SURVIVAL AND GROWTH OF THREE OAK PLANTING STOCKS ON HURRICANE KATRINA DISTURBED LANDS.

By

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Three types of oak planting stock were evaluated to determine their influence on survival and initial growth. Planting stocks utilized include conventional containerized seedlings with a 240 cm^3 container, 1-0, bare-root seedlings, and Root Production Method (RPM™) seedlings with a 11.4 L container. Initially after outplanting and at the conclusion of the first and second growing seasons, height, groundline diameter (GLD), and survival were assessed. Study sites are located in southern Mississippi on lands disturbed by Hurricane Katrina. Species planted were swamp chestnut oak (*Quercus michauxii* Nutt.) and Nuttall oak (*Q. texana* Palmer). A total of 3,600 seedlings were planted in this study: 300 seedlings for each of the six planting stock/species combinations per site. Statistical comparisons of growth and survival among species and planting stock types were performed. RPM™ and bare-root planting stocks exhibited similar growth and survival, while the conventional container stock had significantly lower growth and survival.

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CHAPTER I

INTRODUCTION

Oaks (*Quercus* spp.) are valuable to southern forests for timber production, wildlife habitat, water quality enhancement, flood storage, and nutrient recharge (Hall and Lambou 1989, Ezell et al. 1999a, Moree et al. 2010,). The oak component of many bottomland hardwood stands in the southern United States has been decreasing for many years (Tworkoski et al. 1983, Johnson, R.L. 1984, Nix et al. 1985, Chambers et al. 1987, Nix 1988, Nix and Barry 1992,), and oaks are often not a major component of a stand following most harvests (Johnson and Krinard 1976, Beck and Hooper 1986, Loftis 1988). This may be one of the reasons many non-industrial private landowners (NIPL) in the South are choosing to artificially regenerate oaks on their lands. Successfully regenerating a stand following harvest is one of the challenges in hardwood silviculture (Belli 1999). Many hardwood regeneration managers utilize natural regeneration to adhere to a landowner's objectives (Coder 1994). However, natural regeneration alone is not always practical for all situations when oak regeneration is desired (Dey et al. 2008). Oaks will often comprise a smaller percentage of a regenerated stand when compared to the parent stand (Loftis 1988, Beck and Hooper 1986). Typically, this is because many oaks exhibit slower growth rates than that of light-seeded competitors (Smith 1993, Thompson and Nix 1995). Naturally regenerated oaks are often unable to compete with these faster-growing competitors (Kellison 1993). Oak seedlings are also poor competitors with herbaceous vegetation which grows rapidly in bottomland systems throughout the South. Herbaceous competition is the primary reason for seedling mortality during the first few years of establishment (Smith et al. 1997). Therefore, artificial regeneration is often necessary for oaks to become re-established on a floodplain site (Dey et al. 2003).

Regenerating bottomland sites to enhance wildlife habitat, produce timber, and increase/protect water quality is an important management concern for many forest managers in the South (Wittwer 1991). Artificial regeneration has remained an important forest management option for decades, but has proven to be particularly problematic on mesic sites for oaks (Lorimer 1993, Johnson et al. 2002). Oak regeneration can be complicated by poorly drained soils and flooding which favor species that are more tolerant of wet conditions than most bottomland oaks (Krekeler et al. 2006).

Planting seedlings of poor quality can also complicate artificial oak regeneration (Duryea 1985). Dey and Parker (1997) reported that planting high quality seedlings is an essential element of any artificial regeneration prescription. Seedlings with larger initial diameters and more fully developed root systems have greater survival and growth rates (Kormanick et al. 1995, 1998). Larger seedlings also tend to perform better against competing vegetation (Dey et al. 2008).

Proper planting is also fundamental to ensure seedling survival. Planting, whether hand planting or machine planting, can be effective if experienced, conscientious personnel oversee the planting job (Gardiner et al. 2002). Improper planting such as

J-rooting or shallow planting can increase the chance of mortality for a seedling. Thus, using high quality seedlings provides no advantage if a poor planting job is implemented. Numerous research projects have been conducted to address the previously mentioned regeneration problems, but little research has been conducted comparing the survival and growth of various oak planting stocks. Success of artificial regeneration may be influenced by the type of nursery stock used, including various sizes of bare-root and containerized seedlings (Dey et al. 2008). Nearly all (i.e., >98%) plantings of oak species in the eastern United States are currently accomplished using bare-root nursery stock; and in the South only 0.3% of the oak seedlings produced for the 2003-2004 planting season were containerized seedlings (McNabb and Dos Santos 2004).

There has been little comparative research regarding various hardwood planting stocks. Also, Hurricane Katrina created a need for hardwood regeneration on thousands of acres. This research project had the potential to provide valuable information to land managers considering planting hardwoods.

Objective

To compare early growth and survival of swamp chestnut oak (*Quercus michauxi*i Nutt.) and Nuttall oak (*Quercus texana* Palmer) on Katrina-damaged sites using three planting stocks: 11.4 liter (L) root production method (RPM™) seedlings, containerized seedlings consisting of 240 cm^3 containers produced under conventional nursery practices, and high quality 1-0, bare-root seedlings. RPM™ is the trademark for the root production method which is an air root pruning process developed by the Forrest Keeling Nursery in Missouri (Grossman et al. 2003).

CHAPTER II

LITERATURE REVIEW

Site Preparation

Site preparation is a general term used to describe treatments applied to slash, groundstory vegetation, forest floor, and soil in order to make the site suitable for natural or planted regeneration (Smith et al. 1997). Seedling growth and survival can potentially be improved by utilizing both mechanical and chemical site preparation treatments (Self et al. 2007). Depending on the method, mechanical site preparation can aerate the soil, break the sod, reduce herbaceous competition, improve the nutrient and moisture status of the soil, reduce herbivore habitat, and/or improve access to the site (Baker and Blackmon 1978, Kennedy 1981, 1993).

Herbicides have been used in forestry for more than 60 years (Ezell et al. 1999b). Successful establishment of hardwood plantings often requires thorough weed control with herbicides (Schuler and Robison 2004). Competing vegetation, herbaceous and woody, is arguably the most prohibitive factor in hardwood regeneration success. It has been shown that first year growth and survival can be increased through the use of an herbicide treatment (Krinard and Kennedy 1987). Weed control can effectively increase the early diameter and height growth of hardwood seedlings (Akers et al. 1984). Ezell and Catchot (1998) found an overall first-year survival increase of 20 percent with an application of Oust® for various species of oaks and green ash (*Fraxinus pennsylvanica* Marsh.) in Mississippi. Research initiated in the late 1960's and early 1970's revealed that herbaceous weed control is needed to increase survival and growth of sweetgum (*Liquidambar styraciflua* L.) and green ash seedlings by reducing competition for soil nutrients, water, and light (Zutter et al. 1987). Ezell and Hodges (2002) found that herbaceous weed control increased the survival of Shumard oak (*Q. shumardii* Buckl.) seedlings in Mississippi. Jacobs et al. (2004) found that seedling survival of black walnut (*Juglans nigra* L.), yellow poplar (*Liriodendron tulipifera* L.), and northern red oak (*Q. rubra* L.) on a site that only received mechanical site preparation was 52.17 percent while seedlings planted on a site that received only chemical site preparation was 72.61 percent in Indiana. Ezell et al. (2007) found that herbaceous weed control increased the first-year survival of six oak species in Mississippi.

<u>Hurricane Katrina Caused Forest Disturbance</u>

On August 29, 2005, Hurricane Katrina landed on the Gulf Coastal region 55 kilometers (km) east of New Orleans causing what has been accepted as the most costly natural disaster in U.S. history (Stanturf et al. 2007). The eye of Hurricane Katrina passed through St. Tammany Parish, LA and Hancock and Pearl River Counties, MS (Wang and Xu 2009). According to Oswalt et al. (2008), Hurricane Katrina damaged an estimated 521 million trees of more than one inch diameter at breast height (DBH) and killed 54 million trees in Mississippi, with total tree mortality being less than one percent of Mississippi's forests. As devastating as Hurricane Katrina was to forested areas, not all ecosystems suffered severe damage in the hurricane, as many of the coastal sand-bottom stream systems were unchanged or possibly rejuvenated (Adams 2006).

