carolinense* L.), blackberry, American pokeweed (*Phytolacca americana* L.), hogwort (*Croton capitatus* Michx.), foxtail (*Alopecurus* spp. L.), Japanese climbing fern (*Lygodium japonicum* Murr.), hempvine (*Mikania scandens* Willd.), smooth greenbrier (*Smilax glauca* Walt.), morningglory (*Ipomoea* spp. L.), and woodoats (*Chasmanthium* spp. L.). Soil pH across the site varied from 4.6 to 5.0, which is within the desired pH range for cherrybark and Nuttall oak.

METHODS

Experimental Design and Demarcation

Each of the two study areas was divided into three replicates. Each replicate was located on uniform areas across the site. Six hundred seedlings were planted in each replicate, for a total of 1,800 seedlings planted per site.

On the Garretson tract, two of the replicates were 40 m by 158 m. These replicates consisted of 12 rows of 50 seedlings each. Because of a large flooded area, the third replicate had a different configuration. It was 46 m by 183 m and consisted of 9 rows of 50 seedlings, 5 rows of 25 seedlings, 1 row of 15 seedlings, and 1 row of 10 seedlings.

On the Norris tract, the first replicate was 91 m by 82 m, consisting of 20 rows of 20 seedlings, and 8 rows of 25 seedlings. The second replicate was 76 m by 82 m, consisting of 24 rows of 25 seedlings. The third replicate was 140 m by 82 m, consisting of 21 rows of 25 trees, 1 row of 20 trees, and 3 rows of 10 trees.

The experimental unit was the plot, which has a unique combination of planting stock, species, chemical treatment, and tree shelter application (n=8). The experimental units in each replication were as follows: 50 bare-root Nuttall oak with herbicide treatment and tree shelters, 50 bare-root Nuttall oak with herbicide treatment, 50 bare-root cherrybark oak with herbicide treatment and tree shelters, 50 bare-root cherrybark oak with herbicide treatment, 100 containerized Nuttall oak, 100 containerized cherrybark oak, 100 RPM™ Nuttall oak, and 100 RPM™ cherrybark oak. The location of the six planting stock and species combinations was randomly assigned within each replicate.

All trees were planted on 3.048 m by 3.048 m spacing. The location of each tree to be planted was marked with a 92-cm colored pin flag. Each planting stock and species combination was denoted by a different-colored pin flag. Row ends were marked with a 1-m section of 0.94-cm steel reinforcing bar and flagging. An aluminum tag with the row number was attached to the bar.

Treatments

Protex® tree shelters (Norplex Inc., Auburn, WA) 92 cm tall were placed on half of the bare-root seedlings in March 2010 after initial measurements were taken. All bare-root seedlings received a pre-emergent banded herbicide treatment of Oust® XP (DuPont, Wilmington, DE) (146.16 ml sprayed per ha) 1 week after planting. The herbicide was applied over the top of seedlings by using a backpack sprayer to apply a 1.52-m swath with the seedling as the center of the spray swath.

Seedling Establishment

In early February 2010, the RPM™ seedlings were planted by a contractor. The seedlings were produced from seeds collected in Louisiana and Mississippi and were grown by using the RPM™ at a nursery in Ravenel, South Carolina. Half of the seedlings were planted by using an ASV RC-30 rubber-track loader (ASV, Inc., Grand Rapids, MN) with an auger; the other half were planted with planting shovels. Crews were monitored by a Mississippi State University graduate student to ensure the trees were being planted correctly. Seedlings had an initial average height of 125.5 cm and GLD of 16.5 mm.

Bare-root and containerized seedlings were planted in mid- to late-February 2010 by Mississippi State University personnel. Containerized seedlings were from Rennerwood Inc. in Tennessee Colony, Texas. Bare-root seedlings were from the Molpus Woodlands Group tree nursery in Elberta, Alabama. Bare-root and container seedlings were planted by hand with planting shovels. Bare-root seedlings had an initial average height of 57.2 cm and GLD of 8.1 mm. Containerized seedlings initially averaged 59.7 cm in height and 6.9 cm in GLD.

