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Early survival and growth performance of two oak species and three planting stocks on Hurricane Katrina disturbed lands

By

John Alec Conrad III

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Forestry
in the Department of Forestry

Mississippi State, Mississippi

December 2013

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John Alec Conrad III

2013

Early survival and growth performance of two oak species and three planting stocks on

Hurricane Katrina disturbed lands

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Survival and growth of two oak species, live oak (*Quercus virginiana*) and Nuttall oak (*Quercus texana*), and three planting stocks: 1-0 bareroot, conventional containerized, and Root Production Method (RPM™) seedlings were compared. Conventional containerized live oak and bareroot Nuttall oak seedlings exhibited greatest survival. RPM™ seedlings exhibited the lowest survival in both species. Conventional containerized seedlings exhibited greater groundline diameter (GLD) growth and twice as much height growth as bareroot seedlings during the first year. During the second year, conventional containerized seedlings exhibited greater GLD growth than bareroot seedlings in live oak, but in Nuttall oak, bareroot seedlings exhibited greater GLD growth. RPM™ seedlings exhibited similar GLD growth compared to bareroot seedlings during both years but the least height growth of all planting stocks, regardless of species. Height growth of bareroot and conventional containerized seedlings was similar after two years.

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CHAPTER I

INTRODUCTION

Bottomland hardwoods are diverse communities that provide a number of ecological, societal, and economic benefits. However, conversion to agriculture and mismanagement of existing stands have left these ecosystems either severely fragmented or in poor condition (Creasman et al. 1992; Hodges and Switzer 1979). Recent decades have witnessed an increased interest in bottomland hardwood restoration by both public and private entities concerned with developing their properties for wildlife, recreation, and timber production. Most restoration attempts by nonindustrial private landowners have been implemented through cost-share programs such as the Conservation Reserve Program and Wetlands Reserve Program, both being provisions of the Farm Bill. These programs have resulted in the wide-spread afforestation of marginal cropland in the United States. Although less popularized, federal and state governments and some private organizations also provide funding for restoration of lands impacted by natural disasters. These programs became extremely important following the devastation from Hurricane Katrina inflicted on Gulf Coastal states in 2005. Although the impacts of Katrina were observable in every state from Florida to Texas and as far north as Kentucky, Mississippi received the brunt of the hurricane's force.

Hurricane Katrina had a devastating impact. Initial estimates of damage indicated that approximately 40% of Mississippi's forests exhibited wind-related damage associated with the hurricane (USDA Forest Service 2005). A recent evaluation indicated that hardwoods incurred more damage than softwoods (Oswalt and Oswalt 2008) with bottomland hardwoods exhibiting the most severe forms of structural damage (Chapman et al. 2008; Wang and Xu 2009). Salvage operations on these damaged lands began quickly and ensued for many months.

Following a salvage operation, landowners have a variety of options regarding the re-establishment of hardwoods on their property. When wildlife habitat and timber production are priorities, landowners will likely desire to develop stands abundant in oaks (*Quercus spp.*). While natural regeneration is the least costly method for regenerating oaks, it is sometimes not appropriate, particularly when a natural disaster necessitates harvest before regeneration can be established (Dey et al. 2008). In such cases artificial regeneration may be used to ensure management objectives are met.

Bottomland hardwood restoration has historically relied on artificial regeneration by planting 1-0 bareroot seedlings of a few selected oak species (King and Keeland 1999), but success has frequently been impeded by competing vegetation, herbivory, and flooding (Schweitzer et al. 1999; Stanturf et al. 1998). Recent decades have been marked by an effort to reduce the impacts of these factors by improving site preparation methods, competition control techniques, and seedling performance. The use of high quality seedlings combined with the appropriate chemical and mechanical methods has proven successful at increasing the probability of success with bareroot seedlings (Ezell et al. 2007). Concurrently, techniques for containerized seedling production have improved, and it is thought they may offer the benefits of resistance to flooding, drought, and transplanting shock (Dey et al. 2004).

A relatively new method, the Root Production Method™ (RPM™), is a system of nursery techniques that has resulted in the development of large containerized seedlings with extensive root systems, potentially capable of better enduring drought, flooding, and terminal shoot removal by white-tailed deer (*Odocoileus virginianus*). The cost of containerized seedlings is the primary factor limiting their use. However, proponents contend that large containerized seedlings may be desired by some land managers, particularly those interested in wildlife benefits from hard-mast production or those implementing agroforestry practices that do not require large-scale planting (Dey et al. 2006).

Because silvicultural operations strive to employ the most cost-effective solutions, comparative evaluations of planting stock performance are needed to help foresters make well-informed decisions about regeneration. While results of previous studies comparing oak planting stocks are available in the literature, most studies have been conducted on retired agricultural lands in major river bottoms and only involve the evaluation of a few key oak species (Dey et al. 2008). Information comparing the performance of planting stocks on cutover or storm damaged lands is lacking. With this study, we seek to help fill that void.

Objectives

The overall objective of this study is:

> To evaluate the two-year performance of three planting stocks of two species of oaks planted on lands disturbed by Hurricane Katrina.

Specific objectives include:

1. Compare the two-year survival, height growth, and groundline diameter (GLD) growth of live oak (*Quercus virginiana*) and Nuttall oak (*Quercus texana*).
2. Compare the two-year survival, height growth, and groundline diameter of three planting stocks: high-quality 1-0 bareroot seedlings; containerized seedlings produced under conventional nursery practices; and 11.4 L Root Production Method™ (RPM™) seedlings.

CHAPTER II

LITERATURE REVIEW

Hurricane Katrina

On August 29, 2005, Hurricane Katrina struck the gulf coast of Mississippi and Louisiana as a Category III hurricane. With sustained wind speeds of 201km h^{-1} and peak wind gusts up to 240km h^{-1}, it was the third strongest storm to strike the coastal United States in the past century (Graumann et al. 2005, Chapman et al. 2008). From landfall it proceeded on a northern trajectory into Mississippi, and although it was relegated from hurricane status 241km inland, peak wind gusts greater than 129km hr^{-1} were observed throughout the state (Graumann et al. 2005). The storm left its mark on every Gulf Coastal state from Florida to Texas, but it brought tremendous destruction to Mississippi, Louisiana, and Alabama.

Hurricane Katrina had a devastating impact on gulf coast forests with Mississippi receiving the brunt of the hurricane's force. An initial assessment of damage conducted by USDA Forest Service (2005) estimated that 37% of timberland in Mississippi experienced damage with nearly 90% of the damage occurring in the southernmost eight counties. Oswalt et al. (2008) found similar results. Chambers et al. (2007) estimated that approximately 320 million large trees (DBH > 10cm) either died or experienced severe structural damage as a result of the storm. Although initial estimates indicated that the loss of softwood exceeded that of hardwoods (USDA Forest Service 2005), later evaluations indicate that bottomland hardwood forests were the most severely affected (Chapman et al. 2008; Oswalt and Oswalt 2008; Wang and Xu 2009).

Oak Regeneration

The silvical characteristics of oaks make them extremely challenging to regenerate on high-quality sites, primarily due to their poor competitive ability on moist soils (Clark 1993, Hodges and Gardiner 1993). In general, oaks are moderately intolerant of shade, slow to respond to release, and exhibit delayed juvenile shoot growth (Hodges and Gardiner 1993, Janzen and Hodges 1987, Smith 1993, Loftis 1990). In contrast, rapid initial shoot growth is characteristic of some shade tolerant and many shade intolerant species. When present at high densities, these competitors may be deleterious to oak persistence and development. Generally, only seedlings with established root systems have the competitive ability to survive to successive growing seasons (Meadows and Hodges 1997). First year seedlings can be a good source of regeneration when the preceding fall was characterized by good acorn crop, harvesting operations are conducted in spring, and if precipitation is sufficient to facilitate multiple growth flushes during the first growing season (Hodges, personal communication). However, because of the uncertainty in meeting these conditions, seedlings that have survived more than one growing season are a more dependable source of regeneration.

It is widely accepted that advanced regeneration is necessary to ensure that oaks achieve dominant canopy positions in the succeeding stand (Hodges 1987, Loftis 1990, Clatterbuck and Meadows 1993, Meadows and Hodges 1997, Meadows and Stanturf 1997). Developing advanced regeneration often requires the control of non-commercial species prior to or during harvest operations (Janzen and Hodges 1987; Meadows and

Stanturf 1997). Oak stems should be established and well distributed to compete with light-seeded, shade intolerant species following release. While not always possible, ensuring an adequate distribution of advanced regeneration prior to harvest is a cardinal principle applied when natural regeneration is used to favor oaks.

When feasible, natural regeneration should be implemented in conjunction with a harvesting method that creates openings large enough to meet the light requirements of the target species. Clearcutting, shelterwood, and patch cutting are the most appropriate options (Meadows and Hodges 1997). Clearcutting has been the most dependable method for regenerating oaks in southern bottomlands, and when combined with natural regeneration is the most cost-efficient of all the harvest-regeneration systems (Clatterbuck and Meadows 1993; Dey et al. 2008). A modified shelterwood method, proposed by Hodges (1987), may be used to develop advanced regeneration when clearcutting is unlikely to produce desired results. Patch cutting may be used when aesthetics are a concern, but it is the most costly of the three methods (Meadows and Hodges 1997).

Artificial Regeneration of Oaks

In some situations, it is impractical to rely on natural regeneration to stock stands at levels that satisfy desirable objectives. Examples include afforestation of retired agricultural lands, areas with insufficient or poorly distributed seed sources, or when a salvage operation is conducted before regeneration can be established (Dey et al. 2008). Artificial regeneration of oaks is challenging. Success is often contingent upon a manager's understanding of many factors that are inextricably linked (Dey et al. 2008). The major factors upon which regeneration decisions are based are site quality, prior stand condition, site preparation, species-site suitability, planting stocks, seedling quality, and desired stand structure (Dey et al. 2008; Stanturf et al. 2004; Baker and Broadfoot 1979; Kennedy 1993).