Artificial Regeneration of Oaks

Reforestation is a system or method by which forests are helped to reproduce themselves on previously forested ground (Allen and Sharpe 1960). The most common reforestation method used with planting hardwoods in the South has been to plant seedlings of heavy-seeded species (King and Keeland 1999). The most commonly planted species in bottomland hardwood reforestation efforts are oaks (Schweitzer et al. 1999). Heavy-seeded species are often preferred in artificial hardwood regeneration because of their limited dispersal, importance to wildlife, and high timber value (Allen and Kennedy 1989). While light-seeded tree species could be added to a regeneration effort, they will often colonize a new planting from an adjacent seed source if one is available (Twedt 2004). While it is economical for light-seeded species to blow in, the landowner has no control over timing of rotation or species composition (Gresham 1984). In the absence of artificial regeneration, woody colonization of a site may be delayed if the nearest seed source exceeds 61-79 meter (m) (Allen 1997, Allen et al. 1998).

Species diversity in a planting can be beneficial for the growth and survival of potential crop trees. For example: oaks generally have increased vigor and quality in a stand providing interspecific competition (Lockhart and Hodges 1998). A mixed species planting can increase pest resistance, productivity, product diversity, crop tree quality, canopy species diversity, and wildlife habitat (Steel et al. 1992, Goelz 1995). Also, planting a mix of species will often be more similar to natural stands (Lockhart et al. 1999). While mixed stands are often beneficial, natural homogenous stands of black willow (*Salix nigra* Marsh.), eastern cottonwood (*Populus deltoides* Bartr.), and baldcypress (*Taxodium distichum* L.) are often prevalent in bottomland hardwood ecosystems (Gardiner et al. 2002).

In hardwood plantings, it is vital to properly match species to site conditions. Newly planted seedlings may be subjected to herbaceous competition, herbivory, drought, and flooding which intensifies the need to properly match species to soil and site conditions (Schweitzer et al. 1999). According to Stanturf et al. (2000), the most critical step is properly matching species to site, particularly to hydroperiod. Species may be planted on a site with less frequent flooding conditions than shown for their tolerance class, but not vice versa (Stanturf et al. 2004). While it is pertinent to match species to hydroperiod, many hardwoods can withstand flooding during the dormant season if the seedlings are not inundated for extended periods (Kennedy 1981). Small differences in elevation can result in great differences in site quality primarily due to differences in hydrology, while species occurrence and natural patterns of ecological succession within the floodplain are strongly influenced by these differences in elevation and rates of deposition (Hodges and Switzer 1979, Hodges 1997).

Planting Stocks

Different planting stocks are available for reforestation including: seed, bare-root seedlings, and containerized seedlings. Management objectives should be considered when deciding whether to use bare-root seedlings or containerized seedlings (Gardiner et al. 2002).

Bare-root seedlings are typically readily available and are the most utilized planting stock for artificial regeneration of oaks (Dey et al. 2008). McLeod (2000) found that bare-root planting stock performed as well or better than bigger and more costly planting stocks in South Carolina. Seedling size can be an important factor when determining growth and survival success of many hardwood species (Land 1983, Ruehle and Kormanick 1986, Thompson and Schultz 1995). Large, naturally regenerated, hardwood seedlings are typically more successful in competing with light-seeded species and stump sprouts (Johnson 1975). Other studies have shown that oak survival can be enhanced by planting large, high quality 1-0, bare-root seedlings (Thompson and Schultz 1995). Managers employing an operational hardwood planting generally desire a shoot length of 46-61 cm with a root collar diameter of one centimeter for oak plantings (Gardiner et al. 2002).

Size of containers for containerized seedlings vary greatly, ranging from very small (e.g., 150 cm^3) to very large (e.g., $\geq$ 19 L) (Dey et al. 2008). Moorhead (1978) evaluated containerized seedlings of four bottomland oak species in Mississippi with the following container sizes: 1.9 L, 0.9 L, and 0.5 L. Containerized seedlings have potential growth advantages when compared to bare-root seedlings (Johnson, P. S. 1984) and can possibly extend the planting season (Stanturf et al. 1998, Howell and Harrington 2002) because there is less planting shock resulting from fewer disturbances to the roots. Containerized seedlings also have the potential to exhibit greater survival in the presence of inundated conditions. Humphrey (1994) found that container grown Nuttall oak seedlings survived flooding better than bare-root seedlings. Seedlings that are taller than floodwaters are more likely to survive summer flooding (Kennedy and Krinard 1974).

The use of large containerized stock called root production method (RPM™) seedlings is increasing in the Midwest (Dey et al. 2004). Large containerized seedlings have the potential for better juvenile growth and survival as compared to bare-root seedlings (Johnson, R.L. 1984). RPM™ hardwood seedlings grown in 11.4 L or 18.9 L containers can attain heights greater than or equal to 1.5 m in one or two years in the nursery, and basal diameter and survival of RPM™ seedlings can be significantly greater than bare-root stock (Dey et al. 2003). Dey et al. (2006) found that large containerized seedlings have significantly greater survival and diameter growth as compared to bare-root seedlings after three years for pin oak (*Q. palustris* Muenchh.) and swamp white oak (*Q. bicolor* Willd.) in the Missouri River floodplain.

Though large containerized planting stock can potentially exhibit increased growth and survival as compared to bare-root planting stock, planting larger seedlings may not be cost effective (Bowersox 1993, Howell and Harrington 2002). According to Dey et al. (2006), a large containerized seedling may cost $8.00 compared to $0.50 to $1.00 for a bare-root seedling, but the potential for early acorn production from RPM™ seedlings is worth the additional cost to some wildlife managers. Other studies have shown that the large size of RPM™ seedlings could also increase planting costs as a result of large seedlings being problematic to plant (Stanturf et al. 2004).

CHAPTER III

MATERIALS AND METHODS

Site Description

Two study areas were utilized in this project. The first area, the Gordon Tract, is located approximately 26 km southwest of Poplarville, MS in the floodplain of the Pearl River. The study area encompasses approximately 1.6 hectares (ha) within an area that received a salvage harvest due to damage from Hurricane Katrina. Soil series is Latonia fine sandy loam (coarse-loamy, siliceous, semiactive, thermic Typic Hapludults) with 0 – 2 percent slopes and pH 6.2. Average annual precipitation is 152 centimeters. Average temperature in the winter is 12°C and the average temperature in the summer is 27°C.

Dominant tree species on the site at time of study inititation included: southern magnolia (*Magnolia grandiflora* L.), sweetbay (*M. virginiana* L.), swamp chestnut oak, sweetgum, willow oak (*Q. phellos* L.), water oak (*Q. nigra* L.), white oak (*Q. alba* L.), yellow poplar, spruce pine (*Pinus glabra* Walt.), red maple (*Acer rubrum* L.), and Chinese tallowtree (*Sapium sebiferum* L.). Other woody species on site at time of study initiation included: parsley hawthorn (*Crataegus marshalii* Eggl.), eastern baccharis (*Baccharis halimifolia* L.), American beautyberry (*Callicarpa americana* L.), and loblolly pine (*P. taeda* L.). Dominant vine species on the site at time of study initiation included: muscadine (*Vitis rotundifolia* M.), blackberry (*Rubus* spp.), and dewberry

(*Rubus* spp.). Dominant herbaceous species on the site at time of study initiation included: little bluestem (*Shizachyrium scoparium* Michx.), giant ragweed (*Ambrosia trifida* L.) and dogfennel (*Eupatorium capillifolium* Lam.).

The second study area, the Brooke Tract, is located approximately 21 km northeast of Picayune, MS and is characterized as a coastal flatwoods site. This study area also encompasses approximately 1.6 ha. This site also received a salvage harvest due to damage from Hurricane Katrina. Soil series is Harleston sand (coarse, siliceous, semiactive, thermic Aquic Paleudults) with slopes 0 – 2 percent and pH 4.8. Average annual precipitation is 145 centimeters. Average winter temperature is 11°C and the average summer temperature is 27°C.

Dominant tree species on the site at time of study initiation was longleaf pine (*P. palustris* Mill.). Other woody species present on the site at time of study initiation included: blackgum (*Nyssa sylvatica* Marsh.), Chinese tallowtree, willow oak, water oak, red maple, and persimmon (*Diospyros virginiana* L.). Dominant vine species on the site at time of study initiation included: muscadine and blackberry. Dominant herbaceous species on the site at time of study initiation included: goldenrod (*Solidago* spp.), little bluestem, giant ragweed, and dogfennel.