Seedling Measurements

Height and GLD of each seedling were measured in March 2010 and October 2010. Tree heights were measured in centimeters with a meter stick and were recorded as the height from ground level to the terminal bud.; Digital calipers were used to measure GLDs in millimeters just above the root collar. Survival of seedlings was recorded monthly from May through October 2010 for the first year, and will be recorded at the end of the October 2011 growing season. If ocular observation determined a seedling to be dead, the cambial layer was examined to confirm seedling survival status.

Analysis

Analysis of variance was performed using PROC GLM in SAS software version 9.2® (SAS Institute, Cary, NC). Response variables were height growth, GLD growth, and survival. Means separation of first-year survival, height growth, and diameter growth was analyzed using least square differences (LSD). During analysis of survival data, a histogram of residuals was made. Residuals were not mound and symmetric, so an analysis of plot survival percentage with an arcsine transformation was performed. Differences among treatments were tested at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Overall Survival

A significant difference between sites in this study was not observed; therefore, survival data were analyzed as a whole and not by site. This outcome contrasts with that reported by Ezell and Catchot (1998), who showed that site can have an effect on hardwood seedling survival.

First-year survival for Nuttall oak was higher than survival for cherrybark oak, although cherrybark oak survival was 98.1 percent and the difference was only 1.1 percent across all planting stocks. These results agree with Self et al. (2009), who found Nuttall oak exhibited higher survival than cherrybark oak on a saturated site in Louisiana; however, the difference in this study was much less than they observed. The overall high survival rates are consistent with other studies, including those conducted in a nursery setting (Jacobs 2003).

No significant differences were observed in survival among the three planting stocks. Observed survival of container seedlings (99.4 percent) did not differ from that of bare-root or RPM™ planting stocks (98.0 percent and 98.6 percent, respectively). All three planting stocks exhibited excellent survival rates that would provide adequate stocking in reforestation attempts.

Container Nuttall oak, container cherrybark oak, bare-root Nuttall oak, and RPM™ Nuttall oak all exhibited a survival rate greater than 99 percent. Survival of all other species/planting stock combinations was greater than 97 percent. Cherrybark oak bare-root seedlings exhibited the least survival at 97.1 percent, which is still very high.

Although stem dieback and slow initial growth may result in low survival of bare-root seedlings (Rathfon et al. 1995), the results from this study indicated otherwise. Bare-root seedlings had survival rates of 99.0 percent and 97.1 percent for Nuttall and cherrybark oak, respectively. Bare-root Nuttall oak exhibited only 0.1 percent lower survival than containerized Nuttall oak, and 0.5 percent lower survival than RPM™ Nuttall oak. Bare-root cherrybark oak seedlings exhibited lower survival rates than containerized and RPM™ cherrybark seedlings, but the difference was less than 3 percent in both cases.

Lower second-year survival is expected across all treatments based upon visual observation made throughout the 2011 growing season. High temperatures, a lack of precipitation, and herbivory are the primary reasons for the mortality expected during the 2011 growing season. Although survival across planting stocks is assumed to be lower in year 2, differences in survival rates between planting stocks in year 2 are expected to resemble those in year 1.

Survival: Sheltered vs. Unsheltered Bare-root Seedlings

No significant difference in survival was detected between sheltered and unsheltered seedlings, which exhibited excellent survival levels (97.3 percent and 98.7 percent, respectively). Survival was greater in unsheltered Nuttall oak seedlings (99.6 percent) than in Nuttall oak seedlings with shelters (98.4 percent). Unsheltered cherrybark oak seedlings exhibited a higher survival rate at 98.0 percent compared to sheltered cherrybark oak seedlings, which had the least survival of the species/shelter combinations at 96.3 percent. Sheltered and unsheltered Nuttall oak exhibited greater survival than

sheltered and unsheltered cherrybark oak. Although significant differences were observed, survival was excellent regardless of species/shelter combination.

Overall Height Growth

Analyses of growth data were performed only on seedlings that did not exhibit dieback or resprout ($n=3,017$). Therefore, only seedlings exhibiting an increase in height or GLD were included in the analyses. It was concluded that seedlings not exhibiting an increase in height or GLD were masking the realistic growth potential of the seedlings (Self 2009).