Artificial regeneration establishes stands by either direct seeding or by planting seedlings. While direct seeding has been shown to be an effective means of establishing oaks (Allen 1990), its use has dramatically declined in operational settings (Schoenholtz et al. 2001). Stands successfully sown with acorns often result in greater species diversity and structure than those planted with seedlings, thus direct seeding may be appropriate in situations where the provision of wildlife habitat is the primary objective (Allen 1990; Twedt and Wilson 2002; Haynes 2004). However, the potential for harvesting valuable timber is important to many landowners, and research shows that sites planted with seedlings typically result in greater survival and growth (Allen 1990) and effectively retain their intra-row spacing as much as 18 years after establishment (Twedt and Wilson 2002): a characteristic that permits greater long term flexibility from a management standpoint. While planted sites may develop into oak monocultures that are poor wildlife habitat, this problem can be partially averted by planting species mixtures (Twedt and Wilson 2002). Research also shows that planting mixtures results in better quality timber (Lockhart et al. 2005). A combination of these considerations has led to almost exclusive use of seedlings for oak establishment (King and Keeland 1999; Schoenholtz et al. 2001; Haynes 2004).

Plantation failures have occurred at alarming rates in operational settings (Schoenholtz et al. 2001; Schweitzer et al. 1999, Stanturf et al. 2001). Early growth and survival has been impeded by a myriad of factors including flooding, drought, herbivory, and competing vegetation (Stanturf et al. 2004). Competing vegetation is perhaps the most consistent problem encountered on bottomland sites, limiting the amount of soil moisture and light available to juvenile oak seedlings (Russell et al. 1998, Smith 1993; Hodges and Gardiner 1993). As a result, dieback and resprouting occurs frequently, both of which may compromise a seedling's ability to survive to successive growing seasons (Burkett et al. 2005). Efforts to resolve these issues have led to the developments in almost every facet of the artificial regeneration process. Most notable, perhaps is the production of high quality planting stocks and development of chemical methods for controlling competing vegetation.

Bareroot Seedlings

Bareroot seedlings are offered in a variety of age classes and sizes, but 1-0 seedlings are used most often in operational oak plantings. A typical 1-0 bareroot seedling is between 50 and 70cm in height with a basal diameter between 6 and 8mm (Dey et al. 2010), and has a root system generally characterized by a large tap root with some lateral development (Williams and Craft 1998). Bareroot seedlings can be machine or hand planted, and they perform best when planted from January to mid-March (Stanturf et al. 1998). Measures should be taken to expedite recovery from transplanting shock, including proper storage, handling, and planting practices. These considerations and careful species-site matching are essential to success. Survival during the first two growing seasons is the most critical.

The outcome of bareroot seedling plantings is largely dictated by precipitation and amount of competing vegetation in the early years of establishment. Allen (1990) provides one of the best examples to illustrate this point. He evaluated bareroot plantings on federally owned lands after an average of 7.5 years and observed variable survival ranging from 90% to 55% when minimal or no post-planting treatments were applied. Differences in survival rates were attributed to differences in soil moisture and competing vegetation among sites. The results of this study demonstrated that bareroot seedlings are a viable option for artificial regeneration, but it also highlighted their sensitivity to inadequate moisture and competing vegetation.

The principal way of improving survival is to plant high quality seedlings, and although bareroot seedlings are infrequently graded (Gardiner et al. 2002), some nurseries offer both standard and high-quality stock, the latter of which are visually graded based on their morphological attributes after lifting. Research shows that tall seedlings with large diameters and more extensive lateral root systems perform better than smaller seedlings with poorly developed root systems (Kormanik et al. 1995; Kormanik 1989; Kormanik and Ruehle 1987; Teclaw and Isebrands 1993, Thompson and Schultz 1995).

Height, root collar diameter, and the number of first order lateral roots (FOLR) are frequently used to describe the quality of bareroot seedlings (Clark et al. 2000). The development of the root system should be of primary importance when grading, and this is substantiated by several studies. For instance, one study found that 1-0 bareroot northern red oak seedlings having more than 11 FOLR achieved competitive positions after 3 growing seasons (Kormanik et al. 1995). In another study, acorn production was recorded as early as eight years for seedlings with more than six FOLR (Kormanik et al. 2004). Ezell (2007) recommended six as the “absolute minimum” number of FOLR suitable for planting, and stated that 10-12 is preferable.

While measuring seedling parameters has proven to be a relatively dependable method of determining bareroot quality, Clark et al. (2000) proposed a more operationally friendly approach based entirely on a visual assessment of seedlings to separate them into three categories: cull, good, and premium. Using this method to classify northern red oak (*Quercus rubra*) seedlings, Buckley (2002) observed significant increases in height growth with increasing seedling grade. Unexpectedly, he found the mid-grade seedlings had the greatest survival, which was cautiously interpreted as a possible result of greater deer browsing pressure on the highest grade seedlings.

In a similar but two-year study using the same visual grading process, Oswalt et al. (2006) found that while performance of both premium and good seedlings was excellent, premium seedlings (mean FOLR = 21.49, Ht.= 124.30cm, RCD = 12.26mm) exhibited 31% greater height growth and 35% greater diameter growth than good seedlings (mean FOLR = 16.46, Ht. = 103.85cm, RCD = 10.23mm). Mortality was not observed in the premium seedlings, and survival remained high for the good seedlings throughout the study (≥ 87%). Moreover, nearly half the seedlings had achieved heights greater than what is regarded as the general "browse-line"(1.4m) of white-tailed deer by year two. The results of the previously discussed studies validate Clark et al. (2000) visually based assessment of seedling quality, but more importantly they affirm the utilization of high-quality seedlings to improve outplanting results.

Although properly planting high quality seedlings is critical, it does not necessarily ensure successful establishment. Competition for soil moisture is particularly detrimental and often contributes to mortality during the first few growing seasons (Ezell 2007). Mechanical and chemical methods of controlling competition have been employed to improve survival, although neither has experienced widespread usage in operational plantings. Most hardwood plantings have employed a minimal effort approach. Consequentially, many have resulted in inadequate stocking and some in complete failure (Stanturf et al. 2001). While site and environmental conditions have the potential to be more deleterious, competing vegetation has been a consistent problem on planted bottomland sites and is especially detrimental to small bareroot seedlings.

Fortunately, research has shown that herbaceous weed control provides a cost effective means to deal with this problem. Ezell et al. (2007) investigated the effects of herbaceous weed control on 1-0 bareroot oak plantings and found that plots receiving herbaceous weed control resulted in 20 to 25 percent better survival than untreated areas. Ezell and Hodges (2002) reported increased survival of planted oak seedlings on a cutover site. Moreover, Grebner et al. (2003) found that herbaceous weed control is economically justifiable and desirable under many circumstances. The results of these studies provide strong evidence for the procedural application of herbaceous weed control when planting bareroot seedlings.

Containerized Seedlings

Interest in producing containerized seedlings first arose in the 1970's in response to an increasing demand for seedlings and inconsistencies experienced planting bareroot seedlings. It was thought that the production and use of containerized seedlings could improve efficiencies in virtually all aspects of reforestation from the nursery to planting to outplanting performance (Stein et al. 1975). Containerized seedlings can be produced more expediently and efficiently in terms of acorn usage (Dumbroese and Owston 2003).

They also offer a wider range of planting time, which is advantageous in areas prone to spring flooding (Humphrey 1994).

Containerized seedlings are available in a variety of container sizes ranging from 150cm^3 to over 19L (Dey et al. 2008). While small conventional-sized containerized seedlings are typically shorter than 1-0 bareroot stock and have less root volume and mass, they offer the advantages of a more fibrous root system and thus, a more balanced root: shoot ratio (Burkett and Williams 1998, Humphrey 1994, Williams and Craft 1998). These characteristics better equip containerized seedlings to overcome transplant stress and harsh conditions during the first growing season. Storage and handling malpractices are also less of a concern for containerized seedlings due to the root protection offered by the container and planting media. The potential for frost heaving should be considered when planting containerized seedlings in heavy clays during winter and early spring, but this risk can be avoided altogether by waiting to plant until temperatures are more consistent (Stroupe and Williams 1999).

The survival and early growth advantages of containerized seedlings are well documented. Johnson et al. (1984) reported greater shoot growth, leaf area, and root elongation for containerized northern red oak seedlings compared to both small and large 1-0 and 1-1 bareroot stock after one growing season. Williams and Stroupe (2002) reported that containerized water (*Quercus nigra*) and willow (*Quercus phellos*) oak had over twice the height growth of 1-0 bareroot seedlings after one growing season. Wilson et al. (2007) reported 25% greater survival and positive height growth for container grown northern red oak seedlings compared to 1-0 bareroot seedlings which exhibited dieback overall. Williams and Craft (1998) reported similarly better survival and growth of containerized Nuttall oak seedlings compared to 1-0 bareroot seedlings even when planted late in the growing season. These studies affirm the ability of containerized seedlings to overcome transplanting stress and induce height growth earlier than bareroot seedlings.

While first season survival and growth is extremely important, a few prolonged studies indicate that the advantage of conventional containerized seedlings may diminish in years after establishment. Sweeney et al. (2002) reported slightly greater height growth for containerized seedlings at the end of the first growing season, but noted that by the end of the fourth growing season, 1-0 bareroot seedlings had achieved similar heights. In slightly different circumstances, Burkett and Williams (1998) reported that while containerized seedlings were better able to recover from flooding and heavy herbivory, exhibiting twice the survival (96% vs. 45%) and slightly better height growth during the first year, a report of the fifth year findings showed that surviving bareroot seedlings had surpassed containerized seedlings in height (Burkett et al. 2005).