Experimental Design

A randomized complete block design, with three replicates was employed in this study. The replicates on the Brooke Tract are contiguous (Figure 1). Replicates on the Gordon Tract were physically separated by approximately 91 meters between each block due to residual stems between the harvest areas (Figure 2).

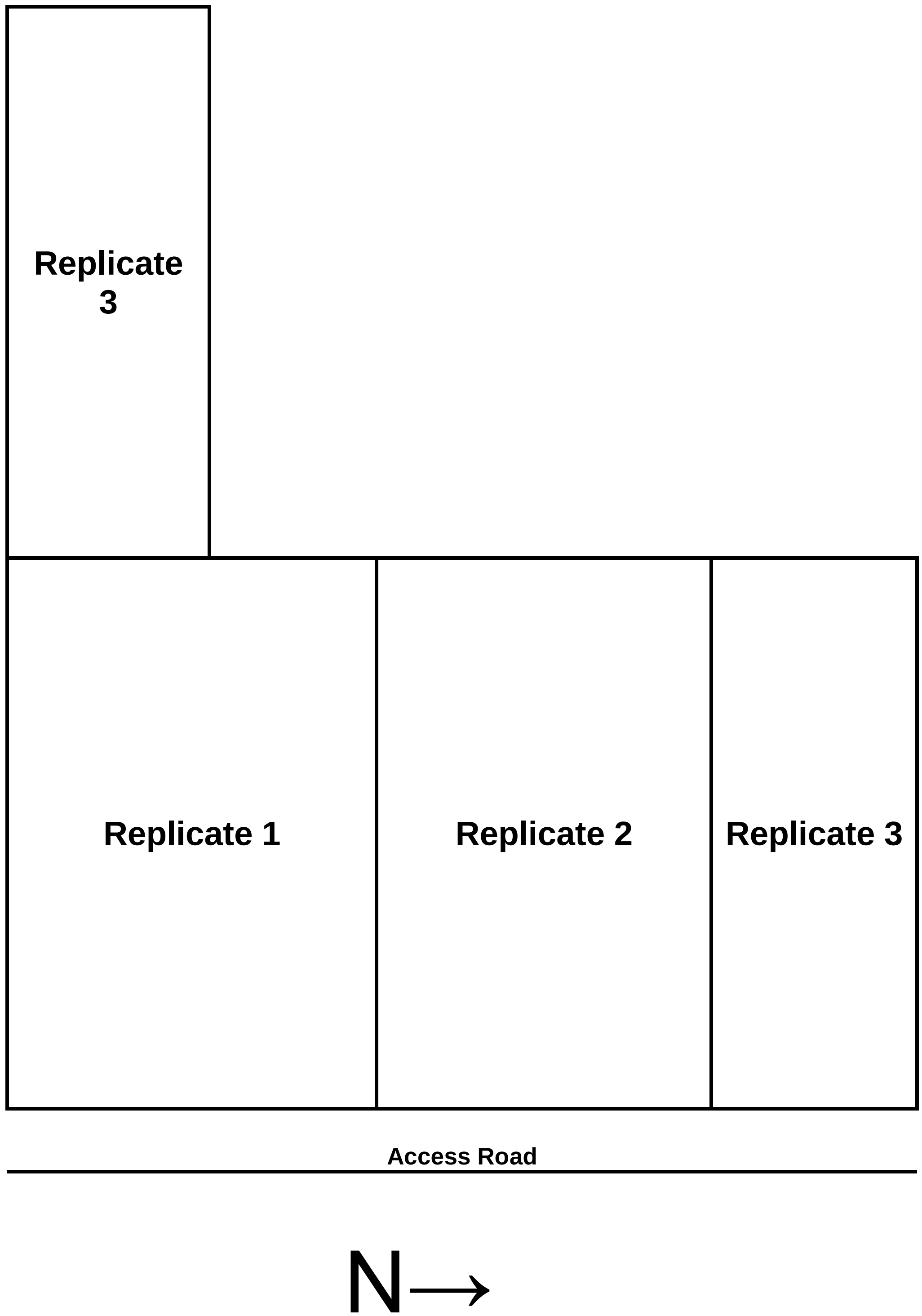

Figure 1. Schematic of plot layout on Brooke Tract.

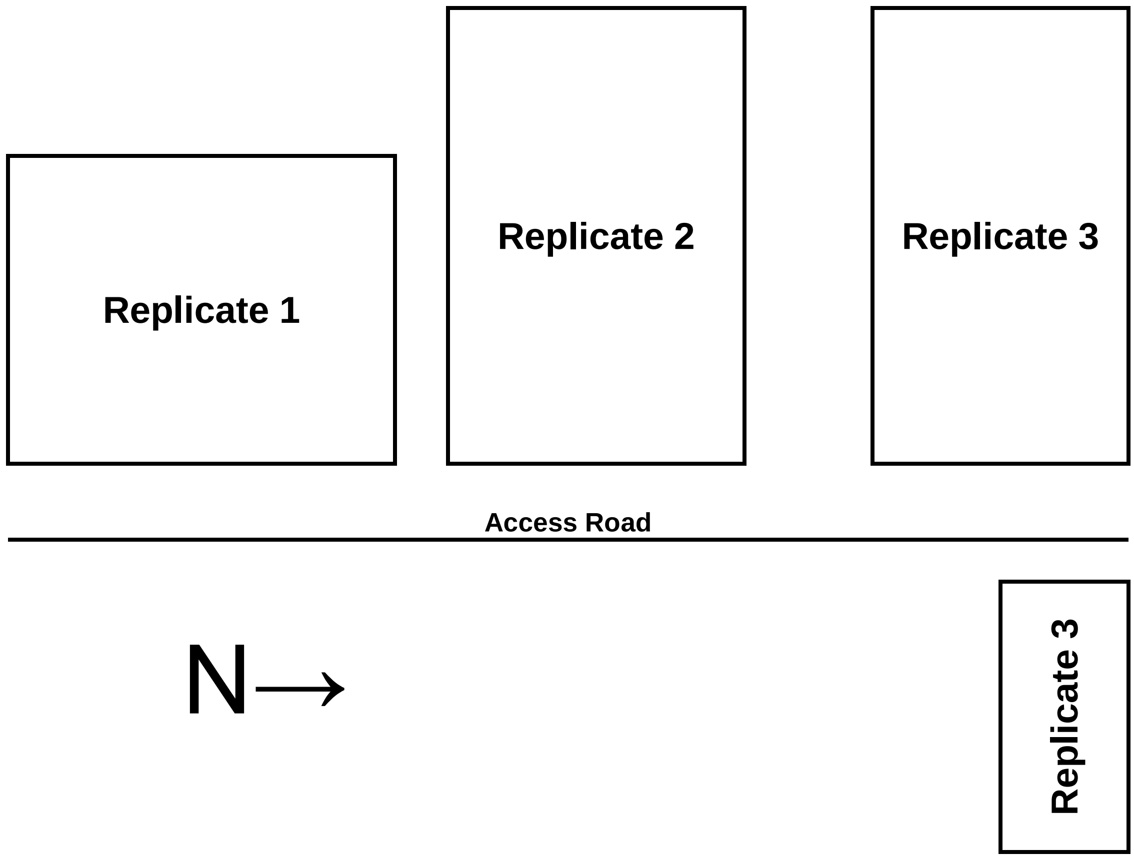

Figure 2. Schematic of plot layout on Gordon Tract.

Plot Establishment

Corners of the study areas were marked with 3 m sections of 2.5 cm polyvinylchloride (PVC) pipe. Individual tree planting spots were marked with 91 cm pin flags with a 10 cm x 13 cm flag. Ends of the rows were marked with 122 cm sections of steel rebar. Each piece of rebar received an aluminum tag with a row number.

Site Preparation

Both mechanical and chemical techniques were utilized during site preparation. The Gordon Tract received mechanical site preparation only. The landowner was responsible for having all the woody harvest debris pushed out of the planting areas following the salvage harvest. Debris was pushed out of the planting sites with a bulldozer.

Both chemical and mechanical site preparation techniques were utilized on the Brooke Tract. First, a broadcast application of Accord XRT® (9.3 L/ha) and Garlon 4® (2.3 L/ha) was applied during the first week of November 2008. Chemical site preparation was deemed necessary due to the presence of undesirable woody species. The landowner was responsible for site preparation which was completed with a sprayer affixed to an agricultural tractor. The planting site was burned three weeks later after the herbicide was applied. After burning, the landowner pushed residual brush out of the planting site with a bulldozer.

