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Artificial Regeneration of Bottomland Hardwoods in Southern Mississippi on Lands Damaged by Hurricane Katrina

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ARTIFICIAL REGENERATION OF BOTTOMLAND HARDWOODS IN SOUTHERN MISSISSIPPI ON LANDS DAMAGED BY HURRICANE KATRINA

By

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ARTIFICIAL REGENERATION OF BOTTOMLAND HARDWOODS IN SOUTHERN

MISSISSIPPI ON LANDS DAMAGED BY HURRICANE KATRINA

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Bare-root, container, and root production method (RPM™) seedlings of two oak species (Nuttall (*Quercus texana* Buckley), cherrybark (*Q. pagoda* Ell.)) were planted on lands damaged by Hurricane Katrina in southern Mississippi to compare the height growth, groundline diameter growth and survival of the different planting stocks. Tree shelters were applied to half of the bare-root seedlings to determine their effect on the height and groundline diameter growth and survival of the seedlings.

RPM seedlings exhibited significantly greater height and groundline diameter growth than bare-root or container seedlings after one growing season. Bare-root seedlings exhibited significantly greater height and groundline diameter growth than container seedlings. Tree shelters significantly increased height growth of bare-root seedlings; however, sheltered bare-root seedlings exhibited significantly less groundline diameter growth than non-sheltered seedlings. Cherrybark oak exhibited greater height growth than Nuttall oak, while Nuttall oak exhibited greater groundline diameter growth than cherrybark across all planting stocks.

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CHAPTER I

INTRODUCTION

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

In order to solve the problem of inadequate oak regeneration, many private landowners have decided 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 reforestation failures (Patterson and Adams 2003). The poor survival of oaks has been linked to a few characteristics such as slow growth, rapid growth of competing vegetation, poor planting, and poor seedling quality (Russell 1971, Johnson et al. 1986, McGee and Loftis 1986, Pope 1993). Because of the potentially high mortality rates, it is important to match species with site, plant vigorous seedlings, and abide by proper planting methods.

In 2005, Hurricane Katrina destroyed thousands of acres of bottomland hardwood forest in Mississippi. Similar to a harvest disturbance, natural regeneration of these hurricane disturbed lands may result in species dominating the site which are undesirable for landowner objectives (Peterson and Pickett 1995, Battaglia et al. 1999, Aust et al. 2006). 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 non-industrial private landowners. Federal programs such as the Wetlands Reserve Program (WRP) and Conservation Reserve Program (CRP) offer cost shares to offset the cost of restoring bottomland hardwoods (Williams and Craft 1998). However, Schweitzer and Stanturf (1997) found that only nine percent of the total reforested land in Mississippi planted in the WRP program met the Natural Resources Conservation Service requirement of at least 125 hard mast stems per acre in three-year-old stands. A possible explanation for the failures is the fact that the program mainly uses direct seeding and bare-root seedlings. The use of a different planting stock may increase the 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 created thus far concerning planting stock comparisons and ensuring proper stocking of oaks on a site. This was a valuable opportunity to study management practices following a major disturbance event and provide managers and private landowners with recommendations for future work.

Objectives

The overall objective of this study was:

To determine the effect of species, planting stock and tree shelters on survival and growth of oak seedlings planted on Hurricane Katrina damaged lands.

Specific objectives included:

a) Compare the overall survival, height growth and groundline diameter (GLD) growth of Nuttall oak (*Quercus texana* Buckley) and cherrybark oak (*Q. pagoda* Ell.) one year after planting.

b) Compare the survival and growth rates of three different planting stocks for Nuttall oak and cherrybark oak one year after planting. The planting stocks included: 1-0 bare-root, containerized (25 in^3 Nuttall, 20.25 in^3 cherrybark), and 3 gallon root production method (RPM™) seedlings.

c) Evaluate the effect of tree shelters on survival and growth rates of bare-root Nuttall oak and cherrybark oak seedlings.

CHAPTER II

LITERATURE REVIEW

Tree Shelters

Tree shelters have been used to establish a wide variety of species, especially oaks, in many locations across Europe (Morrow 1988). In 1986, over six million tree shelters were being used in Great Britain (Potter 1987). McCreary and Tecklin (2001) showed that regardless of size, shelters were effective in increasing height growth of oak seedlings. As a result of reported successes, tree shelters have become popular in the United States. Many studies have been conducted attempting to quantify the effectiveness of shelters on oak seedling growth and survival. These studies have found that utilizing tree shelters increases height growth of oak seedlings during the first and second growing season (Lantagne et al. 1990, Minter et al. 1992, McNeel et al. 1993, Walters 1993, Ponder 1997, Conner et al. 2000, Bendfeldt et al. 2001, McCreary and Tecklin 2001). Some studies have shown that tree shelters could increase height growth of oak seedlings by as much as five times that of unsheltered trees after the third growing season (Tuley 1985, Potter 1988, Lantagne 1991). Studies have shown that tree shelters also significantly affect the GLD growth of oak seedlings after two growing seasons (Kittredge et al. 1992, Dubois et al. 2000). Tree shelters have also been shown to increase survival of oak seedlings (Marquis 1977, Tuley 1983, Lantagne 1991, Ward and

Stephens 1995, Mayhead and Boothman 1997, Schweitzer et al. 1999, West et al. 1999, Dubois et al. 2000).

Although many studies report that tree shelters increase height growth, GLD growth, and survival, few studies attempt to explain these results. Some have suggested that the enhanced growth might be related to the micro-environmental effects of the shelters (Potter 1988, Clatterbuck 1999), which may prolong the growing season (Ponder 1994). Peterson et al. (1994) studied these micro-environmental effects and determined that the high relative humidities inside the tree shelters reduced moisture stress and was shown to correspond with height growth. Potter (1988) showed that the reduced moisture stress was due to the reduction of air movement inside the shelter. Another possible cause for increased height growth of sheltered oak seedlings is that carbon dioxide levels may be higher in sheltered than unsheltered seedlings creating conditions similar to those in a greenhouse (Rendle 1985), which increases seedling growth rates (Frearson and Weiss 1987, Mayhead and Jones 1991, Minter et al. 1992). Increased height growth of sheltered seedlings has also been attributed to a reallocation of growth from roots and branches to the terminal leader as well as physical protection from breakage and animal browse (Lantagne et al. 1990).