In slightly different circumstances when bareroot seedlings received herbaceous weed control during the first year, Hollis (2011) found that both Nuttall and swamp chestnut oak (*Quercus michauxii*) 1-0 bareroot seedlings maintained a consistent survival and height advantage over containerized seedlings both during the first and second growing season. Thus, the advantages of containerized seedlings may not be realized when herbaceous weeds are reduced and growing season conditions are favorable in bareroot plantings.

Studies have demonstrated that performance of containerized seedlings improves with increasing size of containers (Moorehead 1978; Howell and Harrington 2002). Self et al. (2010) observed a similar pattern when comparing small containerized seedlings to potted seedlings. However, large containerized seedlings are much more expensive to purchase and plant, the principal factor inhibiting their use. While costs vary greatly, small containerized seedlings typically cost at least twice as much as bareroot stock to purchase and plant.

Root Production Method™ Seedlings

Conventional size containerized seedlings may potentially have early survival and growth advantages compared to bareroot seedlings, primarily because of the greater capacity of their roots to absorb water and nutrients. However, because of their small stature, they are subject to many of the same factors that inhibit early growth and survival of 1-0 bareroot seedlings such as competing vegetation, white-tailed deer herbivory, and flooding. To overcome these limitations, Forest Keeling Nursery in Elsberry, Missouri developed a nursery process, the Root Production Method™ (RPM™), to produce large containerized seedlings with well developed, fibrous root systems (Dey et al. 2004). The process is unique due to a strict adherence to multistep process of grading, air pruning, and fertilization before they are finally transplanted into 11.3 or 19L pots where they remain for one or two years, respectively. When available for purchase, RPM™ seedlings are often over 1.5m tall, and have substantially larger root systems than 1-0 bareroot seedlings (Dey et al. 2004, Dey et al. 2006).

Because of their height, it is thought that RPM™ seedlings may help reduce the impacts of shading from overhead competition, flooding, and occurrence of deer browsing of terminal buds (Dey et al. 2006). It is also thought that transplanting shock is also less likely to impact survival compared to smaller seedlings due to the large root system's ability to readily establish once planted.

Research conducted with RPM™ seedlings is limited, but most of the information originates from a long-term case study installed on two retired agricultural sites in Missouri (Dey et al. 2003, Dey et al. 2004, Dey et al. 2006, Kabrick et al. 2005, Shaw et al. 2003), comparing the performance of RPM™ and 1-0 bareroot seedlings. Swamp white oak (*Quercus bicolor*) and pin oak (*Quercus palustris*) were chosen for evaluation. Survival, basal diameter growth, and height growth were measured after the first (Shaw et al. 2003.), second (Kabrick et al. 2005), and third (Dey et al. 2003, Dey et al. 2004, Dey et al. 2006) growing seasons to determine if any differences or interactions between species and planting stock existed.

After the first growing season, RPM™ survival and basal diameter growth was greater than that of bareroot seedlings, but differences in height growth were insignificant (Shaw et al. 2003). During successive growing seasons, both planting stocks were subject to intense herbivory by cottontail rabbits (*Silvestris floridanus*) and on one site, growing season flooding. By the end of the third growing season, RPM™ survival remained above 93% compared to bareroot survival which was 54% for pin oak and 76% for swamp white oak. RPM™ consistently yielded greater basal diameter growth in all three growing seasons (Dey et al. 2006). Bareroot seedlings were able to recover to or exceed initial heights, and thus exhibited greater height growth than RPM™ seedlings; however, RPM™ seedlings remained taller at the conclusion of the study. These findings suggest that RPM™ seedlings may have a superior ability to overcome establishment limitations brought about by flooding, intense herbivory, and potentially other sources.

Although large containerized seedlings have rarely been used in operational settings, Dey et al. (2008) reported the increased operational use of RPM™ seedlings in the Midwest. Similar to other containerized seedlings, the main factor limiting the use of RPM™ seedlings is their cost. The per unit cost may be $8.00 for an RPM™ seedling compared to $0.50-1.00 for a 1-0 bareroot seedling (Dey et al. 2006), and because of their size they are more expensive to transport and plant. According to proponents, however, the long term benefits may justify the increased initial costs for some managers, especially those whose primary objective is to provide mast for wildlife. Dey et al. (2006) contended that planting fewer large containerized seedlings per unit area is a more dependable method of ensuring hard mast species will occupy the future overstory, and intensive management of small stands of RPM™ trees may be more desirable than managing for mast production across large areas for some landowners. Implementation of common agroforestry practices such as riparian buffers, wind breaks, alley cropping, or silvopasture are good examples situations wherein landowners might prefer to plant RPM™ seedlings (Dey et al. 2003). Thus, the "role" of RPM™ seedlings may differ from that of smaller planting stocks in bottomland restoration efforts (Dey et al. 2006).

Herbaceous Weed Control

Competing vegetation is the most common detrimental factor affecting newly planted oak seedlings in bottomland areas. Both woody and herbaceous vegetation limit the availability of moisture, light, and nutrients to the slower growing oaks. Moisture availability is often the limiting factor while oaks are establishing their root systems, especially when herbaceous forb and grass coverage is extensive (Ezell 2007). Fortunately, many species are relatively easy to control, and herbicide application is the most cost effective solution. Herbicide applications have been uncommon in operational oak plantings (Haynes 2004), and while many factors have contributed to the high frequency of plantation failures, studies show that chemical control of competition can drastically improve survival, especially herbaceous weed control in the initial years of establishment (Ezell et al. 2007). Research indicates that using of herbaceous weed control alone is an economically desirable alternative to the "plant and walk away" approach (Grebner et al. 2003).

Sulfometuron methyl (Oust® XP)

Sulfometuron methyl, or Oust® XP, is a broad spectrum soil active herbicide that provides effective control of many species of forbs and some grasses. It is suitable for tank mixing with many herbicides commonly used for site preparation. Post-plant, pre-emergent and post-emergent applications are effective with this herbicide. Pre-emergent applications are most effective and should be applied prior to bud-break of crop trees to minimize damage, especially when applied to white oak (*Quercus alba*) (Ezell and Cachot 1998). At a rate of 140g/ha, Oust® XP is effective for controlling many problematic herbaceous species, but it is only moderately effective against species such as goldenrod (*Solidago spp.*), dogfennel (*Eupatorium capillifolium*), and johnsongrass (*Sorghum halepense*); and is ineffective at controlling woody species and some grasses, such as broomsedge (*Andropogon spp.*) (Miller 1993). Site preparation tank mixes containing sulfometuron methyl have been shown to have substantial effects on herbaceous weed establishment. Ezell (2002) observed 80% bareground in July in plots treated the preceding September with site preparation tank mixes containing 210 g/ha Oust® or 539g/ha of Oustar® compared to 15% for those not including either chemical.

In a study investigating the effects of post-plant, pre-emergent application on survival, Ezell and Cachot (1998) reported an average of 20-25% increase in survival for six oak species and green ash (*Fraxinus pennsylvanica*) treated with two rates of (140- and 281g/ha) Oust® compared to untreated areas which averaged 60-70 % survival. The results of two other trials with cherrybark oak (*Quercus pagoda*) and Nuttall oak similarly showed increases in average survival in treated areas ranging from 31-44% greater than control areas in years when precipitation growing season was below average (Ezell et al. 2007). In all three trials nearly all herbicide treatments maintained over 75% average survival during the first growing season (Ezell et al. 2007). Grebner et al. 2003 projected that less than 75% stocking is economically undesirable when timber production is an objective. These studies provide strong evidence to warrant procedural use of competition control in newly established oak plantings, and Oust® XP provides a cost effective means to help ensure their success.

CHAPTER III

MATERIALS AND METHODS

Site Descriptions

Research was conducted on two privately owned tracts near Hattiesburg, Mississippi. Both sites were positioned on minor stream bottoms and contained poorly drained soils. The soil series represented in this study were Trebloc, Bibb, and Jena. Average annual precipitation for the area is 158.7cm.

The Guiles tract (31° 19’ 45.41”N, -89 07’ 56.48”W), in Perry County, was located approximately 10 miles east of Hattiesburg adjacent to the western border of Tallahala Creek. The NRCS Web Soil Survey revealed that Trebloc silt loam (0 to 1 percent slopes, frequently flooded) was the major soil association on site (NRCS 2011), and soil sample analysis indicated that the pH was 4.6. Prior to Katrina, this site was occupied by mixed pine/hardwoods comprised of loblolly pine interspersed with sweetgum (*Liquidambar styraciflua*), water oak, and willow oak. This site was severely impacted by the storm, and according to the landowner, experienced a substantial amount of wind-throw damage. A salvage operation was conducted to remove merchantable timber. Residual stems were injected with a 20% aqueous solution of Arsenal® AC (Imazapyr), and the site was chopped to prepare the site for planting. The subsequent growing season was marked by prolific colonization by winged sumac (*Rhus copallina*). The site received a direct foliar application of 2% Accord® XRT (glyphosate) solution on

November 11, 2010. Herbicide was applied with a Solo® 11.4L piston-pump backpack sprayer. Dry soil conditions, residual slash and debris were reported by planting crews as creating difficult planting conditions on this site.

The second site, the Morgan Tract (31°23'30.73"N, -89°26'07.31"W), is located Forrest County, Mississippi approximately nine miles northeast of Hattiesburg. The NRCS Web Soil Survey revealed that the soil present was a complex of Bibb and Jena (NRCS 2011). Analysis of soil samples indicated that the soil was a sandy loam with a pH of 5.4. Prior to Katrina this site was also a mixed-pine hardwood stand comprised primarily of loblolly pine (*Pinus taeda*) with smaller components of white oak, water oak, southern magnolia (*Magnolia grandiflora*), black cherry (*Prunus serotina*), and sweetgum. Damage to this site was less severe. After merchantable timber was removed, the site was sheared, raked, burned, and cleared with a bulldozer to prepare the site for planting. The intensity of mechanical site preparation abated the need for chemical site preparation on this site.