Seedling Establishment

Two species, Nuttall oak and swamp chestnut oak, were utilized at each research site with three planting stocks for each species: 11.4 L RPM™ seedlings, conventional containerized seedlings with a 240 cm^3 container, and high-quality 1-0, bare-root seedlings, for a total of six species/planting stock combinations. A total of 3,600 seedlings were planted. Each site had a total of 1,800 seedlings planted consisting of: 300 bare-root swamp chestnut oak, 300 bare-root Nuttall oak, 300 RPM™ swamp chestnut oak, 300 RPM™ Nuttall oak, 300 containerized swamp chestnut oak, and 300 containerized Nuttall oak. Each replicate consists of 100 seedlings per species/planting stock combination. Each of the six species/planting stock combinations were randomly assigned within each replicate. Seedlings were planted on 3.05 m x 3.05 m spacing.

RPM™ seedlings were hand planted with planting shovels February 5, 2009, by a crew hired by the Forrest Keeling Nursery in Elsberry, MO. All bare-root and conventional containerized seedlings were hand planted with planting shovels February 21, 2009, by MSU personnel.

Pre-Emergent Herbicide Application

All bare-root seedlings received a post-plant, pre-bud break herbicide treatment of Oust XP® (140.0 g/sprayed hectare) February 29, 2009, applied as a 1.5 m band over the top of the seedlings. Herbicide was applied with 11.4 L backpack sprayers. Caution was taken to only apply the herbicide when there was little to no wind to avoid drift. A Solo® backpack sprayer was used for herbicide application with a total spray volume of 93.5 L/sprayed hectare.

Seedling Measurements

Initial seedling measurements were recorded February 25, 2009. Height was measured to the nearest centimeter on bare-root and conventional container seedlings using meter sticks. Height of RPM™ seedlings was measured to the nearest tenth of a foot using height poles and later converted into centimeters. Groundline diameter (GLD) was measured to the nearest tenth of a millimeter (mm) using digital calipers.

Percent ground cover and survival checks were recorded for the months of June and July 2009. An ocular estimation of percent ground cover was assessed for each row and then averaged by planting stock. Seedling survival was based on visual inspection. If there were no seedling present, it was considered dead. Seedlings that appeared dead received a check of the cambium to verify the survival status. Seedlings that were marked as dead and later observed to be resprouting were included as alive in earlier survival evaluations. Percent ground cover of broadleaves, grasses, shrubs, and vines was recorded based on ocular estimates for each planted row of seedlings.

Height and GLD were recorded following the first growing season. The Brooke Tract was remeasured January 2010 and the Gordon Tract was measured October 17, 2009. Data collection methods remained the same as initial measurement methods and survival was also noted. In the case of resprouts, if the sprout origin was the original stem, GLD of the original stem was recorded. If the root sprout was independent of the above ground stem, the GLD of the root sprout was recorded.

Final seedling measurements for both sites were recorded August 9, 2010. Data collection methods remained unchanged from the previous measurements.

Data Analysis

Statistical Analysis System (SAS) software version 9.2® was used for the statistical analyses. Statistical analyses were performed using PROC SORT, PROC MEANS, PROC GLM, and/or PROC MIXED. Repeated measures were used to analyze height and GLD. Least square means were used to separate any significant differences among treatments. Growth and survival data were analyzed for Nuttall and swamp chestnut oak for interactions among the three planting stocks: RPM™, bare-root, and conventional containerized planting. An arcsine transformation was used to normalize data for survival and ground cover percentages. Actual means are presented for the purpose of interpretation. Differences were considered significant at $\alpha = 0.05$.

CHAPTER IV

GROUND COVER RESULTS AND DISCUSSION

Percent Ground Coverage

Percentages of broadleaf, grass, vine, and shrub coverages can exceed 100 percent as these cover types overlap. Percent ground coverage significantly increased for broadleaf, grass, vine, and shrub species from May to June on both the Brooke and Gordon Tracts (Table 1). The greatest increase in average ground cover on the Brooke Tract was in broadleaves, while the greatest increase in ground cover on the Gordon Tract was grass (Table 1). The least increase in coverage from May to June on the Brooke Tract was vine, while shrub exhibited the least increase in average ground coverage from May to June on the Gordon Tract (Table 1). Though not recorded, grass was observed to be the most dominant cover on both the Brooke and Gordon Tracts throughout years one and two.

Table 1 Average Ground Cover by Vegetation Type and Month of Observation in Study Areas During the First Growing Season

	Brooke			
	BL[1]	Grass	Vine	Shrub
	--------------------percent--------------------			
May	16b[2]	71b	5b	13b
June	44a	88a	11a	23a
	Gordon			
	--------------------percent--------------------			
May	10b	12b	2b	5b
June	20a	46a	15a	14a

[1]Broadleaf.
[2]Values in a column within a site followed by the same lower case letter do not differ at $\alpha = 0.05$.

Broadleaf ground cover was not significantly different among planting stocks in May on the Brooke Tract (Table 2). Grass and shrub cover for RPM™ and conventional containerized was significantly greater than bare-root in May on the Brooke Tract (Table 2). Broadleaf coverage for conventional containerized was significantly greater than RPM™ and bare-root while there was no significant difference between RPM™ and bare-root in June on the Brooke Tract (Table 2). There was no significant difference between RPM™ and convention containerized for grass coverage, while both were significantly greater than bare-root in June on the Brooke Tract (Table 2). There was no significant difference in vine coverage among the three planting stocks in May or June on the Brooke Tract (Table 2). RPM™ and conventional containerized were significantly greater than bare-root in May on the Brooke Tract (Table 2). Shrub coverage was greatest for RPM™ while there was no difference between bare-root and conventional containerized in June on the Brooke Tract (Table 2).

Oust XP® was not effective at controlling all species on the site. Goldenrod, giant ragweed, and dogfennel were the dominant broadleaf species on the Brooke Tract for the months of May and June. Oust XP® is not effective at controlling these species at the rates applied. Oust XP® is also not effective on most vine species, as well, resulting in little difference in vine cover in May and June on the Brooke Tract (Table 2). Little bluestem was the dominant grass cover on the Brooke Tract. Oust XP® is also not effective on most grass species, resulting in little control of grass by June on the Brooke Tract (Table 2). Oust® has been reported to release grasses on hardwood regeneration sites (Groninger and Babassana 2002). Though grass cover was significantly less for bare-root, there will likely be no significant difference by July because grass cover increased from May to June.

Table 2 Average Ground Cover by Planting Stock, Vegetation Type, and Month of Observation During the First Growing Season on the Brooke Tract

	BL[1]	Grass	Vine	Shrub
	--------------------percent--------------------			
May[2]				
RPM™[3]	16ab[4]	86a	7a	14a
BR	11b	46b	3b	6b
CC	22a	82a	5ab	19a
June				
RPM™	41b	94a	13a	30a
BR	39b	79b	10ab	20b
CC	53a	90a	9b	20b

[1]Broadleaf.
[2]May and June analyzed separately.
[3]RPM™ = root production method, BR = bare-root, CC = conventional containerized.
[4]Values in a column within a month followed by the same lower case letter do not differ at $\alpha = 0.05$.

Broadleaf, vine, and shrub coverages were comparable among the three planting stocks in May and June on the Gordon Tract (Table 3). There was no significant difference in grass cover between RPM™ and conventional containerized, while both were significantly greater than bare-root in May and June on the Gordon Tract (Table 3). There was no significant difference in grass coverage between RPM™ and conventional containerized, while both were significantly greater than bare-root (Table 3).

The dominant broadleaf species during May and June on the Gordon Tract was giant ragweed and dogfennel. Oust XP® is not effective at controlling these species at the rate applied. This lack of difference could also be attributed to the overall lack of ground cover on the Gordon Tract.

Not all species were controlled with Oust XP® in this study. However, previous studies have shown Oust® to be effective at reducing ground cover throughout the growing season. Ezell and Catchot (1998) reported the application of Oust® provided excellent competition control 60 days after treatment in Mississippi. Ezell (2002) reported Oust® provided excellent first-year herbaceous weed control in Mississippi. Groninger et al. (2004) reported Oust® provided first-year control of grasses and forbs in Illinois. However, Seifert and Woeste (2002) reported Oust® provided little competition control 90 days after treatment in Indiana. Schweitzer et al. (1999) reported Oust® was not as effective at weed control as more labor intensive methods of mowing and fabric mats placed around seedlings.