Strange and Shea (1998) reported that tree shelters prevented seedling damage from deer browsing and consequently reduced the mortality rate from 34.6 percent to 3.2 percent on northern red oak (*Quercus rubra* L.) in Minnesota. Their results are consistent with other studies that have shown tree shelters reduce browsing (Marquis 1977, Strobi and Wagner 1995, Dubois et al. 2000). A study in New England reported that placing tree shelters around natural regeneration allowed the oaks to grow above the range of deer browse within 1-3 years (Kittredge et al. 1992).

Although the majority of studies have shown that tree shelters increase survival and growth of oak seedlings, there are a few that report otherwise. McNeel et al. (1993) found that there was no significant difference on survival of sheltered and unsheltered northern red oak seedlings in West Virginia. Other studies have agreed with McNeel's findings on the survival of sheltered oak seedlings (Baer 1980, Minter et al. 1992, Clatterbuck 1996). Clatterbuck (1999) reported that after seven growing seasons there was no significant height growth difference between sheltered and unsheltered seedlings of six hardwood species in Tennessee. Other studies have also found that tree shelters have no significant effect on height growth of oak seedlings (Teclaw and Zasada 1996, Zaczek et al. 1997). According to one study, tree shelter effectiveness is related to site quality (Windell 1992). Tree shelters are expensive to purchase and install, and they also require monthly maintenance, which may limit their use in large plantings. Tree shelters 36 inches tall range from $0.79 to $3.74. In large plantings with hundreds of trees per acre, this expense may be too much for a landowner to absorb. High winds may also cause the shelters to come apart, or be pulled from the ground.

Species

Cherrybark oak is recognized as a highly valuable bottomland hardwood tree species (Krinard and Francis 1983, Krinard 1990, Kennedy 1993). Howell and Harrington (2004) found container cherrybark oak seedling survival at the end of the second growing season to be over 90 percent, which is consistent with other studies

(Kormanik et al. 1976, Stanturf and Kennedy 1996). However, Self et al. (2009) observed that Nuttall oak exhibited higher survival than cherrybark oak (61.7 percent and 42.8 percent, respectively) on a site with saturated soil conditions in Louisiana. One of the most important factors affecting seedling survival can be flooding (Krinard and Johnson 1981, Wood 1998). Williams et al. (1992) reported that Nuttall oak exhibited a survival rate of nearly 97.0 percent on an area with high soil moisture, whereas cherrybark oak on the same site exhibited only a 65.0 percent survival rate. Previous studies have found Nuttall oak to be a more water tolerant species than cherrybark oak. (Burns and Honkala 1990). Allen (1990) observed Nuttall oak to exhibit higher growth rates than cherrybark oak when planted on the same site.

Soil pH levels are an important factor in determining how well a species will grow on a site. According to Williston and LaFayette (1978) Nuttall oak will grow in a pH ranging from 3.6-6.8, while cherrybark desires a range of 4.5-6.2. Nutrient absorption levels outside the ranges specified can be toxic to the trees, and may result in severe injury or death. Improper pH levels may also interfere with the uptake of other essential nutrients (Williston and LaFayette 1978).

Bare-root Seedlings

The majority of the hardwood seedlings planted in the southern United States are 1-0 bare-root seedlings (McNabb and Dos Santos 2004). The first number refers to the number of years the seedling was in a nursery bed while the second number refers to the number of years the seedling grew as a nursery outplant (Jacobs 2003). The roots of bare-root seedlings consist primarily of a large tap root with a varying number of primary and secondary laterals (Williams and Craft 1998). Schultz and Thompson (1997) recommended that bare-root oak seedlings have at least five first order lateral roots for successful establishment. Bare-root seedlings have been shown to have excellent survival, especially on high quality sites (Allen 1990, Miwa 1995). Increased survival tends to occur when bare-root seedlings are planted in moist soils (Stanturf et al. 2000). In addition to their high survival rates, Jacobs (2003) noted that 100 bare-root red oak (*Quercus spp.)* seedlings from a nursery in Indiana were $25.30, while 100 seedlings in three gallon pots were $1065.00. Based on these study results, bare-root seedlings are a more cost-effective choice under appropriate conditions (Allen et al. 2001, Burkett et al. 2005).

Bare-root seedlings are less expensive to purchase and plant. Burkett et al. (2005) found that they outgrew containerized seedlings at higher, non-flooded elevations after five growing seasons on the Yazoo National Wildlife Refuge in Mississippi. However, it has been noted that bare-root seedlings commonly have negligible height growth after the first growing season due to shoot dieback (Johnson 1984, Shaw et al. 2003).