Cherrybark and Nuttall oak height growth (16.1 cm and 15.3 cm, respectively) were not significantly different (Table 1). Average height growth was greater in RPM™ seedlings than in bare-root and container seedlings (26.3 cm, 10.7 cm, and 7.3 cm, respectively). Bare-root seedlings exhibited greater height growth than container seedlings, which is not typical (William and Stroupe 2002). However, similar results have been reported in one earlier study on the Yazoo National Refuge in Mississippi (Burkett et al. 2005). Results in this study could reflect the high quality of the bare-root seedlings, whose substantial number (average >8) of first-order lateral roots would allow allocation of resources to height growth. Another possible explanation is planting quality. Operational planters often tend to focus more on planting speed than planting quality, but in this study, great care was taken to plant all seedlings properly.

The greatest height growth of all the species/planting stock combinations occurred in RPM™ cherrybark oak (28.7 cm), RPM™ Nuttall oak (23.8 cm), and bare-root Nuttall oak (13.0 cm) (Table 2). Establishment of an adequate root system before outplanting made RPM™ seedlings less susceptible to transplant shock than were other planted seedlings. Dey et al. (2004) reported comparable height growth in RPM™ oak seedlings in Missouri. Containerized cherrybark oak exhibited slightly greater height growth than bare-root cherrybark oak (8.1 cm and 7.8 cm, respectively); however, the difference was not significant (Table 2).

Container Nuttall oak seedlings showed the least growth of the species/planting stock combinations. It is not typical for bare-root seedlings to outperform containerized seedlings although Self et al. (2009) observed bare-root seedlings exhibited greater height growth than containerized seedlings. In contrast, Rathfon et al. (1995) found no significant difference in height growth of bare-root and container red oak (*Q. rubra* L.) seedlings after one growing season. Height growth data were reported by site because of the statistical differences found between sites for height growth.

Table 1.—Average growth by species after one growing season on seedlings not exhibiting dieback/resprouts (all planting stocks and treatments)

Species	Height [†]	GLD
	---cm---	---mm---
Cherrybark oak	16.1 a [‡]	2.3 b
Nuttall oak	15.3 a	3.5 a

[†] Values are means of six replications.

[‡] Means within a column followed by the same letter do not differ at $\alpha = .05$.

Table 2.—Average growth after one growing season based on seedlings not exhibiting dieback/resprouts (all treatments)

Species	Height [†]	GLD
	--cm--	--mm--
Cherrybark oak		
Bare-root	7.8 d [‡]	1.3 c [†]
Container	8.1 d	1.4 c
RPM™	28.7 a	3.7 b
Nuttall oak		
Bare-root	13.0 c	3.6 b
Container	6.3 e	1.9 c
RPM™	23.8 b	4.7 a

[†] Values are means of six replications.

[‡] Means within a column followed by the same letter do not differ at $\alpha = .05$.

Height Growth Variation on the Garretson Tract

On the Garretson tract, RPM™ seedlings significantly outperformed both the bare-root and containerized seedlings in height growth (27.8 cm, 13.3 cm, and 8.8 cm, respectively). Other studies such as Shaw et al. (2003) reported similar results in which height growth of RPM™ seedlings exceeded that of bare-root and containerized seedlings.

The greatest height growth of any species/planting stock combination on the Garretson tract occurred in RPM™ cherrybark oak, RPM™ Nuttall oak, and bare-root Nuttall oak (30.2 cm, 25.1 cm, and 16.2 cm, respectively) (Table 3). Cherrybark oak bare-root and container seedlings exhibited similar height growths (9.6 cm and 9.5 cm, respectively). Container Nuttall seedlings exhibited the least height growth with only 7.2 cm of growth after the first growing season (Table 3).

RPM™ cherrybark oak seedlings exhibited approximately 30 percent greater height growth than any other cherrybark oak planting stock (Table 3). Bare-root Nuttall oak outperformed container seedlings of both species. The Nuttall bare-root seedlings may have performed so well because they were well suited for the site. No significant difference was found in height and GLD growth by species, so species were not analyzed by site.

Table 3.—Average height growth after one growing season based on seedlings not exhibiting dieback/resprouts on the Garretson and Norris tracts (all treatments)

	-----Site-----	
	Garretson	Norris
Cherrybark oak		
RPM™	30.2 a [†]	27.1 a [†]
Bare-root	9.6 d	6.5 d
Container	9.5 d	5.6 d
Nuttall oak		
RPM™	25.1 b	22.8 b
Bare-root	16.2 c	5.8 d
Container	7.2 e	8.8 c

[†] Means followed by the same letter do not differ at $\alpha = .05$.