Table 3 Average Ground Cover by Planting Stock, Vegetation Type, and Month of Observation During the First Growing Season on the Gordon Tract

	BL[1]	Grass	Vine	Shrub
	--------------------percent--------------------			
May[2]				
RPM™[3]	11a[4]	13a	2a	6a
BR	8ab	8b	2a	4ab
CC	10ab	16a	1a	7a
June				
RPM™	23a	56a	21a	16a
BR	18a	31b	13ab	13ab
CC	20a	52a	15ab	14ab

[1]Broadleaf.
[2]May and June analyzed separately.
[3]RPM™ = root production method, BR = bare-root, CC = conventional containerized.
[4]Values in a column within a month followed by the same lower case letter do not differ at $\alpha = 0.05$.

CHAPTER V

SURVIVAL RESULTS AND DISCUSSION

Average Survival for May and June by Species/Planting Stock Combinations During the First Growing Season

Results indicate that poor planting quality was not a problem for this study. Survival remained high throughout June which indicated a lack of mortality due to transplanting shock. Excellent survival of the RPM™ and bare-root seedlings in this study could be attributed to proper planting and high seedling quality. RPM™ seedlings were large potted seedlings and the bare-root seedlings had well-development root systems with 18-20 first-order lateral roots. Stem height of the conventional containerized seedlings was comparable to the bare-root seedlings. Seedling mortality is often highest initially after transplanting. Previous studies have shown the greatest mortality can result from planting stress (Vyse 1981, Waters et al. 1991).

The greatest decrease in average survival for RPM™ seedlings was from May to June for Nuttall oak on the Brooke Tract (1.3%) and swamp chestnut oak on the Gordon Tract (1.3%) (Table 4). The greatest decrease in average survival for bare-root seedlings was from May to June on the Gordon Tract for swamp chestnut oak (3.0%) (Table 4). The greatest decrease in average survival for the conventional containerized seedlings was on the Gordon Tract for swamp chestnut oak (10.7%) (Table 4). On the Brooke

Tract, RPM™ (0.7%) and bare-root (0.7%) seedlings had the least decrease in average survival, while conventional containerized (3.7%) seedlings had the greatest decrease in survival from May to June for both species (Table 4). On the Gordon Tract, RPM™ (1.0%) seedlings had the least decrease in survival from May to June followed by bare-root (2.4%) and conventional containerized (8.7%) seedlings for both species (Table 4).

Table 4 Average First-Year Survival by Month of Observation, Species, Planting Stock, and Site During the First Growing Season

	Brooke Tract		Gordon Tract	
	May	June	May	June
	---------------percent---------------			
Nuttall Oak				
RPM™[1]	99.0a[2]	97.7a	99.7a	99.0a
BR	97.7a	97.3a	97.0a	95.3a
CC	92.0b	87.3b	91.0b	84.3b
Swamp Chestnut Oak				
RPM™	98.7a	98.7a	99.3a	98.0a
BR	97.7a	96.7a	96.7a	93.7a
CC	85.6b	78.2b	89.0b	78.3b

[1]RPM™ = root production method, BR = bare-root, CC = conventional containerized.
[2]Values in a column followed by the same letter do not differ at $\alpha = 0.05$.

Previous studies have shown that water deficit can be a primary contributor to early mortality of newly planted seedlings (Kozlowski and Davies 1975, Kramer 1986). Mortality during the month of June could be attributed to the lack of rainfall. Though no rain gauges were installed on the sites, monthly precipitation data from the nearest weather station were examined. The weather station was located approximately 25.7 km from both the Brooke and Gordon Tracts, and recorded precipitation levels 6.4 centimeters below average for April, 8.9 centimeters below average for July, and no precipitation recorded for the months of June and September. Johns et al. (1999) reported less than 73 percent first-year survival for seven species of 1-0, bare-root hardwood seedlings in the presence of a deficit of growing season rainfall in Texas. Self et al. (2007) concluded that a droughty summer condition was the primary contributor to seedling mortality for bare-root, potted, and containerized oak seedlings in Louisiana. Wittwer (1991) reported greater than 84 percent first-year survival for 1-0, bare-root willow oak seedlings when the growing season precipitation was 22.6 centimeters below average in Oklahoma. Previous studies have shown early hardwood seedling survival can be excellent in years of adequate rainfall. Self et al. (2010) reported greater than 96 percent survival of bare-root oak seedlings in Mississippi during a period of above average rainfall. It is possible that the lack of rainfall with associated lack of soil moisture was a major contributor to first-year seedling mortality in this study.

The survival of conventional containerized seedlings was significantly less than RPM™ or bare-root seedlings. Application of herbaceous weed control is possibly the reason for higher survival of bare-root seedlings compared to conventional containerized seedlings in this study. Of the three planting stocks, only bare-root seedlings received herbaceous weed control. Russell et al. (1997) concluded that competing vegetation is the primary cause of oak seedling mortality because competing vegetation can capture much of the available soil moisture (Newton and Comeau 1990). Herbaceous weed control has been shown to be effective at increasing early survival of bare-root oak seedlings (Ezell and Hodges 2002, Ezell and Catchot 1998) due to reduced competition for soil moisture, while containerized oak seedlings have been shown in previous studies to have excellent early survival without herbaceous weed control (Miller 1999). The application of Oust XP® is possibly the reason why the bare-root seedlings had higher survival than conventional containerized seedlings. Plots with bare-root seedlings also had less ground coverage, resulting from the application of Oust XP®, than conventional containerized or RPM™ seedlings. This possibly led to less competition for soil moisture because available soil moisture decreases with increased ground cover (Adams et al. 1991). With the smallest and shallowest root system of the three planting stocks in this study, the conventional containerized seedlings may not have been able to compete with herbaceous competition for soil moisture as well as the bare-root and RPM™ seedlings. Although RPM™ seedlings did not receive herbaceous weed control, previous works indicate that survival of RPM™ seedlings was not affected by herbaceous weed control (Dey et al. 2006).

Previous studies have shown, however, that conventional containerized oak seedlings exhibit greater survival than bare-root seedlings without herbaceous weed control. Williams and Craft (1997) reported first-year survival of Nuttall oak seedlings to be greater for containerized (84%) seedlings than bare-root (38%) seedlings in Mississippi without weed control. Miller (1999) reported containerized oak seedlings to exhibit greater survival than 1-0, bare-root seedlings without the application of herbaceous weed control. Burkett and Williams (1998) reported 96% first-year survival of containerized seedlings, whereas 1-0, bare-root seedlings averaged 45% for Nuttall oak seedlings in Mississippi without weed control. In the same study Burkett et al. (2005) reported third-year survival of 1-0 bare-root (47%) seedlings to be greater than containerized (39%) seedlings. Williams and Stroupe (2002) reported a first-year survival of 81% for bare-root seedlings and 83% for containerized seedlings of water and willow oaks in Texas.

With the documented lack of rainfall during the first growing season, results of this study indicate that small containerized seedlings may be susceptible to a lack of soil moisture combined with herbaceous competition. Self et al (2007) reported first-year survival of 50.2 percent for small containerized Nuttall oak and cherrybark oak seedlings with droughty growing season conditions in Louisiana. Alkire (2011) found that small conventional containerized swamp chestnut oak and cherrybark oak (*Q. pagoda* Raf.) seedlings can exhibit excellent first-year survival if the seedlings receive adequate rainfall during the growing season in Mississippi. Alkire (2011) also applied Oust XP® to bare-root seedlings and reported that all planting stocks and species had greater than 97 percent survival at the conclusion of the first growing season. These results indicate that in years of adequate growing season rainfall, conventional containerized seedlings can have excellent survival.