<u>Container Seedlings</u>

Only 0.3 percent of oak seedlings planting in the South are containerized seedlings (McNabb and dos Santos 2004). Containerized seedlings were first produced in order to accelerate reforestation, improve seedling survival and growth, extend planting seasons, achieve greater planting efficiencies, and create an intact seedling for outplanting (Stein et al. 1975). Containerized seedling production promotes fibrous root system development, produces morphologically improved seedlings with compact root

systems, and protects the roots until outplanting (Dixon et al 1981, Landis et al. 1990, Howell and Harrington 2004). Due to their advanced fibrous root system, containerized oak seedlings have been shown to exhibit better survival than bare-root seedlings (Rathfon et al. 1995, Burkett and Williams 1998) on droughty sites (Arnott 1975, Hobbs and Wearstler 1983, Nilsson and Orlander 1995), and on flood prone sites (Humphrey 1994, Howell 2001). Williams and Craft (1998) reported that containerized Nuttall oak seedlings exhibited better survival than bare-root or direct seeded Nuttall oak regardless of planting date when planted in Sharkey soil. Burkett et al. (2005) found that containerized seedlings exceeded 96 percent survival while bareroot seedlings had a survival rate of only 45 percent on the Yazoo National Wildlife Refuge in Mississippi. This is consistent with studies that have shown that containerized seedlings had survival rates twice that of bareroot seedlings (White et al. 1970, McDonald 1991, Self et al. 2009). One explanation for the higher survival rates of containerized seedlings on poor sites is that containerized seedlings experience lower handling stresses prior to and during planting (White et al. 1970), and lower stress on drier sites due to increased water holding capabilities from the container (Hobbs and Wearstler 1983, Nilsson and Orlander 1995).

RPM™ Seedlings

Kormanik et al. (1995) found that seedlings with larger initial diameters exhibit greater survival and growth rates on bottomland sites. Thus, RPM™ seedlings may be effectively used to reforest bottomland hardwood sites, due to their larger sizes. RPM™ is an air pruning method developed by Forrest Keeling Nursery in Elsberry, MO (Lovelace 1998). Air pruning is a proven way to promote lateral root growth and a dense fibrous root system (Dey et al. 2004). Air pruning promotes new root sprouts, encourages branched roots, and prevents roots from spiraling. Seedlings grown using this method tend to attain basal diameters of 2.5 centimeters, heights greater than 1.5 meters, and root systems with a volume four to nine times greater than bareroot seedlings one to two years after out planting (Shaw et al. 2003). Air pruned root systems provide better absorption and utilization of oxygen, water, and nutrients due to a large surface area (Grossman et al. 2003b). Other advantages of RPM™ seedlings include improved growth and survival, a terminal shoot above deer browse (4 ft.) and flooding heights, and precocious mast production (Grossman et al. 2003b). Shaw et al. (2003) found survival of RPM™ seedlings to be approximately 99 percent on sites in Missouri. Other studies have found RPM™ seedling survival over 94 percent (Dey et al. 2003). Studies have also shown that RPM™ seedlings exhibit greater basal diameter growth than containerized and bareroot planting stocks (Dey et al. 2003, Shaw et al. 2003, Kabrick et al. 2005). Davis and Jacobs (2004) reported RPM™ seedlings showed reduced water stress on reclamation sites.

Seedling Morphology

Although planting stock can have a significant influence on survival, height growth, and diameter growth, inferior seedling morphology within each stock may negatively impact growth rates and survival (Pope 1993). Some of these morphological characteristics which may indicate oak seedling field performance include stem size, foliage biomass, leaf area, shoot/root ratio, and number of first order lateral roots (Moorhead 1981, Hodges and Gardiner 1993, Kormanik et al. 1998, Howell and

Harrington 2004). Grossnickle (2005) concluded that root growth may be the most critical factor in the establishment of planted seedlings. These conclusions were derived on the premise that an adequate root system allows the seedling to establish a proper water balance which allows the seedling to respond to conditions such as drought (Margolis and Landis 1990). Along with the previously mentioned characteristics, it has been recommended that a competitive seedling should have a stem height above 1.5 meters and a GLD above ten millimeters to overcome deer browse and competing vegetation (Hannah 1987, Pope 1993). Although deer browse can have a significant effect on seedling survival, one of the greatest causes of mortality on many sites is planting stress (Vyse 1981, Waters et al. 1991), therefore it is important to plant seedlings with favorable root morphology.

Some research also suggests that seedlings grown from larger acorns show increased root collar diameter, survival and height (Bonfil 1998, Ke and Werger 1999, Grossman et al. 2003a). However, Long and Jones (1996) found no relationship between acorn size and seedling growth.

Hurricane Katrina

Natural disasters such as hurricanes may have devastating effects on the landscape; however they do provide rare and unique opportunities to develop new regeneration cohorts (King and Allen 1996). On August 29, 2005, Hurricane Katrina, termed the most costly natural disaster in U.S. history, made landfall 34 miles east of New Orleans, LA (Stanturf et al. 2007). Tree mortality after Hurricane Katrina has been estimated as high as 66.8 million stems for trees with a diameter at breast height (dbh) greater than one inch, while total trees greater than one inch dbh that experienced damage was estimated at 521 million (Oswalt et al. 2008). In addition to the trees over one inch dbh damaged, smaller hardwood regeneration could have also been damaged from large branches falling from the overstory as was observed after a hurricane in Puerto Rico (Frangi and Lugo 1991). Mississippi forests suffered 67 percent of the tree damage caused by Hurricane Katrina (FIA 2005), with bottomland hardwood forests suffering the greatest percentage of damage of all hardwoods (Chapman et al. 2008). Delayed mortality of sprouting trees during hurricanes such as Katrina may have made the damage to impacted forests much greater than could be quantified (Smith et al. 1994, Walker et al. 1996, Xi et al. 2008).

Herbicide

Competing vegetation is possibly the most influential factor in oak plantation failures. Both herbaceous and woody competition may pose a threat to the survival of planted oak seedlings, with herbaceous competition posing the greatest threat during the first years of establishment (Stanturf et al. 2004). Controlling competing vegetation is an essential component of hardwood plantation establishment (Bey et al. 1976). Bare-root oak seedlings grown in bottomlands do not grow well with competing vegetation; therefore, herbicides such as Oust® are necessary to facilitate growth (Schweitzer and Stanfurf 1997). Herbicides applied post planting have been shown effective in reducing vegetative competition (Stanturf et al. 2004), however Groninger et al. (2004) found Oust® application will release and increase broomsedge (*Andropogon virginicus* L.)

cover when that species is present. Broomsedge is not controlled by Oust® according to the herbicide label.