Plot Demarcation

A rectangular study area was established at each site to accommodate 1800 seedlings planted on a 3.05m by 3.0 m spacing. A compass and two 300m surveyor's tapes were used to ensure row straightness and uniform tree spacing. Each study area was divided into three blocked replicates. Six plots containing 100 planting locations were randomly assigned to groups of adjacent rows within each replicate to represent each of the six species and planting stock combinations. Pin flags of different colors were used distinguish species and planting stock combinations and mark planting locations. A piece of 1.2m rebar was placed at the beginning and ending of each planting row and attached with an aluminum tag denoting the replicate, row number, species, and planting stock. The corners of each study area were marked with 3.0m piece of 2.5cm diameter polyvinyl chloride (PVC) pipe placed over a 1.2m piece of rebar.

Seedling Establishment

Two oak species, Nuttall oak and live oak, and three planting stocks: high-quality 1-0 bareroot, 240cm^3 conventional containerized, and 11.4L RPM™ (Root Production Method) seedlings were selected for evaluation. Each of the three planting stocks was purchased from a separate nursery. Bareroot seedlings were purchased from Molpus Woodlands Group™ in Elberta, Alabama. Conventional containerized seedlings were purchased from Rennerwood Incorporated ™ in Tennessee Colony, Texas. RPM™ seedlings were purchased from RPM Ecosystems™ in Ocean Springs, Mississippi.

A total of 3,600 seedlings were planted for the study with 1,800 seedlings per site: 300 hundred seedlings per species and planting stock combination. Bareroot seedlings and conventional containerized seedlings were planted by Mississippi State University personnel on the first two weekends of February in 2011. Bareroot and conventional containerized seedlings were planted with planting shovels. RPM™ seedlings were planted by a commercial planting crew on February 19, 2011 using planting shovels. Seedlings were planted next to pre-marked pin flags to ensure uniform spacing. Each planting operation was supervised by a graduate research assistant to ensure a quality planting job.

Pre-Emergent Herbicide Application and Groundcover Evaluations

Plots planted with bareroot and conventional containerized seedlings were treated with a post-plant, pre-bud break application of Oust® XP (140g/ sprayed ha) in February 2009. An 11.4L Solo® piston-pump backpack sprayer equipped with a TeeJet 8003 Visiflo® nozzle, specially designed to minimize wind drift, was used to apply the herbicide as a 1.5m band over the top of seedlings. Herbicide was applied in the morning when wind was minimal as a primary precaution to avoid herbicide drift into untreated plots. To evaluate the effectiveness of the pre-emergent application, estimates of percent ground cover for four vegetation types (grass, broadleaf forb, vines, and shrub) and bareground were performed on a per plot basis monthly from May through September in 2011. Bareroot and conventional containerized seedlings represented treatment plots, whereas RPM™ plots were considered untreated checks.

Seedling Survival and Measurements

Survival was recorded during initial, first-year, and final measurement periods, but also monthly during the first growing season from May-September, 2011 to determine if planting shock contributed to mortality. The cambium layer was nicked to affirm suspected mortality during each survival evaluation.

Initial groundline diameter (GLD) and height measurements were recorded on March 26, 2011. Height of bareroot and conventional containerized seedlings was measured to the nearest centimeter using a meter stick. Height of RPM™ seedlings was measured to the nearest tenth of a foot using a telescopic height pole. Groundline diameter measurements were measured to the nearest tenth of a millimeter using Mititoyo® digital calipers. Only the living portion of the dominant stem was measured in height and GLD measurements in the case that a seedling exhibited die back or had died back completely and re-sprouted. First year groundline diameter and height measurements were recorded in October 12, 2011 on the Guiles tract and on February 25, 2012 on the Morgan tract. Final survival and measurements were recorded on October 12 and 13, 2012.

Rainfall

A Rainwise™ rain gauge equipped with a Hobo™ data logger was installed on each site to record monthly rainfall. Data was uploaded to a laptop computer into Boxcar 4.0® software. Rainfall data will be used as an explanatory factor to support conclusions about survival and growth.

Experimental Design and Data Analysis

A randomized complete block design with a factorial arrangement of treatments was used for this study. Three blocks were established on each site. Individual blocks were sub-divided into six rectangular plots. Each plot was a single replicate for a unique species and planting stock combination and contained 100 seedlings each. The plot was considered the experimental unit for survival, measurements, and groundcover evaluations. Data was analyzed using Statistical Analysis System (SAS) software version 9.2®.

An Analysis of Variance using PROC GLIMMIX (SAS version 9.2®) was used to analyze survival and groundcover percentage data. Levene's test was used to test for homogeneity of variances within factors prior to analysis. Both types of data were arcsine square-root transformed prior to analysis. Groundcover percentages were analyzed for differences between treated and untreated plots for each vegetation cover type. Survival data was tested for differences between sites, species, and planting stocks, and for interactions among these factors. Means separation was performed using least squared differences at the 0.05 level of significance.

PROC GLIMMIX was also used to analyze height growth and GLD data which were tested for differences between sites, between species, among planting stocks, and for interactions between these factors. Height growth and GLD data were analyzed excluding seedlings that had completely dieback and resprouted. Pseudolikelihood estimation was used to determine differences between treatments which were considered significant at the 0.05 level.

CHAPTER IV

RESULTS AND DISCUSSION

Ground Coverage

Broadleaf Coverage

The Guiles site had significantly greater broadleaf coverage than the Morgan site in May (Table1). Canada goldenrod (*Solidago canadensis*) and horseweed (*Conyza canadensis*) were the dominant species on the Guiles site, but dogfennel, cudweed (*Gnaphalium obtusifolium*), common ragweed (*Ambrosia artemisifolia*) and yellow sorrel (*Oxalis stricta*) were also common. Control and treated plots on the Guiles site had 22.5% and 11.8% broadleaf coverage in May, respectively. In contrast, control and treated plots on the Morgan site had very little broadleaf cover in May (3.5% and 1.5%, respectively). Broadleaf coverage on the Morgan site mostly comprised of dogfennel and American burnweed (*Erechtites hieracifolia*).

Table 1 Average percent broadleaf coverage in control and treated plots by site and month of observation in 2011.

	May	June	July	August	September
			----------percent----------		
Guiles					
Control	22.5 A[1]c[2]	26.7 Ac	41.7 Ab	66.7 Aa	68.3 Aa
Treated	11.8 Bd	13.5 Bd	25.0 Bc	44.2 Bb	51.7 BCa
Morgan					
Control	3.5 Cd	10.0 Cc	43.3 Ab	68.3 Aa	68.3 ABa
Treated	1.3 Dd	3.8 Dd	20.0 Bc	35.0 Ba	38.3 Ca

[1]Means followed by the same uppercase letter in a column are not significantly different ($\alpha = 0.05$).
[2]Means followed by the same lowercase letter in a row are not significantly different ($\alpha = 0.05$).

Broadleaf coverage did not change significantly from May to June on the Guiles site in control or treated plots. A significant increase in coverage from May to June was observed in control plots but not in treated plots on the Morgan site. A substantial increase in average broadleaf coverage was observed from June to July on both sites. On the Guiles site, broadleaf coverage almost doubled in treated plots from June to July. In comparison, broadleaf coverage on the Morgan site more than quadrupled in control and treated plots from June to July. The large increase in broadleaf cover on the Morgan site was primarily attributed to rapid growth and colonization of dogfennel, American burnweed, and pokeweed (*Phytolacca americana*). In July and months thereafter, there was no significant difference between sites.

On both sites, control plots had at least twice the broadleaf coverage as treated plots in through June, and differences between control and treated plots were significant throughout the growing season on both sites. Thus, broadleaf control was considered acceptable on both sites. Broadleaf cover on both sites was largely comprised on species that are typically only suppressed by Oust® XP at the rate applied (140g/ sprayed ha). In general; sprayed bands were still distinguishable at the end of the growing season on both sites by reduced broadleaf cover. On the Guiles site, this was due to release of grasses or vines. On the Morgan site, it appeared that the duration of control was longer. Oust® XP is effective at lower rates on more course textured soils than fine textured ones, and is more effective on dogfennel and fireweed than it is on goldenrod and horseweed at the rate applied (DuPont 2009).

Grass coverage

Grasses were relatively abundant on the Guiles site in May, 22.5% and 11.8% in control and treated plots, respectively. In contrast, the Morgan site had only 4.5% coverage in control plots and only 1.3% grass coverage in treated plots (Table 2). The difference between sites was largely because grasses on the Guiles site sprouted from established rootstock. Typically, Accord® XRT provides excellent control of annual and perennial grasses, but because glyphosate is only foliar active, it is only effective when the plants are actively growing (Dow Agrosciences 2006). Thus, the chemical, which was applied on November 11, 2010, was not expected to control established grasses, which may have been dormant at the time of application.

Table 2 Average percent grass in treated and control plots by site and month of observation in 2011.

	May	June	July	August	September
			----------percent----------		
Guiles					
Control	28.3 A[1]b[2]	35.0 Ab	68.3 Aa	73.3 Aa	70.0 Aa
Treated	17.7 Bd	23.3 Bc	35.8 Bb	64.2 Aa	64.2 Aa
Morgan					
Control	4.5 Cd	14.2 Cc	31.7 Bb	46.7 Ba	48.3 Ba
Treated	1.3 De	3.0 Dd	14.3 Cc	22.9 Cb	32.5 Ca

[1]Means followed by the same uppercase letter in a column are not significantly different ($\alpha = 0.05$).
[2] Means followed by the same lowercase letter in a row are not significantly different ($\alpha = 0.05$).