Survival Differences by Planting Stock

No observed significant differences were detected in average survival between RPM™ and bare-root seedlings in comparisons of site or year (Table 5). Survival of RPM™ and bare-root seedlings was greater than 90 percent on both sites (Table 5). Survival of RPM™ seedlings dropped 0.7 percent from year one to year two on the Brooke Tract and 4.4 percent on the Gordon Tract (Table 5). Average survival of bare-root seedlings dropped 0.8 percent from year one to year two on the Brooke Tract and 2.2 percent on the Gordon Tract (Table 5). Average survival for conventional containerized seedlings dropped 4.3 percent from year one to year two on the Brooke Tract and 3.8 percent on the Gordon Tract (Table 5). Precipitation data for the second growing season was also noted. Second growing season precipitation was reported to be 3.2 centimeters less than the first growing season while, second year mortality was less than the first year. This shows that once the seedlings become established, after the first growing season, they are less susceptible to lack of rainfall.

Second-year survival of conventional containerized seedlings averaged 72-75 percent (Table 5). Though conventional containerized seedlings had lower survival than RPM™ and bare-root seedlings, 72 percent survival is typically considered acceptable for most land managers. With greater than 90 percent survival, either RPM™ or bare-root seedlings would be acceptable for any afforestation/reforestation purposes.

Previous studies have shown RPM™ oak seedlings to exhibit greater survival than bare-root seedlings. Kabrick et al. (2005) reported RPM™ swamp white and pin oaks exhibited greater second-year survival then 1-0, bare-root seedlings in Missouri. Dey et al. (2003) reported survival of RPM™ swamp white and pin oaks to be significantly greater than 1-0, bare-root seedlings.

Table 5 Average Survival by Planting Stock, Site, and Year for All Species

	Brooke Tract[2]		Gordon Tract	
	Year 1	Year 2	Year 1	Year 2
	--------------------------percent--------------------------			
RPM™[1]	97.2a[3]	96.5a	97.7a	93.3a
BR	96.6a	95.8a	92.5a	90.3a
CC	79.3b	75.0b	76.6b	72.8b

[1]RPM™ = root production method, BR = bare-root, CC = conventional containerized.
[2]Brooke Tract and Gordon Tract were analyzed separately.
[3]Values in a column followed by the same letter do not differ at $\alpha = 0.05$.

Survival Differences by Species

There was no significant difference in first-year survival between Nuttall oak and swamp chestnut oak on either Brooke or Gordon Tracts (Table 6). There was also no significant difference in second-year survival between Nuttall oak and swamp chestnut oak seedlings on the Brooke Tract (Table 6). However, Nuttall oak (90.2%) seedlings had significantly higher survival than swamp chestnut oak seedlings (80.8%) for second-year survival on the Gordon Tract (Table 6). This difference is likely due to survival of conventional containerized Nuttall oak seedlings being greater than conventional container swamp chestnut oak seedlings (Table 7).

Survival of Nuttall oak seedlings was not significantly greater than that of swamp chestnut oak except for year two on the Gordon Tract (Table 6). Nuttall oak seedlings (all planting stocks) exhibited over 90 percent second-year survival in this study (Table 6). These results might have been anticipated as Nuttall oak is known to exhibit greater juvenile growth and survival than most other oak species (Miwa et al. 1992, Williams et al. 1992, Ozalp et al. 1997, Sung et al. 2004). Taylor et al. (2004) found that bare-root Nuttall oak seedling survival was 95 percent at the conclusion of the second growing season where intensive competition control was applied in Alabama. However, swamp chestnut oak has also been reported to exhibit good early survival (Johnson and Krinard 1987). Though swamp chestnut oak seedling survival was less than Nuttall oak in this study, greater than 80 percent is typically considered very good survival.

Table 6 Average Survival by Species, Site, and Year for All Planting Stocks

	Brooke Tract[1]		Gordon Tract	
	Year 1	Year 2	Year 1	Year 2
	---------------------------percent---------------------------			
Nuttall Oak	92.7a[2]	91.6a	91.3a	90.2a
Swamp Chestnut Oak	89.3a	86.7a	86.6a	80.8b

[1]Brooke Tract and Gordon Tract were analyzed separately.
[2]Values in a column followed by the same letter do not differ at $\alpha = 0.05$.

<u>Survival Differences by Species/Planting Stock Combinations</u>

RPM™ and bare-root seedlings had similar survival on both tracts for both years (Table 7). Greatest first-year survival was in RPM™ Nuttall oak (98.7%) on the Gordon Tract and RPM™ swamp chestnut oak (98.7%) on the Brooke Tract (Table 7). Greatest second-year survival was in RPM™ Nuttall oak (98.3%) on the Gordon Tract and RPM™ swamp chestnut oak (98.3%) on the Brooke Tract (Table 7). Conventional containerized swamp chestnut oak seedlings on the Gordon Tract had the lowest first-year (71.3%) and second-year (66.0%) survival (Table 7). Survival of RPM™ and bare-root seedlings was not significantly different between Nuttall and swamp chestnut oaks on either tract for year one and year two observations (Table 7). Survival of conventional containerized seedlings was observed to be significantly less than RPM™ and bare-root for all comparisons (site, species, year) (Table 7).

The greatest decrease in survival of RPM™ seedlings was from year one (96.7%) to year two (88.3%) for swamp chestnut oak on the Gordon Tract (Table 7). Replicate one was observed to be wetter than replicates two and three for the second year on the Gordon Tract. Second-year survival of RPM™ seedlings in replicate one was 78 percent while second year survival was higher for replicate two (96%) and replicate three (91%). Swamp chestnut oak survival was lower for all species/planting stock combinations and years on the Gordon Tract (Table 7). Burns and Honkala (1990) reported that swamp chestnut oak is not as water tolerant as Nuttall oak.

Table 7 Average Survival by Species, Planting Stock, Site, and Year

	Brooke Tract[2]		Gordon Tract	
	Year 1	Year 2	Year 1	Year 2
	--------------------------percent--------------------------			
Nuttall Oak				
RPM™[1]	95.7a[3]	94.7a	98.7a	98.3a
BR	97.0a	96.3a	93.3a	92.6a
CC	85.3b	83.7b	81.9b	79.6b
Swamp Chestnut Oak				
RPM™	98.7a	98.3a	96.7a	88.3a
BR	96.0a	95.3a	91.7a	88.0a
CC	73.2b	66.2b	71.3b	66.0b

[1]RPM™ = root production method, BR = bare-root, CC = conventional containerized.
[2]The Brooke Tract and Gordon Tract were analyzed separately.
[3]Values in a column followed by the same letter do not differ at $\alpha = 0.05$.

Greater survival for both RPM™ and bare-root was possibly the result of larger, more, well-developed initial root systems. Seedlings with large roots systems are better at over-coming planting stress (McGilvray and Barnett 1982, Larsen et al. 1988, Blake et al. 1989, Rose et al. 1991a, b, Haase and Rose 1993). Size and quality of oak planting stocks can be an important factor related to early growth and survival (Gardiner et al. 2002). Though the bare-root and conventional containerized seedlings were comparable in height, the bare-root seedlings had larger root systems and GLD.

Numerous studies have reported that survival of bare-root hardwood seedlings is typically less than conventional containerized seedlings (Rathfon et al. 1995, Burkett 1996, Williams and Craft 1997, Allen et al. 2001, Howell 2002, Howell and Harrington 2002). Findings of this study do not correspond with these previous studies. White et al. (1970) reported containerized hardwood seedlings had better survival than bare-root seedlings in Michigan. The difference in survival in this study may be due to the small size of the container utilized for the containerized planting stock. Howell and Harrington (2002) found survival increased with increasing container size. They found that seedlings grown in small containers, such as the ones utilized here, exhibited lower survival than those grown in larger containers. Moorhead (1978) found that container size did not affect first-year survival of four bottomland oak species in Mississippi but seedlings grown in 1.5 L containers exhibited more height growth than seedlings grown in 0.5 L.