Studies have shown that after a pre-emergent application of Oust®, survival of red oak and ash seedlings increased approximately 15-23 percent (Ezell and Catchot 1998). Ezell et al. (2007) reported that survival was 21 to 44 percent higher on areas treated with Oust® compared to non-treated areas, depending on rainfall amounts during the first growing season.

Caution should be taken when applying herbicide to oak seedlings because of their susceptibility to damage. However, at least eight hardwood species are known to be tolerant to a pre-emergent Oust® application (Rhodenbaugh and Yeiser 1994). In support of these findings Ezell and Catchot (1998) reported no damage was exhibited after a pre-emergent treatment of Oust® applied over the top of red oak and ash seedlings.

CHAPTER III

MATERIALS AND METHODS

Site Description

Two study areas on bottomland hardwood sites damaged by Hurricane Katrina were chosen for reforestation and evaluation. 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 prep 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 prior to the first growing season included blazing star (*Liatris spicata* Willd.), boneset (*Eupatorium spp.* L.), partridge pea (*Chamaecrista fasciculate* Michx.), broomsedge, blackberry (*Rubus* L.), rush (*Juncus* L.), goldenrod (*Oligoneuron* Small), gallberry (*Ilex* Chapm.), and hoary mountain mint (*Pycanthemum incanum* L). Tree species present on the area prior to the salvage cut included blackgum (*Nyssa sylvatica* Marsh.), sweetgum (*Liquidambar styraciflua* L.), 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 (*Quercus 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 while smaller stumps were removed. The dominant tree species on the area prior to 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 yucca (*Yucca* L.), Carolina horsenettle (*Solanum carolinense* L.), *Rubus* spp., 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 4.6-5.0, which is within the pH range for cherrybark and Nuttall oak.

<u>Demarcation</u>

The study areas were divided into three replicates. Each replicate was located on uniform areas across the site. On the Garretson tract, two of the replicates were 130 ft. X 520 ft. These replicates consisted of 12 rows of 50 seedlings each. Because of a large flooded area, the third replicate had a different configuration, of 150 ft. X 600 ft. and consisted of nine rows of 50 seedlings, five rows of 25 seedlings, one row of 15 seedlings, and one row of 10 seedlings.

On the Norris tract, the first replicate was 300 ft. X 270 ft. consisting of 20 rows of 20 seedlings, and eight rows of 25 seedlings. The second replicate was 250 ft. X 270 ft. consisting of 24 rows of 25 seedlings. The third replicate was 460 ft. X 270 ft. consisting of 21 rows of 25 trees, one row of 20 trees, and three rows of 10 trees.

All trees were planted on 10 ft. X 10 ft. spacing. The location of each tree to be planted was marked with a 36-inch colored pin flag. Each planting stock/species combination was denoted by a different color pin flag. Row ends were marked with a four-foot section of 3/8" steel rebar and flagging. An aluminum tag with the row number was attached to the rebar.

Treatments

Treatments included planting stock, species, herbicide treatment, and tree shelters. Protex tree shelters 36-inches tall were placed on half of the bare-root seedlings March 2010 after initial measurements were taken. All bare-root seedlings received a post planting, pre-emergent (one week after planting) banded herbicide treatment of Oust XP® (2 oz/ sprayed acre). The herbicide was applied over the top of seedlings using a backpack sprayer to apply a five-foot swath with the seedling as the center of the spray swath.

Seedling Establishment

RPM™ seedlings were planted in early February 2010 by a contractor. The RPM™ seedlings were produced from seeds collected in Louisiana and Mississippi. The seedlings were grown using the RPM™ at a nursery in Ravenel, South Carolina. Half of the RPM™ seedlings were planted using an ASV R-series RC-30 rubber track loader with an auger, while the other half were planted using planting shovels. Crews were monitored by a Mississippi State University graduate student to ensure the trees were being planted correctly. RPM™ 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 hand planted using planting shovels. Bare-root seedlings had an initial average height of 57.2 cm and GLD of 8.1 mm, while containerized seedlings initially averaged a height of 59.7 cm and GLD of 6.9 cm.

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, while GLD's were measured in millimeters using digital calipers. Height measurements were recorded as the height from ground level to the terminal bud. GLD's were measured just above the root collar. Survival of the seedlings was recorded monthly from May-October 2010. If ocular observations determined seedlings to be dead, the cambium layer was examined to confirm the seedlings status.

Experimental Design and Analysis

Experimental design for this study was a randomized complete block design with three replicates per site. The randomized complete block design assumes homogeneity of variances, and that the experimental units are homogeneous. The experimental unit was the plot, which has its own 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 for a total of 600 seedlings per replicate. Each site had a total of 1800 seedlings planted. The location of the six planting stock and species combinations was randomly assigned within each replicate. Analysis of variance was performed using PROC GLM in statistical analysis systems (SAS) software version 9.2®. 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). When analyzing the survival data, a histogram of residuals was made. Since the residuals were not mounded and symmetric, an analysis of percent plot survival with an arc sine transformation was performed. Differences among treatments were tested at $\alpha = 0.05$.

CHAPTER IV

RESULTS AND DISCUSSION

Overall Survival

Ezell and Catchot (1998) showed that site can have an effect on hardwood seedlings survival. However, a significant difference between sites in this study was not observed; therefore survival data were analyzed as a whole and not by site.

Survival for Nuttall oak was significantly higher than survival for cherrybark oak, although cherrybark oak survival was 98.1 percent and the difference was only 1.1 percent (Table 1). These results agree with Self et al. (2009) which found Nuttall oak to exhibit higher survival than cherrybark oak on a saturated site in Louisiana, but the difference in this study was much less than Self et al. (2009) found.

There were no significant differences observed in survival among planting stocks. Although no significant differences were observed, container seedlings exhibited the highest survival rates at 99.4 percent (Table 2). Bare-root seedlings exhibited the lowest survival level of the planting stocks; however bare-root survival was still exceptional (98.0 percent). Overall survival of all planting stocks after one growing season was over 98 percent or higher, which is excellent.