Oust® XP reduced grass coverage on the Guiles site. However, there was little difference between control and treatment plots by August, primarily due to release of grasses into sprayed bands. Little blue stem (*Schizachyrium scoparium*)and various panic grasses (*Panicum spp., Dicanthelium spp.*) were the dominant species on the Guiles site. Oust® XP does not control little bluestem, and the effectiveness of the herbicide on panic grass varies by species (DuPont 2009). Coverage by crabgrass (*Digitaria spp.*) and knotgrass (*Paspalum spp.*) was also notable, and only short term control of these species was achieved. Patches of cogongrass (*Imperata cylyndrica*) were observed forming monocultures in sprayed bands. Oust® XP does not effectively control cogongrass, and has been reported to increase cogongrass abundance when applied as a stand-alone treatment (Faircloth et al. 2005).

Chemical site preparation was not required on the Morgan site. The site was sheared, root-raked, piled and burned in February. Thus, grasses on this site were represented by new germinants and were sparsely distributed in both control and treatment plots during May and June. Oust® XP is more effective for controlling fresh germinants compared to established plants, and is effective at lower rates on course textured soils (DuPont 2009). Little bluestem and panic grasses were also the dominant species on the Morgan site, but they were not abundant until July. In contrast to the Guiles site, differences between control and treated plots on the Morgan site remained significant throughout the growing season.

Vine Coverage

On both sites, the major vine species present were blackberry (*Rubus spp.*), muscadine grape (*Vitis rotundifolia*), and peppervine (*Ampelopsis arborea*), poison ivy (*Toxicodendron radicans*), purple passionflower (*Passiflora incarnata*), trumpet creeper (*Campsis radicans*), Japanese honeysuckle (*Lonicera japonica*), and small-leaf morningglory (*Jaquemontia tamnifolia*) were abundant on the Guiles site. These species occurred on the Morgan site, but were less abundant compared to the Guiles site (Table 3).

Vine coverage was comparable between sites for most of the growing season. Treated and control plots on the Guiles site had slightly greater vine coverage than the Morgan site throughout the growing season, but there was no significant difference comparing control plots between sites in August (Table 3). Oust® XP did not reduce vine coverage on either site, which was expected because Oust® XP does not control most vines (DuPont 2009).

Table 3 Average percent vine coverage in treated and control plots by site and month of observation in 2011.

	May	June	July	August	September
			----------percent----------		
Guiles					
Control	8.0 A[1]b[2]	8.7 Ab	16.7 Aa	15.8 Ba	19.2 Aa
Treated	7.1 Ab	7.8 Ab	16.3 Aa	19.2 Aa	17.9 Aa
Morgan					
Control	1.8 Bc	4.0 Bc	10.3 Bb	15.0 BCa	12.8 Ba
Treated	1.5 Bc	2.4 Bc	7.3 Bb	12.3 Ca	12.1 Ba

[1]Means followed by the same uppercase letter in a column are not significantly different ($\alpha = 0.05$).
[2] Means followed by the same lowercase letter in a row are not significantly different ($\alpha = 0.05$).

On the Guiles site, colonization of small-leaf morningglory into sprayed bands in August resulted in significantly greater vine coverage in treated plots compared to control plots. In September, however, there was no significant difference in vine coverage between treatments. Although not significant, treated plots on both sites and control plots on the Morgan site exhibited a slight reduction in vine coverage from August to September. This was probably a result of vines being visually obstructed by other vegetation types.

Shrub Coverage

The Guiles site had significantly greater shrub coverage than the Morgan site in control and treated plots in May (Table 4). It was evident by the abundance of re-sprouted winged sumac on the Guiles site in May that Accord® XRT only suppressed the species. This result was consistent with the herbicide label (Dow Agrosciences 2006). Other common species included yaupon (*Ilex vomitoria*), eastern baccharis (*Baccharis* *halimifolia*), gallberry (*Ilex glabra*), tree sparkleberry (*Vaccinium arboreum*), red maple (*Acer rubrum*), sweetgum, and Chinese tallow tree (*Triadica sebifera*).

Table 4 Average percent shrub coverage in treated and control plots by site and month of observation in 2011.

	May	June	July	August	September
			----------percent----------		
Guiles					
Control	10.0 B[1]a[2]	12.5 ABa	15.0 Aa	15.8 Aa	15.0 Aa
Treated	13.8 Ab	14.3 Ab	16.4 Aab	19.2 Aa	15.4 Aab
Morgan					
Control	5.0 BCd	7.3 BCc	10.0 ABbc	13.3 Aa	11.5 Aab
Treated	3.2 Cd	5.3 Cc	8.8 Bb	11.7 Aa	10.5 Aab

[1]Means followed by the same uppercase letter in a column are not significantly different (α =0.05).
[2]Means followed by the same lowercase letter in a row are not significantly different (α = 0.05).

In contrast, there were few established shrubs on the Morgan site during the early growing season, likely because the site received more intensive mechanical site preparation. The most abundant species on this site were American beautyberry (*Callicarpa americana*), and yaupon. Black cherry, tree sparkleberry, Elliott's huckleberry (*Vaccinium elliotii*), gallberry, sweetgum, red maple, and Chinese tallow tree were also present. In June, there was no significant difference in shrub coverage comparing control plots between the sites. The difference between sites comparing treated plots was not significant by August.

Oust® XP is not recommended for control of woody plants (DuPont 2009), and did not reduce shrub coverage on either site. On the Guiles site, treated plots had significantly greater shrub coverage compared to control plots in May due to greater coverage of winged sumac, but there was no significant difference during the rest of the growing season. Shrub coverage was similar in control and treated plots on the Morgan site throughout the growing season.

Bareground

The Guiles site had significantly less bareground than the Morgan site during the first growing season (Table 5). Average percent bareground in control and treated plots on the Guiles site was approximately half that of the Morgan site in May and June. In July, sprayed bands on the Guiles site had largely been invaded by grasses or vines. Site differences in bareground coverage in control and treated plots decreased as the growing season progressed. However, treated plots on the Guiles site had 18.6% less average bareground coverage than those on the Morgan site in September. Shallow ponding was observed in July, August, and September evaluations on the Morgan site but not on the Guiles site. Ponding was concentrated in depressions created by harvesting or site preparation equipment and encompassed a greater area in treated plots compared to control plots. Ponding alone may have helped to reduce competition by preventing germination of competitors. However, it is possible that the chemical could have concentrated in depressions, resulting in a longer duration of control. Oust® XP can become mobile in saturated soils (DuPont 2009). Differences in species complex and plant development stage likely also contributed to site differences in bareground.

Table 5 Average percent bareground in control and treated plots by site and month of observation in 2011.

	May	June	July	August	September
			----------percent----------		
Guiles					
Control	36.7 D[1]a[2]	25.8 Db	4.5 Cc	1.0 Cd	1.0 Cd
Treated	50.8 Ca	43.3 Cb	11.4 Bc	1.6 Cd	1.0 Cd
Morgan					
Control	85.0 Ba	70.0 Bb	15.8 Bc	8.5 Bd	7.7 Bd
Treated	93.8 Aa	89.6 Ab	55.8 Ac	27.9 Ad	19.6 Ae

[1] Means followed by the same uppercase letter in a column are not significantly different ($\alpha = 0.05$).
[2] Means followed by the same lowercase letter in a row are not significantly different ($\alpha = 0.05$).

As indicated by the differences in percent bareground between herbicide treated and control plots, Oust® XP application was effective at increasing the amount of bareground on both sites (Table 5). However, competition control was only effective until July on the Guiles site. In August, bareground was virtually non-existent on the Guiles site: 1.0% and 1.6% in control and treated plots, respectively (Table 5). In contrast, herbicide treated plots had significantly greater bareground than control plots on the Morgan site for the entire growing season. At the end of the growing season in September, bareground was reduced to 7.7% in control plots on the Morgan site, but treated plots maintained 19.6% bareground.

Rainfall by Site and Year

Hardware malfunction inhibited rainfall collection during most of the first growing season, and thus, it is not known if there was a difference between sites in 2011. However, the nearest quality controlled weather station (10-km from Guiles site, 20km from Morgan site) reported 40% less rainfall than the long term average during April and May 2011.

In 2012, the Guiles site received less rainfall than the Morgan site from January to September. There was a greater difference in rainfall between sites during the dormant season months than during the growing season. From February through March, 30.8cm more rainfall was recorded on the Morgan site than the Guiles site. From April to September, the Guiles site received approximately 10cm less rainfall than the Morgan site.

Table 6 Rainfall during the second growing season by site.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Total
	---------------------------------------cm---------------------------------------									
Guiles	7.5	11.8	11.8	10.6	5.9	11.0	5.9	35.4	3.2	91.3
Morgan	18.1	23.2	20.6	9.8	6.1	6.1	11.7	39.7.	8.7	144.0

Monthly Survival during the First Growing Season

Monthly survival evaluations were conducted during the first growing season to determine the impact of transplant shock, drought, and competing vegetation on survival. Survival ranged from 93.8% (bareroot live oak) to 97.8% (containerized live oak) in May 2011, suggesting that few seedlings died as a direct result of transplant shock (Table 7). However, all treatments experienced the greatest mortality in June. June declines in survival were greatly influenced by results on the Guiles site. This site had greater competing vegetation than the Morgan site (Tables1-5). Although vegetation coverage did not change appreciably from May to June, June mortality may have reflected a time-lagged response to drought. As previously mentioned, it is not known whether there was a difference in rainfall between sites, but moisture was likely already limited due a severe drought that occurred in April and May (NOAA 2011). Seedlings were also exhibiting signs of moisture stress in May, and symptoms were noticeably more severe on the Guiles site than on the Morgan site. The combination of competing vegetation and drought has been shown to have the greater impacts on oak survival than either of these factors alone (Davis et al. 1999).