Height Growth Variation: Sheltered vs. Unsheltered Bare-root Seedlings on the Garretson Tract

Seedlings with tree shelters exhibited greater height growth than unsheltered bare-root seedlings on the Garretson tract (16.7 cm and 9.4 cm, respectively). Sheltered Nuttall oak seedlings had greater height growth than any other species/shelter combination (20.8 cm). Sheltered cherrybark oak exhibited slightly greater growth than either Nuttall or cherrybark oak without shelters (10.2 cm, 9.7 cm, and 9.0 cm, respectively), but the difference was not significant.

Height Growth Variation on the Norris Tract

When planting stocks of both species were combined for analysis, RPM™ seedlings exhibited greater height growth than bare-root or container seedlings (24.7 cm, 7.4 cm, and 6.2, respectively). Planting stock results for the Norris tract are consistent with results from the Garretson tract.

RPM™ cherrybark oak, RPM™ Nuttall oak, and bare-root Nuttall oak had the greatest height growth of any species/planting stock combination (27.1 cm, 22.8 cm, and 8.8 cm, respectively) (Table 4). Container cherrybark, container Nuttall, and bare-root cherrybark

Table 4.—Average growth by species for sheltered and unsheltered bare-root seedlings after one growing season on seedlings not exhibiting dieback/resprouts

Treatment	Height [†]	GLD
	---cm---	---mm---
Nuttall oak		
Shelter	17.0 a [†]	3.1 b
No shelter	7.5 b	4.2 a
Cherrybark oak		
Shelter	8.5 b	1.3 c
No shelter	7.1 b	1.4 c

[†] Values are means of six replications.

[‡] Means within a column followed by the same letter do not differ at $\alpha = .05$.

oak growth were not significantly different (6.5 cm, 5.8 cm, and 5.6 cm, respectively). Height growth of RPM™ cherrybark was significantly greater than that of other species/planting stock combinations (Table 3). The second-highest height growth occurred in RPM™ Nuttall oak. Other than RPM™ seedlings of both species, Nuttall oak bare-root seedlings significantly outperformed all other species/planting stock combinations.

Height Growth Variation: Sheltered vs. Unsheltered Bare-root Seedlings

Sheltered seedlings exhibited greater height growth than unsheltered seedlings (13.6 cm and 7.3 cm, respectively). Shelters have been used in Europe for decades with great success (Morrow 1988), and, more recently, have been reported to provide beneficial increases in first-year height growth of seedlings in the United States (Bendfeldt et al. 2001, Conner et. al 2000). Thus, results of this study are consistent with earlier work in that shelters increased seedling height growth by nearly twofold. It is important to note that these results may be skewed slightly by the extraordinary height growth of sheltered Nuttall oak.

Sheltered bare-root Nuttall oak seedlings had at least twice the height growth of unsheltered Nuttall oak, sheltered cherrybark oak, and unsheltered cherrybark oak (17.0 cm, 7.5 cm, 8.5 cm, and 7.1 cm, respectively) (Table 4). Shelters have been known to increase height growth by as much as five times that of unsheltered seedlings (Potter 1987, 1988; Tuley 1985).

Height Growth Variation: Sheltered vs. Unsheltered Bare-root Seedlings on the Norris Tract

Sheltered seedlings exhibited greater height growth than unsheltered seedlings on the Norris tract (9.7 cm and 4.5 cm, respectively). Sheltered Nuttall oak seedlings had the greatest height growth of any species/shelter combination (11.9 cm) (Table 5). Sheltered cherrybark oak outperformed unsheltered seedlings of Nuttall and cherrybark oak (6.7 cm, 4.8 cm, and 4.1 cm, respectively) (Table 5). Unsheltered trees exhibited similar height growth rates and were not significantly different.

Table 5.—Average height growth by species for sheltered and unsheltered bare-root seedlings after one growing season on seedlings not exhibiting dieback/resprouts on the Norris tract

Treatment	Height [†]
	---cm---
Nuttall oak	
Shelter	11.9 a [‡]
No shelter	4.8 c
Cherrybark oak	
Shelter	6.7 b
No shelter	4.1 c

[†] Values are means of six replications.