Container Nuttall oak, container cherrybark oak, bare-root Nuttall oak, and RPM™ Nuttall oak all exhibited a survival percentage greater than 99 percent (Table 3). All other species/planting stock combinations exhibited survival 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 (Table 3). Bare-root Nuttall oak only exhibited 0.1 percent lower survival than containerized Nuttall oak, and 0.5 percent lower survival than RPM™ Nuttall. Bare-root cherrybark oak seedlings exhibited lower survival rates than both containerized and RPM™ cherrybark seedlings, however the difference was less than three percent in both cases (Table 3).

Table 1 Average Survival by Species After one Growing Season (all planting stocks and treatments)

Species	Survival[1]
	-----%-----
Cherrybark oak	98.1 B[2]
Nuttall oak	99.2 A

[1] Values are means of six replications
[2] Means followed by the same letter do not differ at α=.05

Table 2 Average Survival by Planting Stock After one Growing Season (all species and treatments)

Planting Stock	Survival[1]
	----%----
RPM™	98.6 AB[2]
Bare-root	98.0 B
Container	99.4 A

[1] Values are means of six replications
[2] Means followed by the same letter do not differ at α=.05

Table 3 Average Seedling Survival at Monthly Observations, May-October 2010 (all treatments)

	Timing of Observation					
Planting Stock	May	June	July	August	September	October
	percent[1]					
Container						
CBO	99.8	99.8	99.8	99.7	99.7	99.7 A[3]
NUO	99.3	99.3	99.1	99.1	99.1	99.1 AB
Bare-root						
CBO	99.2	98.4	97.1	97.1	97.1	97.1 C
NUO	99.1	99.1	99.0	99.0	99.0	99.0 AB
RPM™						
CBO	97.6	97.6	97.6	97.6	97.6	97.6 CB
NUO	99.6	99.6	99.5	99.5	99.5	99.5 A

[1] Values are means of six replications
[2] CBO= cherrybark oak, NUO= Nuttall oak
[3] Means followed by the same letter do not differ α=.05

Survival: Sheltered vs. Non-Sheltered Bare-root Seedlings

No significant difference in survival was detected between sheltered and non-sheltered seedlings. Both sheltered and non-sheltered seedlings exhibited excellent survival levels above 97 percent (97.3 percent and 98.8 percent, respectively) (Table 4).

Non-sheltered Nuttall oak seedlings exhibited the greatest survival at 99.6 percent. Cherrybark oak seedlings with shelters had the least survival of the species/shelter combinations (Table 5). Sheltered and non-sheltered Nuttall oak exhibited greater survival levels than sheltered and non-sheltered cherrybark oak. Although significant differences were observed, regardless of species/shelter combination survival was excellent.

Table 4 Survival for Sheltered and Non-sheltered Bare-root Seedlings After one Growing Season

Treatment	Survival[1]
	-----%-----
Shelter	97.3 A[2]
No Shelter	98.7 A

[1] Values are means of six replications
[2] Means followed by the same letter do not differ at α=.05

Table 5 Survival by Species for Sheltered and Non-sheltered Bare-root Seedlings After One Growing Season

Treatment	Survival[1]
	-----%-----
Nuttall oak	
Shelter	98.4 A[2]
No Shelter	99.6 A
Cherrybark oak	
Shelter	96.3 B
No Shelter	98.0 A

[1] Values are means of six replications
[2] Means followed by the same letter do not differ at α=.05

Survival Summary

First year survival of Nuttall and cherrybark oak seedlings was excellent. Although Nuttall oak seedlings exhibited a significantly greater survival percentage than cherrybark oak seedlings, survival of both species was greater than 98 percent. The high survival rates are consistent with other studies, including studies conducted in a nursery setting (Jacobs 2003).

All planting stocks exhibited excellent survival after one growing season. Container seedlings exhibited the greatest survival; however, the survival level was not statistically different from the survival levels of RPM™ seedlings.
Tree shelters did not affect the survival of oak seedlings. Sheltered and non-sheltered seedlings all exhibited survival levels of over 97 percent.

Growth

Analyses of growth data were performed only on seedlings that did not exhibit dieback or resprout (n=3017). Therefore, only seedlings exhibiting an increase in height or groundline diameter were included in the analyses. It was concluded that seedlings not exhibiting an increase in height or groundline diameter were masking the realistic growth potential of the seedlings.

Overall Height Growth

Overall, cherrybark oak exhibited greater height growth than Nuttall oak (16.1 cm and 15.3 cm, respectively) (Table 7), however the difference was not significant. RPM™ seedlings exhibited significantly greater average height growth than bare-root and container seedlings (26.3 cm, 10.7 cm, and 7.3 cm, respectively) (Table 8). Bare-root seedlings exhibited significantly greater height growth than container seedlings which is not typical. 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 be due to the fact that bare-root seedlings were high-quality with a substantial number (average > 8) of first order lateral roots allowing seedlings to allocate resources to height growth. Another possible explanation is planting quality. Operational planters often tend to focus more on planting speed than planting quality, however in this study great care was taken to plant all seedlings properly.

RPM™ cherrybark oak, RPM™ Nuttall oak, and bare-root Nuttall oak exhibited the greatest height growth of all the species/planting stock combinations (28.7 cm, 23.8 cm, and 13.0 cm, respectively) (Table 6). Due to an adequate root system being established prior to outplanting, RPM™ seedlings were subject to less transplant shock than other planted seedlings. Dey et al. (2004) reported comparable height growth in Missouri. Containerized cherrybark oak exhibited greater height growth than bare-root cherrybark (8.1 cm and 7.8 cm, respectively); however the difference was not significant (Table 6). The least growth of all the species/planting stock combinations occurred in container Nuttall seedlings (6.3 cm). It is not typical for bare-root seedlings to outperform containerized seedlings; however 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 (*Quercus rubra* L) seedlings after one growing season.