Table 7 Overall survival by species, planting stock, and time of evaluation (includes both sites).

	May	June	July	Aug	Sep	Oct 2011	Oct 2012
	------------------------- percent -------------------------						
live oak							
BRT[1]	93.8	87.5	84.7	82.0	79.8	77.8 B[2]	74.2 B
CON	97.8	93.2	92.7	92.5	92.3	92.3 A	91.8 A
RPM™	97.0	82.8	82.8	82.3	78.6	76.6 B	71.2 B
Total	96.2	87.8	86.7	85.6	83.6	82.2	79.1
Nuttall oak							
BRT	97.3	95.2	95.0	95.0	94.2	93.8 A	91.8 A
CON	96.7	92.0	90.8	89.8	88.8	87.5 B	84.2 B
RPM™	95.9	89.4	86.6	85.7	84.8	84.1 B	82.9 B
Total	96.6	92.2	90.8	90.2	89.3	88.5	86.3

[1]BRT = 1-0 bareroot, CON = conventional containerized, RPM™ = Root Production Method™
[2]Means followed by the same uppercase letter in a column within a species are not significantly different ($\alpha = 0.05$).

July was marked by a substantial increase in competing vegetation, which continued to increase until August or September depending on treatment and site (Tables 1-5). However, relative to June, only minor declines in survival were observed during months from July to October and mortality during this period ranged from 0.3% (live oak containerized) to 6.8% (live oak bareroot) among species and planting stock combinations (Table 7).

Differences in Survival between Species

With all planting stocks combined, Nuttall oak exhibited 6.3% greater overall survival than live oak by the end of the first growing season (88.5% and 82.2%, respectively)(Table 7). Neither species exhibited an appreciable decline in survival after October 2011, and by the end of the second growing season, overall survival of Nuttall oak was 86.3% and live oak was 79.1%. Species ranking was not consistent when planting stocks were analyzed separately. Although Nuttall oak survival was greater in bareroot and RPM™ planting stocks, conventional containerized live oak slightly out-performed Nuttall oak conventional containerized seedlings.

Differences in Survival among Planting Stocks

Overall, there was no significant difference in survival between bareroot seedlings and conventional containerized seedlings, and survival of these planting stocks was numerically comparable after the first (89.9% and 85.8%, respectively) and second growing seasons (88.0% and 83.0%, respectively)(Table 7). RPM™ seedlings were severely impacted by wind damage and exhibited the lowest survival in both the first and second growing seasons (80.3%, and 77.7%, respectively).

Planting stock comparisons varied by species. In live oak, conventional containerized seedlings exhibited the highest survival (92.3%), which was significantly greater than bareroot or RPM™ seedlings (74.2% and 71.2%, respectively)(Table 7).

Bareroot and RPM™ live oak seedlings exhibited the lowest survival of all species and planting stock combinations.

Live oak bareroot seedlings exhibited the lowest survival by May (93.8%), indicating that transplant shock more problematic in these seedlings than other species and planting stock combinations. Leaf discoloration and abscission were commonly observed in live oak bareroot seedlings in May and June. Presumably, live oak bareroot seedlings may have been more susceptible to transplant shock than other seedling types due to transpirational loss of moisture through their leaves and lack of protection of their root systems prior to planting. Goodman et al. (2009) proposed this as a possible reason why water oak, a semi-evergreen species, may be more susceptible transplant stress than other oak species.

Wind damage, reflected by leaning stems and windthrow, was more commonly observed in live oak RPM™ seedlings than it Nuttall oak RPM™ seedlings, likely because they retained their leaves when planted. Leaf discoloration and abscission were also commonly observed in RPM™ live oak seedlings. These symptoms were less severe in RPM™ Nuttall oak seedlings, and many were fully foliated with green leaves.

In contrast to live oak, bareroot seedlings exhibited the greatest survival in Nuttall oak (91.8%), which was significantly greater than conventional containerized seedlings or RPM™ seedlings (84.2% and 84.9%, respectively)(Table 7). This result was not expected, and bareroot seedlings generally don't survive as well as containerized seedlings. Williams and Craft (1998) reported that containerized Nuttall oak seedlings exhibited greater survival than bareroot seedlings in a study conducted in a retired agricultural field in Mississippi. Self et al. (2010) reported similar results. In this study, the root systems of bareroot seedlings were longer, vertically, than conventional containerized seedlings and required a deeper planting slit. Thus they may have exhibited greater survival due to a greater ability to acquire moisture at greater depths. Moisture loss is greatest in the first few centimeters of soil due to evaporation and transpiration by competing vegetation (Smith et al. 1997). Although survival differed between Nuttall oak planting stocks, survival of all three planting stocks was considered acceptable.

Differences in Survival between Sites

Survival was significantly different between sites. Survival on the Guiles site was significantly less than survival the Morgan site (Table 8). In May during the first growing season, survival on the Guiles site was 4% less than the Morgan site overall. A substantial decline in overall survival on the Guiles site occurred in June (11.8%), and this accounted for most of the difference in survival between sites. As previously mentioned, it is thought that the drastic decline was a result of greater competition on the Guiles site, perhaps combined with droughty conditions.

June mortality on the Morgan site (1.7% overall) was much less than observed on the Guiles site. No month was distinguished by drastic survival declines on the Morgan site, but the greatest declines were observed during August, September, and October. These months were also distinguished by substantial increases in competing vegetation and declines in bareground (Tables 1-5). At the end of the first growing season, overall survival on the Guiles site was 16.5% lower than survival on the Morgan site (93.5% and 77.1%, respectively)(Table 8). Competing vegetation appeared to be a major reason for differences in survival between sites.

Table 8 Survival by site and species/planting stock combination recorded monthly during 2011.

Spp./ stock	May	June	July	Aug	Sep	Oct 2011	Oct 2012
		------------------------ percent ------------------------					
				Guiles			
L / BRT[1]	90.3	79.0	74.3	70.7	70.3	68.0	64.7
L / CON	96.3	87.0	86.0	86.0	86.0	86.0	86.0
L / RPM	98.0	75.3	75.3	75.3	71.2	70.6	62.2
N / BRT	94.7	90.3	90.0	90.0	88.3	87.7	85.3
N / CON	94.0	85.3	83.0	81.3	79.3	77.3	73.7
N / RPM™	91.8	81.0	75.5	75.5	74.5	73.2	72.1
Total	94.2	83.0	80.7	79.8	78.3	77.1 B[2]	74.0 B
				Morgan			
L / BRT	97.3	96.0	95.0	93.3	89.3	87.7	83.7
L / CON	99.3	99.3	99.3	99.0	98.7	98.7	97.7
L / RPM	96.0	90.3	90.3	89.3	85.9	82.6	80.2
N / BRT	100.0	100.0	100.0	100.0	100.0	100.0	98.3
N / CON	99.3	98.7	98.7	98.3	98.3	97.7	94.7
N / RPM™	100.0	97.8	97.8	95.9	95.1	95.1	93.6
Total	98.7	97.0	96.8	96.0	94.6	93.6 A	91.4 A

[1]Species (L = live oak, N = Nuttall oak) / planting stock (BRT = 1-0 bareroot, CON = conventional containerized, RPM™ = Root Production Method).
[2]Means followed by the same uppercase letter in a column are not significantly different (α =0.05).

Although the Morgan site received approximately 10cm more rainfall than the Guiles site during the second growing season from April to September 2012 (Table 6), the lack of appreciable declines in survival (3.1% Morgan, 2.2% Guiles) suggests lack of moisture alone did not cause a large decrease in survival (Table 8). Mortality on the Guiles site was primarily concentrated in areas with intense grass or vine competition, whereas mortality on the Morgan site was primarily concentrated in areas that frequently flooded. By the end of the second growing season, survival on the Guiles site (74.0%)

had approached a level that would be concerning to many managers. Survival on the Morgan site (91.4%), however, was considered excellent.

On the Guiles site, Accord® XRT, which only has foliar activity, was not effective for controlling competitors established prior to planting, likely because most plants were dormant by November 11, 2010 when the chemical was applied. Moreover, roller chopping likely only suppressed established competitors. This is supported by the difference in bareground between control plots for both sites in May (Table 5) and agrees with others' work (Fredrickson et al. 1991). Overall, survival would have likely been unacceptable on the Guiles site had bareroot and containerized seedlings not received herbaceous weed control. Ezell et al. (2007) reported that herbaceous weed control improved oak seedlings survival by 20-25% compared to untreated areas in an evaluation of six bottomland oak species. The Oust® XP application reduced broadleaf and grass coverage on the Guiles site, but effects were only temporary or not effective for some species such as Canada goldenrod, horseweed, or panic grass. Control of other competitors, such as little blue stem, cogongrass, and various shrubs and woody vines was not achieved, nor was it expected. Cogongrass, which thrives with fire and soil disturbance, would have likely been a severe problem had more intensive mechanical treatments been applied.

With the exception of a few stump sprouts, shearing, root raking, and burning on the Morgan site virtually eliminated all vegetation on the Morgan site. This resulted in a mostly weed-free environment during the early growing season: 85.0% and 95% bareground in control and treated plots in May, respectively (Tables 5). Presumably, competition reduction in May and June, resulting from the site preparation and herbaceous weed control, allowed seedlings to become established well enough to be more competitive in later months. Even many RPM™ seedlings were able to recover from the moisture stress induced by wind damage which resulted in exposure of their root systems; either by developing new shoots from the primary stem or re-sprouting from the root collar area.