Ezell and Hodges (2002) found that competition control increased the survival of bare-root oak seedlings in Mississippi. Ezell and Catchot (1998) reported that first-year survival of bare-root oak seedlings increased about 20 percent for seedlings receiving competition control in Mississippi. Ezell et al. (2007) reported that bare-root oak seedling survival increased 21 percent to 44 percent for seedlings receiving herbaceous weed control as compared to seedlings in untreated areas in Mississippi. However, there have been studies showing that competition control resulted in no increase in survival. Dubois et al. (2000) reported no significant difference in survival of 1-0, bare-root cherrybark oak seedlings receiving competition control, tree shelter only, tree shelter with competition control, or seedlings without a shelter or competition control two years after planting in Alabama. Nix (1988) found that first-year survival of bare-root cherrybark oak was the same for all seedlings receiving various methods of weed control in South Carolina. Nix and Cox (1986) also reported, after two growing seasons, bare-root cherrybark oak seedling survival was the same for the seedlings receiving four treatment combinations: seedlings planted in a clearcut, seedlings planted in a shelterwood, and a pre-harvest disking of each with fifteen seedlings of each treatment receiving a direct-spraying of glyphosate at the time of initial measurements in South Carolina. Dey et al. (2006) found first-year survival of RPM™ swamp white oak seedlings to be 95% without the application of competition control in Missouri. Gardiner and Yeiser (1999) found first-year survival of bare-root cherrybark oak (98%) seedlings underplanted in a hardwood stand in Arkansas was not affected by herbicide applications. Ezell and Shankle (2004) also found first-year survival of several hardwood species to be greater than or equal to 91 percent, regardless of competition control treatment in Mississippi. However, these results were attributed to adequate first-year rainfall. Though all bare-root seedlings received herbaceous weed control, it is probable the excellent survival of the bare-root seedlings in this study is attributed to the herbaceous weed control.

CHAPTER VI

HEIGHT RESULTS AND DISCUSSION

Height Differences by Species

Analyses of total height indicated differences between species, site, and year (Table 8). Average height for Nuttall oak seedlings was found to be greater than swamp chestnut oak seedlings for years one and two on both sites (Table 8). Nuttall oak was significantly larger than swamp chestnut oak for both years on both tracts (Table 8). Nuttall oak seedlings on the Brooke Tract and swamp chestnut oak seedlings on the Gordon Tract did not have a significant increase in height from year one to year two (Table 8). Nuttall oak seedlings on the Gordon Tract and swamp chestnut oak seedlings on the Brooke Tract did have a significant increase in height from year one to year two (Table 8).

As noted earlier, these results were anticipated as Nuttall oak has been shown to exhibit greater early growth and survival than many other oak species. Twedt and Wilson (2002) reported Nuttall oak to have the greatest height of five bare-root and direct-seeded oak seedlings in Mississippi. Williams et al. (1992) reported 1-0, bare-root Nuttall oak seedlings to have the greatest first-year height and root collar diameter among three oak species in Mississippi. Jeffreys et al. (2010) reported Nuttall oak to have the greatest tenth-year DBH and height across all treatments among three oak species in Mississippi.

Table 8 Average Total Height by Species, Site, and Year for All Planting Stocks

	Brooke Tract[1]		Gordon Tract	
	Year 1	Year 2	Year 1	Year 2
	--------------------cm--------------------			
Nuttall oak	128.8A[2]a[3]	131.6Aa	125.8Ba	134.3Aa
Swamp Chestnut oak	102.6Bb	111.6Ab	97.2Ab	101.5Ab

[1]Brooke Tract and Gordon Tract were analyzed separately.
[2]Values in a row followed by the same upper case letter do not differ at $\alpha = 0.05$.
[3]Values in a column followed by the same lower case letter do not differ at $\alpha = 0.05$.

Height Differences by Species/Planting Stock Combinations

Initially RPM™ seedlings were the tallest while conventional containerized seedlings were taller than the bare-root seedlings (Table 9). For both years and species, RPM™ seedlings had the greatest height, while bare-root seedlings had a greater height than conventional containerized seedlings on both tracts (Table 9). Conventional containerized Nuttall oak and swamp chestnut oak, as well as, RPM™ Nuttall oak seedlings decreased in height from year one to year two on the Brooke Tract (Table 9). Though these species/planting stock combinations had a decrease in height, it was not a significant decrease (Table 9). There was no significant difference in total height of RPM™ Nuttall and swamp chestnut oak seedlings from year one to year two on the Brooke Tract and swamp chestnut oak on the Gordon Tract (Table 9). Swamp chestnut oak seedlings on the Brooke Tract are the only RPM™ seedlings to have a significant increase in total height from year one to year two (Table 9). Nuttall oak seedlings on the

Brooke Tract are the only RPM™ seedlings to have a decrease in total height from year one (241.8cm) to year two (236.6cm) on the Brooke Tract (Table 9). Oaks have been shown to exhibit dieback during the first few growing seasons after outplanting (Dey et al. 2003, Larsen and Johnson 1998). Though bare-root seedlings were observed to exhibit some dieback, the bare-root seedlings averaged an increase in first year height (Table 9).

Bare-root Nuttall oak seedlings had a significant increase in height from year one (65.5cm) to year two (84.9cm) on the Gordon Tract (Table 9). Bare-root swamp chestnut oak seedlings did not have a significant increase in height from year one (49.2cm) to year two (59.3cm) on the Gordon Tract (Table 9). There was no significant difference in height of conventional containerized Nuttall oak seedlings from year one (64.2cm) to year two (66.9cm) or conventional containerized swamp chestnut oak seedlings from year one (46.1cm) to year two (50.5cm) on the Gordon Tract (Table 9). Height difference was not significant for conventional containerized Nuttall oak seedlings from year one (67.2cm) to year two (60.6cm) on the Brooke Tract (Table 9). Height difference was also not significant for conventional containerized swamp chestnut oak seedlings from year one (46.3cm) to year two (44.8cm) on the Brooke Tract (Table 9). Both species of bare-root as well as RPM™ swamp chestnut oak seedlings had a significant increase in height from year one to year two on the Brooke Tract (Table 9). Bare-root Nuttall oak seedlings had an increase in height from year one (72.0cm) to year two (89.2cm) on the Brooke Tract (Table 9). Bare-root swamp chestnut oak seedlings had an increase in height from year one (57.4cm) to year two (75.5cm) on the Brooke Tract (Table 9). RPM™ swamp chestnut oak seedlings also had an increase in average height from year one (185.8cm) to year two (192.3cm) on the Brooke Tract (Table 8).

Table 9 Initial Height, Year One, and Year Two Average Height by Species, Planting Stock, Site, and Year

		Brooke Tract[3]		Gordon Tract	
NUO[1]	Initial Height	Year 1	Year 2	Year 1	Year 2
	----	----	cm	----	----
RPM™[2]	225.6	241.8A[4]a[5]	236.6Aa	233.5Aa	235.7Aa
BR	66.7	72.0Bb	89.2Ab	65.5Bb	84.9Ab
CC	73.9	67.2Ac	60.6Ac	64.2Ab	66.9Ac
SCO					
RPM™	168.6	185.8Ba	192.3Aa	180.2Aa	181.1Aa
BR	47.5	57.4Bb	75.5Ab	49.2Ab	59.3Ab
CC	53.2	46.3Ac	44.8Ac	46.1Ab	50.5Ab

[1]Species analyzed separately.
[2]RPM™ = root production method, BR = bare-root, CC = conventional containerized.
[3]Brooke Tract and Gordon Tract were analyzed separately.
[4]Values in a row followed by the same upper case letter do not differ at $\alpha = 0.05$.
[5]Values in a column within a species followed by the same lower case letter do not differ at $\alpha = 0.05$.

Nuttall oak and swamp chestnut oak for all three planting stocks had an increase in height from year one to year two on the Gordon Tract (Table 9). Year-one height of RPM™ seedlings was significantly greater than bare-root and conventional containerized seedlings on both sites (Table 9). There was no significant difference in year-one height between the bare-root and conventional containerized seedlings for either species on the Gordon Tract (Table 9). The year-two height of the RPM™ seedlings was significantly greater than both bare-root and conventional containerized seedlings for both species and site (Table 9). The height of the bare-root Nuttall oak seedlings was significantly greater than the conventional containerized seedlings, while bare-root swamp chestnut oak seedlings were not significantly greater than conventional containerized seedlings on the Gordon Tract (Table 9).

Previous research comparing RPM™ seedlings to bare-root seedlings has been variable. Several previous studies have documented RPM™ seedlings to have greater height growth than other planting stocks. Shaw et al. (2003) reported that RPM™ pin oak and swamp white oak seedlings to have greater first-year height growth as compared to bare-root seedlings in Missouri. Dey et al. (2003) reported RPM™ pin oak and swamp white oak seedlings had greater first-year height growth than bare-root seedlings in Missouri. Dey et al. (2004) and Kabrick et al. (2005) also reported RPM™ pin and swamp white oak seedlings had greater first-year height growth than bare-root seedlings in Missouri. However, several studies have reported RPM™ hardwood seedlings to have less early height growth than bare-root seedlings in Missouri (Dey et al. 2003, 2004, 2006, Kabrick et al. 2005). The authors did note that the height growth of RPM™ seedlings could have been negated by rabbit herbivory.