Table 6 Average Growth After One Growing Season Based on Seedlings Not Exhibiting Dieback/Resprouts (all treatments)

Species	Height[1]	GLD
	--cm--	--mm--
Cherrybark oak		
Bare-root	7.8 D[2]	1.3 C[1]
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

[1] Values are means of six replications
[2] Means within a column followed by the same letter do not differ at α=.05

Table 7 Average Growth by Species After one Growing Season on Seedlings not Exhibiting Dieback/Resprouts (all planting stocks and treatments)

Species	Height[1]	GLD
	---cm---	---mm---
Cherrybark oak	16.1 A[2]	2.3 B
Nuttall oak	15.3 A	3.5 A

[1] Values are means of six replications
[2] Means within a column followed by the same letter do not differ at α=.05

Table 8 Average Growth by Planting Stock After one Growing Season on Seedlings not Exhibiting Dieback/Resprouts (all species and treatments)

Planting Stock	Height[1]	GLD
	---cm---	---mm---
RPM™	26.3 A[2]	4.7 A
Bare-root	10.7 B	2.6 B
Container	7.3 C	1.6 C

[1] Values are means of six replications
[2] Means within a column followed by the same letter do not differ at α=.05

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

Sheltered seedlings exhibited significantly greater height growth than non sheltered seedlings (13.6 cm and 7.3 cm, respectively) (Table 10). Shelters have been used in Europe for decades with great success (Morrow 1988), and more recently, shelters have been reported to provide beneficial increases in first year height growth of seedlings in the United States (Conner et. al 2000, Bendfeldt et al. 2001). 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 exhibited significantly greater height growth than non-sheltered Nuttall oak, sheltered cherrybark or non-sheltered cherrybark oak (17.0 cm, 7.5 cm, 8.5 cm, and 7.1 cm, respectively) (Table 9). Sheltered Nuttall oak exhibited at least two times the height growth of non-sheltered cherrybark oak and Nuttall oak and sheltered cherrybark oak (Table 9). Shelters have been known to increase height growth by as much as five times that of unsheltered seedlings (Tuley 1985, Potter 1988).

Table 9 Average Growth by Species for Sheltered and Non-sheltered Bare-root Seedlings After One Growing Season on Seedlings not Exhibiting Dieback/Resprouts

Treatment	Height[1]	GLD
	---cm---	---mm---
Nuttall oak		
Shelter	17.0 A[2]	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

[1] Values are means of six replications
[2] Means within a column followed by the same letter do not differ at α=.05

Table 10 Average Growth for Sheltered and Non-sheltered Bare-root Seedlings after one Growing Season on Seedlings not Exhibiting Dieback/Resprouts

Treatment	Height[1]	GLD
	---cm---	---mm---
Shelter	13.6 A[2]	2.4 B
No Shelter	7.3 B	2.9 A

[1] Values are means of six replications
[2] Means within a column followed by the same letter do not differ at α=.05

Growth Variation by Site

Although the Garretson and Norris tracts were very similar, some results indicated a significant difference in growth between the two (Table 11). Due to the tract differences, each tract was analyzed separately when a significant difference was present to ensure any differentiation between tracts was taken into account.

Table 11 Average Growth by Site After One Growing Season on Seedlings not Exhibiting Dieback/Resprouts (all planting stocks, species and treatments)

	----------Site----------	
Growth	Garretson	Norris
Ht[1]	12.7 A[3]	8.6 B
GLD[2]	2.4 A	2.1 A

[1] in cm
[2] in mm
[3] rows followed by the same letter do not differ at α=.05

Height Growth Variation on the Garretson Tract

On the Garretson tract, RPM™ seedlings significantly outperformed both the containerized and bare-root seedlings in height growth (27.8 cm, 8.8 cm, and 13.3 cm, respectively) (Table 13).RPM™ seedlings exhibited over three times the height growth of container seedlings, and doubled the height growth of bare-root seedlings. Other studies such as Shaw et al. (2003) reported similar results in which RPM™ seedlings significantly outperformed bare-root and container seedlings. Few previous studies have reported results in which bare-root seedlings have significantly outperformed containerized seedlings.

RPM™ cherrybark oak, RPM™ Nuttall oak, and bare-root Nuttall oak exhibited the greatest height growth of any species/planting stock combination on the Garretson tract (30.2 cm, 25.1 cm, and 16.2 cm, respectively) (Table 12). 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 12).

RPM™ cherrybark oak seedlings exhibited approximately 30 percent greater height growth than any other cherrybark oak planting stock (Table 12). Bare-root Nuttall significantly outperformed container seedlings of both species. The Nuttall bare-root seedlings may have performed so well because they were well suited for the site. Due to the lack of a significant difference in height and GLD growth by species, species was not analyzed by site.

Table 12 Average Height Growth After One Growing Season Based on Seedlings not Exhibiting Dieback/Resprouts on the Garretson Tract (all treatments)

Species	Height
	----cm----
Cherrybark oak	
RPM™	30.2 A[1]
Bare-root	9.6 D
Container	9.5 D
Nuttall oak	
RPM™	25.1 B
Bare-root	16.2 C
Container	7.2 E

[1] means followed by the same letter do not differ at α=.05

Table 13 Average Height Growth by Planting Stock After one Growing Season on Seedlings not Exhibiting Dieback/Resprouts on the Garretson Tract (all species and treatments)

Planting Stock	Height[1]
	--cm--
RPM™	27.8 A[2]
Bare-root	13.3 B
Container	8.8 C

[1] Values are means of six replications
[2] Means followed by the same letter do not differ at α=.05

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

Seedlings with tree shelters exhibited significantly greater height growth than non-sheltered bare-root seedlings on the Garretson tract (16.7 cm and 9.4 cm, respectively) (Table 15). Sheltered Nuttall oak seedlings exhibited greater height growth than any other species/shelter combination (20.8 cm). Sheltered cherrybark oak exhibited slightly greater growth than either Nuttall oak or cherrybark oak without shelters (10.2 cm, 9.7 cm, and 9.0 cm, respectively) (Table 14), but the difference was not significant.