Survival Summary and Discussion

Results of this study were consistent with others who attributed competition for moisture to be the most limiting factor to survival of planted oak seedlings (Ezell et al. 2007, Russell et al.1998). Herbaceous weed control was considered effective on both sites (Tables 1-5), and control was consistent with what should be expected based on Oust® XP's label (DuPont 2009). However, differences in the level of competition between sites, caused by uncontrolled species, contributed to differences in survival between sites (Tables 1-5). Since bottomland sites can differ greatly with respect to soil characteristics, past land use, and drainage characteristics (Stringer et al. 2009), this has been a common observation in oak plantings (Ezell and Catchot 1997, Kabrick et al. 2005, Jacobs et al. 2012).

This was the third study in a series of five similarly designed studies with similar objectives. One of the primary objectives of this research was to evaluate the performance of various oak species in minor bottomlands in southern Mississippi. This was the third consecutive time Nuttall oak has been evaluated as part of this research. Second year overall survival of Nuttall oak (86.3%) was comparable with second year results from 2009 and 2010 Nuttall oak plantings (approximately 90%) (Hollis 2011, Ezell, unpublished data). Survival in all three evaluations was considered very good. On a planting stock basis, Nuttall oak bareroot seedlings exhibited the greatest survival, followed by conventional containerized and RPM™ seedlings (91.8%, 84.2%, and 82.9%, respectively)(Table 7). Survival of all three planting stocks was considered good. Accordingly, private landowners impacted by Hurricane Katrina would probably find Nuttall oak an excellent choice for reforestation.

A thorough review of the literature yielded no research to compare live oak results, and this was possibly the first time live oak survival has been evaluated on clear-cut sites using planting stocks designed for use in forestry. However, the species has been described as being adapted to a wide range of soil conditions (Gilman and Watson 1994). Conventional containerized live oak seedlings exhibited much greater survival (91.8%) than bareroot seedlings (74.2%)(Table 7). The relative low survival of live oak bareroot seedlings compared to conventional containerized seedlings may have reflected a greater susceptibility to transplant stress. It is thought that live oak seedlings may be more susceptible to moisture loss than seedlings of deciduous oak species. The comparison of bareroot live oak survival (74.2%) to bareroot Nuttall oak survival (91.8%) seemed to support this notion (Table 7). Goodman et al. (2009) suggested that water oak, a semi-evergreen species, may have a greater propensity for transplant stress than other bottomland oaks if seedlings are physiologically active when planted. Live oak's growth form precludes its value for timber production, and would likely only be considered by landowners whose primary objectives were wildlife and aesthetics. With these in mind, the overall second year survival of live oak (79.1%) would likely be acceptable to many managers (Table 7).

The second major objective of this research was to compare the performance of three planting stocks. Generally, containerized seedlings are expected to exhibit greater survival than bareroot seedlings (Dey et al. 2008) which have shown a greater propensity for transplant stress (Burkett and Williams 1998). In this study, no significant differences were detected in overall survival between bareroot and containerized seedlings after the first or second growing season (Table 7). Overall, results were not consistent others who have reported greater survival of containerized seedlings compared to 1-0 bareroot seedlings (Williams and Craft 1998, Howell and Harrington 2002, Shaw et al. 2003, Dey et al. 2006, Self et al. 2010). Rather, results suggest that bareroot seedlings can exhibit similar or comparable survival to small and large containerized seedlings if competition is controlled while seedlings are becoming established. This is also supported by the work of others. In a previous trial where only bareroot seedlings received herbaceous weed control, Hollis (2011) observed significantly greater first and second year survival of 1-0 bareroot compared to conventional containerized seedlings of the same species. Rathfon et al. (1995) observed over 99% survival for 1-0 bareroot and containerized northern red oak seedlings when competition was reduced by tillage.

It is realized that the scope of conclusions that can be drawn from a two year study are limited, and few long term studies have been conducted to determine if differences between planting stocks persist for more than three years. It often takes 8 to 10 years for oaks to achieve dominant or co-dominant crown positions. In one eight year study, Henderson et al. (2009) reported no significant differences in survival between bareroot and RPM™ pin oak seedlings, and bareroot seedlings had caught up to RPM™ seedlings planted in un-mounded plots in height despite fertilization of RPM™ seedlings in the second and third year. Accordingly, 1-0 bareroot seedlings are probably the most cost-effective choice for most reforestation applications. In agreement with Ezell and Hodges (2002), results demonstrated that satisfactory survival of 1-0 bareroot seedlings can be achieved when high quality seedlings are used, planted properly, and herbaceous weed control is implemented during at least part of the first growing season.

Groundline Diameter Growth

Groundline Diameter Growth Differences between Species

When all planting stocks were combined, Nuttall oak exhibited 2.2mm greater average GLD growth than live oak during the first growing season (Table 9). During the second growing season, live oak seedlings exhibited slightly greater average GLD growth than Nuttall oak (3.3mm and 2.3mm, respectively). With respect to cumulative average GLD growth, Nuttall oak slightly exceeded live oak in (8.8mm and 7.7mm, respectively).

Table 9 Average initial groundline diameter and groundline diameter growth by species (all sites and planting stocks).

	Initial	GLD Growth		
		2011	2012	Cumulative
	-- mm --	---------- mm ----------		
Live oak	8.7	4.4 B[1]	3.3 A	7.7 B
Nuttall oak	10.6	6.6 A	2.3 B	8.8 A

[1]Means followed by the same uppercase letter in a column do not differ significantly ($\alpha = 0.05$).

On a planting stock basis, Nuttall oak exhibited greater GLD growth than live oak in all planting stocks during the first growing season (Table 10). During the second growing season, there was no significant difference in growth between species in RPM™ planting stock. In bareroot and conventional containerized stocks; however, live oak exceeded Nuttall oak during the second year. Nuttall oak seedlings exhibited greater cumulative GLD growth than live oak seedlings in bareroot and RPM™ planting stocks, but there was no significant difference between the species in conventional containerized stock.

Table 10 Average initial groundline diameter and groundline diameter growth by planting stock and species (all sites).

	Initial	GLD Growth					
		2011		2012		Cumulative	
	--- cm ---	------------ cm ------------					
BRT[1]							
LIO[2]	6.1	3.3	B[3]	3.2	A	6.5	B
NUO	7.1	5.7	A	2.6	B	8.3	A
CON							
LIO	5.4	5.7	B	3.9	A	9.6	A
NUO	5.8	7.9	A	1.6	B	9.5	A
RPM							
LIO	16.5	3.7	B	2.5	A	6.2	B
NUO	20.0	6.2	A	2.6	A	8.7	A

[1]BRT = 1-0 bareroot; CON = conventional containerized; RPM™ = Root Production Method. Planting stocks were analyzed separately
[2]LIO = live oak, NUO = Nuttall oak
[3]Means followed by the same uppercase letter within a species do not differ significantly ($\alpha = 0.05$).

Diameter growth near the ground level is correlated with root growth (Dey and Parker 1997; Jacobs and Seifert 2004), and oak seedlings are known to emphasize root growth before initiating shoot growth (Hodges and Gardiner1993); an adaptation for dealing with moisture stress. Reduced GLD growth during the second year may suggest surviving seedlings had become sufficiently acclimated to site conditions. A similar pattern of has been observed in other studies (Hollis 2011, Henderson et al. 2009).

Groundline Diameter Growth Differences among Planting Stocks

Initially, the average GLD of RPM™ seedlings (18.4mm) was more than twice as large the other two planting stocks (Table 11). Containerized and bareroot seedlings were similar in caliper, with conventional containerized seedlings being slightly smaller (5.6mm and 6.7mm, respectively).

Table 11 Average initial groundline diameter and groundline diameter growth by planting stock.

	Initial	GLD Growth		
		2011	2012	Cumulative
	--- mm ---	------------- mm ------------		
BRT[1]	6.7	4.7 B[2]	2.9 A	7.5 B
CON	5.6	6.7 A	2.8 A	9.6 A
RPM™	18.4	5.1 B	2.5 B	7.6 B

[1] BRT = 1-0 bareroot, CON = conventional containerized, RPM™ = Root Production Method

[2] Means followed by the same uppercase letter in a column do not differ significantly ($\alpha = 0.05$).

During the first growing season, conventional containerized seedlings exhibited the greatest overall GLD growth (6.7mm), which was significantly greater than bareroot or RPM™ seedlings (Table 11). There was no significant difference between bareroot and RPM™ seedlings, which grew by approximately the same amount during the first year (4.7mm and 5.1mm, respectively).

During the second growing season, bareroot and containerized seedlings exhibited approximately the same GLD growth (2.9mm and 2.8mm, respectively), and RPM™ seedlings exhibited the least GLD growth (2.5mm) (Table 11). With respect to cumulative growth, the overall average GLD growth of conventional containerized seedlings was approximately 1.5mm greater than that of bareroot or RPM™ seedlings, which grew by approximately the same amount (7.5mm and 7.6mm).

Groundline Diameter Growth Differences among Live oak Planting Stocks

During the first growing season, live oak containerized seedlings exhibited the greatest GLD growth (5.7mm), and there was no significant difference in growth between live oak bareroot or RPM™ seedlings (Table 12). Live oak containerized seedlings also exhibited the greatest GLD growth during the second growing season (3.9mm). Live oak bareroot seedlings exhibited slightly, although significantly, less second year growth than live oak containerized seedlings (3.2mm). RPM™ seedlings exhibited the lowest GLD growth (2.5mm). Live oak planting stock comparisons for cumulative growth did not differ from the first growing season results. Conventional containerized seedlings exhibited significantly greater GLD growth than bareroot or RPM™ seedlings, which were not significantly different. Greater growth of conventional containerized seedlings was perhaps explained by protection of their root systems prior to planting and lack of wind damage.