[‡] Means followed by the same letter do not differ at $\alpha = .05$.

Height Growth Summary

Although height growth patterns on both sites were consistent, the amount of height growth varied by site (Table 6). Cherrybark oak had greater incremental growth than Nuttall oak. Bare-root seedlings outgrew container seedlings on both sites. Containerized seedlings exhibited the least height growth of the planting stocks in this study. Typically container seedlings have greater height growth than bare-root seedlings (Williams and Craft 1998). RPM™ cherrybark oak seedlings exhibited the greatest height growth of all species/planting stock combinations; container Nuttall oak seedlings exhibited the least height growth of all combinations. Bare-root Nuttall and cherrybark oak seedlings outgrew container Nuttall seedlings; however, their growth rates were not significantly different from container cherrybark seedlings even though they exhibited greater performance.

Table 6.—Average growth by site after one growing season on seedlings not exhibiting dieback/resprouts (all planting stocks, species, and treatments)

Growth	-----Site-----	
	Garretson	Norris
Ht (cm)	12.7 a [†]	8.6 b
GLD (mm)	2.4 a	2.1 a

[†] Means within a row followed by the same letter do not differ at $\alpha = .05$.

Overall GLD Growth

The data for GLD growth were not analyzed by site because the growth did not vary by site (Table 6). When data for both species were combined for analysis, RPM™ seedlings exhibited the greatest GLD growth of all the planting stocks (4.7 mm). Container seedlings exhibited significantly less GLD growth than bare-root seedlings (1.6 mm, 2.6 mm, respectively). Bare-root seedlings are generally expected to have less GLD growth than container seedlings (Rathfon et al. 1995, Williams and Craft 1998, Williams and Stroupe 2002).

For all planting stocks, GLD growth was greater for Nuttall than for cherrybark oak (3.5 mm and 2.3 mm, respectively) (Table 1). The greatest amount of GLD growth occurred in RPM™ Nuttall oak, RPM™ cherrybark oak, and bare-root Nuttall oak (4.7 mm, 3.7 mm, and 3.6 mm, respectively) (Table 2), and that of RPM™ Nuttall oak was significantly greater than for any other species/planting stock combination. Bare-root cherrybark oak, container Nuttall oak, and container cherrybark oak seedlings exhibited similar GLD growth (1.3 mm, 1.9 mm, and 1.4 mm, respectively) (Table 2).

GLD Growth Variation: Sheltered vs. Unsheltered Bare-root Seedlings

When both species were combined for analysis, sheltered seedlings exhibited significantly less GLD growth than unsheltered seedlings (2.4 mm and 2.9 mm, respectively). Unsheltered Nuttall oak seedlings exhibited greater GLD growth than sheltered Nuttall oak seedlings (4.2 mm and 3.1 mm, respectively) (Table 4).

There was no significant GLD difference between sheltered and unsheltered cherrybark oak seedlings (1.3 mm and 1.4 mm, respectively), which indicates that the benefit of tree shelters may not offset the cost of installation. McCreary and Tecklin (2001) found that blue oak (*Q. douglasii*) seedlings with shelters exhibited significantly greater growth than unsheltered seedlings. However, Teclaw and Zasada (1996) found that tree shelters had no effect on growth of northern red oak.

CONCLUSIONS

Many managerial decisions can be made based upon the data collected. Survival is often linked to growing conditions, but the first step in obtaining good survival is the use of careful planting techniques and selecting species adapted to the site characteristics. If rapid height growth is desired to get oak seedlings above competing vegetation on bottomland sites, consider planting cherrybark RPM™ seedlings if economically feasible. The price of the RPM™ planting stock in 2011 was \$11.50 per seedling. If the decision is left between bare-root (\$0.25/seedling) and containerized (\$1.25/seedling) planting stocks, this study indicated bare-root Nuttall and cherrybark seedlings outgrew the containerized seedlings in height. However, containerized planting stocks typically outgrow bare-root planting stocks due to less planting stress on the seedling (Williams and Stroupe 2002). Another consideration in deciding between species to plant is the greater GLD growth observed in Nuttall compared to cherrybark seedlings. This study also indicates that the use of tree shelters can increase height when planting bare-root Nuttall or cherrybark oak seedlings, but this alternative may not be economically feasible when labor expenses associated with installing shelters across large planting sites are considered.

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