Table 14 Average Height Growth by Species for Sheltered and Non-sheltered Bare-root Seedlings After One Growing Season on Seedlings not Exhibiting Dieback/Resprouts on the Garretson Tract

Treatment	Height[1]
	---cm---
Nuttall oak	
Shelter	20.8 A[2]
No Shelter	9.7 B
Cherrybark oak	
Shelter	10.2 B
No Shelter	9.0 B

[1] Values are means of six replications
[2] Means followed by the same letter do not differ at α=.05

Table 15 Average Height Growth for Sheltered and Non-sheltered Bare-root Seedlings After one Growing Season on Seedlings not Exhibiting Dieback/Resprouts on the Garretson Tract

Treatment	Height[1]
	----cm----
Shelter	16.7 A[2]
No Shelter	9.4 B

[1] Values are means of six replications
[2] Means followed by the same letter do not differ at α=.05

Height Growth Variation on the Norris Tract

When planting stocks of both species were combined for analysis, RPM™ seedlings exhibited significantly greater height growth than bare-root or container seedlings (24.7 cm, 7.4 cm, and 6.2, respectively) (Table 17). 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 exhibited the greatest height growth of any species/planting stock combination (27.1 cm, 22.8 cm, and 8.8 cm, respectively) (Table 16). Container cherrybark oak, container Nuttall oak, and bare-root cherrybark oak growth were not significantly different (6.5 cm, 5.8 cm, and 5.6 cm, respectively). RPM™ cherrybark exhibited height growth that was significantly greater than any other species/planting stock combination (Table 16). RPM™ Nuttall oak exhibited significantly higher height growth than any other species/planting stock combination except for RPM™ cherrybark in which it exhibited significantly less height growth. Other than RPM™ seedlings of both species, Nuttall oak bare-root seedlings significantly outperformed all other species/planting stock combinations.

Table 16 Average Height Growth After One Growing Season Based on Seedlings not Exhibiting Dieback/Resprouts on the Norris Tract (all treatments)

Species	Height
	----cm----
Cherrybark oak	
RPM™	27.1 A[1]
Container	6.5 D
Bare-root	5.6 D
Nuttall oak	
RPM™	22.8 B
Container	5.8 D
Bare-root	8.8 C

[1] Means followed by the same letter do not differ at α=.05

Table 17 Average Height Growth by Planting Stock After on Growing Season on Seedlings notExhibiting Dieback/Resprouts on the Norris Tract (all species and treatments)

Planting Stock	Height[1]
	---cm---
RPM™	24.7 A[2]
Bare-root	7.4 B
Container	6.2 B

[1] Values are means of six replications
[2] Means followed by the same letter do not differ at α=.05

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

Sheltered seedlings exhibited greater height growth than non-sheltered seedlings on the Norris tract (9.7 cm and 4.5 cm, respectively) (Table 19). Sheltered Nuttall oak seedlings exhibited significantly greater growth than any other species/shelter combination (11.9 cm) (Table 18). Sheltered cherrybark oak significantly outperformed non-sheltered seedlings of Nuttall and cherrybark oak (6.7 cm, 4.8 cm, and 4.1 cm, respectively) (Table 18). Unsheltered trees exhibited similar height growth rates, and were not significantly different.

Table 18 Average Height Growth by Species for Sheltered and Non-Sheltered Bare-root Seedlings After One Growing Season on Seedlings not Exhibiting Dieback/Resprouts on the Norris Tract

Treatment	Height[1]
	---cm---
Nuttall oak	
Shelter	11.9 A[2]
No Shelter	4.8 C
Cherrybark oak	
Shelter	6.7 B
No Shelter	4.1 C

[1] Values are means of six replications
[2] Means followed by the same letter do not differ at α=.05

Table 19 Average Height Growth for Sheltered and Non-sheltered Bare-root Seedlings After on Growing Season on Seedlings not Exhibiting Dieback/Resprouts on the Norris Tract

Treatment	Height[1]
	---cm---
Shelter	9.7 A[2]
No Shelter	4.5 B

[1] Values are means of six replications
[2] Means followed by the same letter do not differ α=.05

Height Growth Summary

Height growth patterns on both sites were consistent; however, the amount of height growth did vary by site. Cherrybark oak exhibited a greater amount of growth than Nuttall oak.

On a planting stock basis, RPM™ seedlings exhibited significantly greater height growth than bare-root or container seedlings. Bare-root seedlings significantly outgrew container seedlings on both sites. Containerized seedlings exhibited the least height growth of the planting stocks in this study. Most studies report that container seedlings have greater height growth than bare-root seedlings.

RPM™ cherrybark oak seedlings exhibited the greatest amount of height growth of all the species/planting stock combinations. Container seedlings usually exhibit greater height growth than bare-root seedlings across species, but results indicated that container Nuttall oak seedlings exhibited the least height growth of all species/planting stock combinations. Bare-root Nuttall oak 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.

Tree shelters increased height growth of bare-root seedlings of both species. Sheltered Nuttall oak seedlings exhibited greater height growth than sheltered cherrybark or non-sheltered bare-root seedlings.

Overall GLD Growth

When both species were combined for analysis, RPM™ seedlings exhibited the greatest GLD growth of all the planting stocks (4.7 mm) (Table 8). Container seedlings exhibited significantly less GLD growth than bare-root seedlings (1.6 mm, 2.6 mm, respectively) (Table 8). Bare-root seedlings are generally expected to exhibit less GLD growth than container seedlings (Rathfon et al.1995, Williams and Craft 1998).