Previous studies have shown containerized oak seedlings to have greater height growth than other planting stocks. Teclaw and Isebrands (1993) reported northern red oak containerized seedlings had better height growth than bare-root seedlings after two and three growing seasons. Burkett and Williams (1998) reported small containerized Nuttall oak seedlings had greater first-year height growth compared to bare-root seedlings in Mississippi, Louisiana, and Texas. Williams and Stroupe (2002) reported that small containerized water and willow oak seedlings had greater first-year height growth than bare-root seedlings in Texas. However, Kormanik et al. (1976) reported bare-root cherrybark oak seedlings had greater height growth than small containerized seedlings for the first four years after outplanting in Georgia.

In three of four comparisons, RPM™ seedlings grew less than or equal to 2.2 cm or decreased in height from year one to year two. Conventional containerized seedlings grew less than or equal to 4.4 cm or decreased in height for all comparisons. Bare-root seedlings grew 9-18 cm in all comparisons.

The small amount of second-year height growth of RPM™ seedlings and greater height growth of bare-root seedlings in this study was surprising. Having a small container size, the conventional containerized seedlings were shallow planted. RPM™ seedlings with an 11.4 L container, which is much larger than the conventional containerized container of 240 cm^3, were not planted as deep as the bare-root seedlings which had long fibrous roots. Bare-root seedlings being planted deeper could have led to these seedlings being less susceptible to dry soil conditions. Also, the root system of the RPM™ and containerized seedlings may not have been sufficient to support early stem growth once taken out of the nursery and outplanted in a natural setting. As stated earlier, bare-root seedlings have been shown to exhibit dieback during the first few growing season following outplanting but the bare-root seedlings had more height growth than RPM™ and conventional containerized seedlings. These trends may not continue after the first two growing seasons when the roots of all planting stocks become more well-established.

CHAPTER VII

GROUNDLINE DIAMETER RESULTS AND DISCUSSION

Groundline Diameter Differences by Species

Nuttall oak seedlings had a significantly larger GLD than swamp chestnut oak seedlings for years one and two on both tracts (Table 10). Average GLD of Nuttall oak seedlings was 2.56 mm larger the first year and 2.72 mm larger the second year as compared to the swamp chestnut oak seedlings on the Brooke Tract (Table 10). GLD of Nuttall oak seedlings on the Gordon Tract was 3.22 millimeters larger the first year and 4.20 mm larger the second year as compared to swamp chestnut oak seedlings (Table 10).

Both species had a significant increase in GLD from year one to year two on both sites (Table 10). Nuttall oak seedlings had a significant increase in GLD from year one (17.01mm) to year two (19.40mm) on the Brooke Tract (Table 10). Swamp chestnut oak seedlings also had a significant increase in GLD from the first year (14.45mm) to the second year (16.68mm) on the Brooke Tract (Table 10). This trend continued on the Gordon Tract with Nuttall oak having a significant increase in GLD from year one (16.96mm) to year two (19.89mm) (Table 10). Swamp chestnut oak seedlings also had a significant increase in GLD from year one (13.74mm) to year two (15.69mm) on the Gordon Tract (Table 10). Again, as noted earlier, differences among species could have been anticipated as Nuttall oak is documented to exhibit more juvenile growth than most other oak species.

Table 10   Average GLD by Species, Site, and Year for All Planting Stocks.

	Brooke Tract[1]		Gordon Tract	
	Year 1	Year 2	Year 1	Year 2
	--------------------mm--------------------			
Nuttall Oak	17.01B[2]a[3]	19.40Aa	16.96Ba	19.89Aa
Swamp Chestnut Oak	14.45Bb	16.68Ab	13.74Bb	15.69Ab

[1]Brooke Tract and Gordon Tract were analyzed separately.
[2]Values in a row followed by the same upper case letter do not differ at $\alpha = 0.05$.
[3]Values in a column followed by the same lower case letter do not different at $\alpha = 0.05$.

Groundline Diameter Differences by Species/Planting Stock Combinations

Initially RPM™ seedlings had the largest groundline diameter, while bare-root seedlings were larger than conventional containerized seedlings (Table 11). RPM™ seedlings had a significantly larger GLD than bare-root or containerized seedlings for both species and years on the Brooke Tract (Table 11). Bare-root seedlings had a significantly larger GLD than the conventional containerized seedlings for both species and years on the Brooke Tract (Table 11). All species/planting stock combinations except conventional containerized swamp chestnut oak exhibited a significant increase in GLD on the Brooke Tract (Table 11).

Table 11 Initial Groundline Diameter, Year One, and Year Two Average GLD by Species, Planting Stock, Site, and Year

		Brooke Tract[3]		Gordon Tract	
	Initial GLD	Year 1	Year 2	Year 1	Year 2
NUO[1]	---------------------------cm----------------------------				
RPM™[2]	22.15	27.57B[4]a[5]	29.53Aa	24.70Ba	29.21Aa
BR	10.45	14.18Bb	17.84Ab	14.56Ab	16.82Ab
CC	6.55	8.40Bc	9.63Ac	10.33Ac	11.81Ac
SCO					
RPM™	18.65	22.87Ba	27.37Aa	21.12Ba	25.14Aa
BR	8.35	11.91Bb	12.72Ab	10.59Ab	11.71Ab
CC	5.15	6.03Ac	6.62Ac	7.68Ac	8.27Ac

[1]Species analyzed separately.
[2]RPM™ = root production method, BR = bare-root, CC = conventional containerized.
[3]Brooke Tract and Gordon Tract were analyzed separately.
[4]Values in a row followed by the same upper case letter do not differ at $\alpha = 0.05$.
[5]Values in a column within a species followed by the same lower case letter do not differ at $\alpha = 0.05$.

As on the Brooke Tract, RPM™ seedlings had a larger GLD than bare-root and containerized seedlings for both species and years on the Gordon Tract (Table 11). Bare-root and conventional containerized seedlings for both species did not have a significant increase in GLD on the Gordon Tract. Both species of RPM™ seedlings had a significant increase in GLD on the Gordon Tract (Table 11).

Oak seedlings have been shown to delay the full allocation of resources to height growth in order to increase root production for the first several years after transplanting. Long and Jones (1996) analyzed the growth of fourteen oak species in Alabama and reported that oak seedlings adjusted the allocation of carbon in order to increase the seedlings' ability to capitalize on limited resources to increase survival during periods of stress. Kormanik et al. (2006) observed that northern red oak seedlings had limited height growth for the first three growing seasons, while root growth was rapid during this period in North Carolina. Measurements of RPM™ seedlings in this study indicate these seedlings could be delaying height growth in order to allocate more resources to root production. Bare-root seedlings had an overall significant increase in height and an increase in GLD, while conventional containerized seedlings had an overall dieback in stem height and little GLD growth. Results of this study show that high-quality 1-0, bare-root oak seedlings can have comparable early growth to more expensive planting stocks.

CHAPTER VIII

CONCLUSIONS

Research has reported varying growth and survival among various planting stocks utilized for hardwood regeneration (Johnson et al. 1984, Thompson and Schultz 1995, McLeod 2000, Dey et al. 2006). Overall, bare-root seedlings had similar first and second-year survival to the RPM™ seedlings but more second-year height growth. This study found that high quality 1-0, bare-root seedlings that are properly handled can perform as well or better than more expensive containerized planting stocks.

Further research is needed to determine if current growth patterns will continue for several growing seasons and to assess the full potential of these three planting stocks. RPM™ seedlings could possibly remain largest of the planting stocks for several years or indefinitely. However, if bare-root seedlings continue second-year height growth patterns, they will be as tall or taller than RPM™ seedlings in a few growing seasons. While the conventional containerized seedlings had a smaller groundline diameter and smaller root system, once these seedlings get a well-established root system, they could possibly become as large as bare-root and/or RPM™ seedlings.

Although economics of each planting stock were not evaluated in this study, bare-root seedlings cost $.25 each, conventional containerized $1.25 each, and RPM™ $15 each. Given that the bare-root seedlings performed as well or better than either the

RPM™ or conventional containerized seedlings through the second year, this study indicates that bare-root seedlings could possibly be the most cost-effective choice when deciding which planting stock to utilize for optimizing early growth and survival.

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