Nuttall oak, for all planting stocks, exhibited significantly greater GLD growth than cherrybark oak (3.5 mm and 2.3 mm, respectively) (Table 7). RPM™ Nuttall oak, RPM™ cherrybark oak, and bare-root Nuttall oak exhibited the greatest amount of GLD growth (4.7 mm, 3.7 mm, and 3.6 mm, respectively) (Table 6). 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 6). RPM™ Nuttall oak exhibited a significantly greater GLD growth than any other species/planting stock combination.

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

When both species were combined for analysis, sheltered seedlings exhibited significantly less GLD growth than non-sheltered seedlings (2.4 mm and 2.9 mm, respectively) (Table 10).

There was not a significant GLD difference between sheltered and non-sheltered cherrybark oak seedlings (1.3 mm and 1.4 mm, respectively). Non-sheltered Nuttall oak seedlings exhibited greater GLD growth than sheltered Nuttall oak seedlings (4.2 mm and 3.1 mm, respectively) (Table 9).

GLD Growth Summary

Nuttall oak exhibited significantly greater GLD growth than cherrybark oak (3.5 mm and 2.3 mm, respectively) overall. RPM™ seedlings exhibited significantly greater GLD growth than bare-root or container seedlings. Bare-root seedlings significantly outperformed container seedlings.

Nuttall RPM™ seedlings exhibited the greatest amount of GLD growth when compared to the other species/planting stock combinations. RPM™ cherrybark oak and bare-root Nuttall oak exhibited significantly greater GLD growth than any of the remaining species/planting stock combinations. Dey et al. (2004) reported that RPM™ oak seedlings significantly outperformed bare-root seedlings in Missouri; however, our study did not agree with these results.

Overall, seedlings without tree shelters exhibited significantly greater GLD growth than seedlings with tree shelters. However, there was not a significant difference between sheltered and non-sheltered cherrybark oak seedlings, which indicates that the benefit of tree shelters may not offset the cost of installation. McCreary and Tecklin (2001) found that blue oak (*Quercus douglasii*) seedlings with shelters exhibited significantly greater growth than non-sheltered seedlings. However, Teclaw and Zasada (1996) found that tree shelters had no effect on growth of northern red oak.

CHAPTER V

SUMMARY

A possible explanation for Nuttall oak's better performance than cherrybark can be found in Moorhead (1981) in which he found that increasing container size increased height growth. Although the container sizes were very similar, Nuttall containers were slightly larger. Nuttall oak exhibited greater survival and GLD growth than cherrybark oak. Cherrybark oak exhibited greater height growth than Nuttall oak; however, the difference was less than one centimeter (16.1 cm and 15.3 respectively). Both species exhibited survival rates over 98 percent, which is excellent for any planting.

RPM™ seedlings exhibited the greatest amount of height and GLD growth and had a survival rate of 98.6 percent. It is not surprising that RPM™ seedlings exhibited the greatest amount of growth as they already possessed an established root system at the time of planting which could allow them to allocate resources more toward above-ground growth than adding roots. Container seedlings also had an established root system prior to planting. Container seedling height and GLD growth was significantly less than bare-root and RPM™ seedlings. Container seedlings usually outperform bare-root seedlings; however, the high quality of the bare-root seedlings in this study possibly produced different results as compared to many earlier studies. Container seedlings exhibited the greatest survival; however, survival levels of the planting stocks only differed by 0.8

percent and all were greater than 98 percent. Bare-root seedlings are not generally expected to perform as well as container or RPM™ seedlings. Although bare-root seedlings did not outperform RPM™ seedlings, survival differences were negligible between the two.

RPM™ cherrybark oak and RPM™ Nuttall oak exhibited the greatest height and GLD growth, respectively, among the species/planting stock combinations. Bare-root Nuttall exhibited significantly greater height growth than container seedlings of either species or bare-root cherrybark seedlings. Although container seedlings exhibited the least amount of height and GLD growth, container Nuttall exhibited the greatest survival. Growth of container seedlings may have been affected by the lack of an adequate root system. It is possible that container seedlings allocated resources toward root growth for stabilization rather than allocating resources for height and GLD growth.

Tree shelters increased the height growth of bare-root seedlings. Although tree shelters allow sunlight through, it is possible that the increased height growth was due to the seedlings attempting to grow out the top of the shelter. Non-sheltered bare-root seedlings exhibited greater GLD growth and survival than sheltered bare-root seedlings. Irrespective of whether a seedling was sheltered or not, excellent survival was observed.

Sheltered and non-sheltered Nuttall oak exhibited greater survival than sheltered and non-sheltered cherrybark oak. On a species basis non-sheltered bare-root seedlings outperformed sheltered bare-root seedlings in GLD growth and survival.

CHAPTER VI

CONCLUSIONS

Tree shelters are expensive to install and require monthly maintenance, which may limit their use in large plantings. Shelters may actually hurt seedling growth and survival in sandy soils where the stakes can be influenced by the wind causing erosion around the base of the seedling. From the results of this study, tree shelters do not provide enough benefit to justify their use unless your objective is to produce height growth as fast as possible or deer browse is a great concern.

Oak regeneration assessment typically requires more than one growing season to allow the seedlings to become acclimated to the site (Kruse and Groninger 2003, Collins and Battaglia 2008). Results presented were for the first growing season. Based on the results from this study, RPM™ seedlings would be the best choice for gaining the largest first year height and diameter growth. In terms of stand establishment, RPM™, bare-root, and container seedlings all exhibited excellent survival levels, and a stand could be regenerated using any of the three. Long term stand establishment decisions should not be based on results from one year of data. Therefore, continual monitoring of this study should continue to further the understanding of oak seedling growth. Bare-root seedlings were the least expensive of all the planting stocks in this study. Due to their excellent survival and acceptable growth, they are the most economical choice.

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