Table 12 Average initial groundline diameter measurements and groundline diameter growth for live oak by planting stock (both sites).

	Initial	GLD Growth		
		2011	2012	Cumulative
	--- mm ---	------------- mm ------------		
BRT[1]	6.1	3.3 B[2]	3.2 B	6.5 B
CON	5.4	5.7 A	3.9 A	9.6 A
RPM	16.5	3.7 B	2.5 C	6.2 B

[1] BRT = 1-0 bareroot, CON = conventional containerized, RPM™ = Root Production Method

[2] Means followed by the same uppercase letter in a column do not differ significantly ($\alpha = 0.05$).

Groundline Diameter Growth Differences among Nuttall oak Planting Stocks

Similar to live oak, Nuttall oak conventional containerized seedlings exhibited greater GLD growth than bareroot or RPM™ seedlings during the first growing season (Table 13). However, during the second growing season, conventional containerized seedlings exhibited the least GLD growth (1.6mm). Nuttall oak bareroot and RPM™ seedlings exhibited the same GLD growth during the second growing season (2.6mm). Cumulative results were similar to the first growing season. Nuttall oak conventional containerized seedlings significantly out-performed bareroot or RPM™ seedlings.

Table 13 Average initial groundline diameter measurements and groundline diameter growth for Nuttall oak by planting stock (both sites).

	Initial	GLD Growth		
		2011	2012	Cumulative
BRT[1]	7.1	5.7 B[2]	2.6 A	8.3 B
CON	5.8	7.9 A	1.6 B	9.5 A
RPM	20.0	6.2 B	2.6 A	8.7 B

[1] BRT = 1-0 bareroot, CON = conventional containerized, RPM™ = Root Production Method

[2] Means followed by the same uppercase letter in a column are not significantly different ($\alpha = 0.05$).

Groundline Diameter Growth Differences among Planting Stocks by Site

On the Guiles site, conventional containerized seedlings exhibited slightly, although not significantly, greater GLD growth than bareroot seedlings during the first growing season (Table 14). RPM™ seedlings exhibited significantly less GLD growth than conventional containerized seedlings but the same average GLD growth as bareroot seedlings (2.8mm) during the first year on the Guiles site.

During the second growing season on the Guiles site, bareroot and conventional containerized seedlings exhibited similar GLD growth (3.5mm and 3.1mm), and RPM™ seedlings exhibited the least GLD growth (1.9mm). With respect to cumulative results, there was no significant difference between bareroot and containerized seedlings. Significant differences of cumulative results were similar to the first year. RPM™ seedlings exhibited less cumulative GLD growth (4.7mm) than conventional containerized seedlings (6.3mm) but not significantly less than bareroot seedlings (6.2mm).

Table 14 Average initial groundline diameter and groundline diameter growth by planting stock and site (all species).

	Initial	GLD Growth		
		2011	2012	Cumulative
	--- mm ---	------------ mm -----------		
Guiles				
BRT[1]	7.2	2.8 B[2]	3.5 A	6.2 AB
CON	5.8	3.2 A	3.1 A	6.3 A
RPM™	18.1	2.8 B	1.9 B	4.7 B
Morgan				
BRT	6.3	6.2 B	2.4 A	8.5 B
CON	5.5	9.6 A	2.6 A	12.2 A
RPM™	18.7	6.8 B	3.1 A	9.8 B

[1]BRT = 1-0 bareroot; CON = conventional containerized; RPM™ = Root Production Method.
[2] Means followed by the same uppercase letter in a column within a site do not differ significantly
($\alpha = 0.05$).

On the Morgan site, conventional containerized seedlings exhibited greater GLD growth (9.6mm) during the first growing season than both bareroot and RPM™ seedlings, which were not significantly different (6.2mm and 6.8mm, respectively)(Table

14). However, there were no significant differences in second year GLD growth among planting stocks. Cumulative growth results were similar to first year results. Containerized seedlings exhibited significantly greater GLD growth than bareroot or RPM™ seedlings, which were not significantly different.

Groundline Diameter Growth Differences between Sites

Despite similar initial average GLD's, seedlings on the Morgan site exhibited more than twice the average GLD growth of seedlings on the Guiles site during the first growing season (7.6mm and 3.0mm, respectively)(Table 15). In contrast, the sites exhibited approximately the same overall average GLD growth during the second growing season. On the Guiles site, GLD growth during the second year (2.9mm) was comparable to the first year. However, seedlings on the Morgan site grew less than half as much during the second growing season (2.6mm) compared to the first growing season. Flooding may have been a reason for the large difference between years on the Morgan site by its influence on growth or by erosion of the soil around the base of the seedlings. This was more commonly observed in conventional containerized and RPM™ seedlings compared to bareroot seedlings because their planting medium, which was coarse textured, was more susceptible to erosion than soil on site.

Table 15 Average initial groundline diameter and groundline diameter growth by site (all species and planting stocks).

	Initial	GLD Growth					
		2011		2012		Cumulative	
	--- mm ---	------------ mm ------------					
Guiles	9.7	3.0	B[1]	2.9	A	5.8	B
Morgan	9.7	7.6	A	2.6	A	10.2	A

[1] Means followed by the same uppercase letter in a column do not differ significantly ($\alpha = 0.05$).

Height Growth

Height Growth Differences between Species

Nuttall oak exhibited greater overall average height growth than live oak, but this was heavily influenced by extreme dieback in live oak RPM™ seedlings. Accordingly, species comparisons are presented separately by planting stock (Table 16). During the first growing season, height growth differences between species were not significant in bareroot and conventional containerized stock. During the second growing season, live oak exhibited significantly greater height growth than Nuttall oak in both bareroot and conventional containerized stocks. With respect to cumulative height growth, differences between species were not significant in either planting stock. This was a surprising result because Nuttall oak is known to exhibit more rapid juvenile height growth than many other oak species (Allen 1990, Miwa et al. 1992, Michalek et al. 1992).

Table 16 Average initial height and height growth by planting stock and species (both sites).

	Initial	Height Growth					
		2011		2012		Cumulative	
	--- cm ---	------------ cm ------------					
BRT[1]							
LIO[2]	43.6	9.7	A[3]	32.1	A	41.8	A
NUO	50.2	11.2	A	24.0	B	35.2	A
CON							
LIO	73.5	18.9	A	23.1	A	42.0	A
NUO	50.0	20.3	A	14.3	B	34.5	A
RPM							
LIO	201.8	-37.8	B	-4.1	A	-42.0	B
NUO	196.7	5.8	A	-3.2	A	2.6	A

[1] Planting stocks were analyzed separately. BRT = 1-0 bareroot; CON = conventional containerized; RPM™ = Root Production Method.
[2]LIO = live oak, NUO = Nuttall oak
[3]Means followed by the same uppercase letter in a column do not differ significantly ($\alpha = 0.05$).

First year height growth of Nuttall oak RPM™ seedlings (5.8cm), although negligible, was significantly greater than live oak RPM™ seedlings, which exhibited severe dieback (-37.8cm) (Table 16). As previously mentioned, wind damage did not affect Nuttall oak RPM™ seedlings as severely as live oak RPM™ seedlings. Although many Nuttall oak RPM™ seedlings were leaning, many trees that were nearly completely laid over were fully foliated, and some exhibited stem elongation. RPM™ seedlings did not exhibit an increase in height during the second growing season. It appeared that RPM™ seedlings in both species were investing resources in sprouts rather than the original main stem.

Height Growth Differences among Planting Stocks

Overall, conventional containerized seedlings exhibited greater average height growth than bareroot seedlings during the first growing season (Table 17). However, height growth of bareroot seedlings exceeded that of conventional containerized seedlings during the second growing season (27.6cm and 18.8cm, respectively). By the end of the second growing season, there was less than 1.0cm difference in total average height growth between bareroot (38.1cm) and conventional containerized seedlings (38.4cm). Conventional containerized and bareroot seedlings exhibited significantly greater height growth than RPM™ seedlings, which exhibited an overall decrease in height after the first and second growing seasons.

Table 17 Average initial height and height growth by planting stock (both species and sites).

	Initial	Height Growth					
		2011		2012		Cumulative	
	--- cm ---	------------ cm -----------					
BRT[1]	47.3	10.6	B[2]	27.6	A	38.1	A
CON	62.2	19.6	A	18.8	B	38.4	A
RPM	199.0	-13.9	C	-3.6	C	-17.5	B

[1]BRT = 1-0 bareroot; CON = conventional containerized; RPM™ = Root Production Method.
[2]Means followed by the same uppercase letter in a column do not differ significantly ($\alpha = 0.05$).

Height growth Differences among live oak Planting Stocks

During the first growing season, live oak conventional containerized seedlings exhibited slightly greater height growth than bareroot live oak seedlings (18.9 and 9.7cm, respectively) (Table 18). RPM™ live oak seedlings in extreme dieback, declining in height by approximately 20%. The extensive dieback exhibited by live oak RPM™ seedlings further reflects the severity of wind damage they incurred.

Table 18 Average initial height and height growth of live oak seedlings by planting stock and time of evaluation (both sites).

	Initial	Height Growth					
		2011		2012		Cumulative	
	--- cm ---	------------ cm -----------					
BRT[1]	43.6	9.7	A[2]	32.1	A	41.8	A
CON	73.5	18.9	A	23.1	B	42.0	A
RPM	201.8	-37.9	B	-4.1	C	-42.0	B

[1]BRT = 1-0 bareroot; CON = conventional containerized; RPM™ = Root Production Method.
[2]Means followed by the same uppercase letter in a column do not differ significantly ($\alpha = 0.05$).

During the second growing season, bareroot live oak seedlings exhibited significantly greater height growth than conventional containerized live oak seedlings (32.1cm and 23.1cm respectively) (Table 18). Subsequently, there was only 0.2cm difference in total average height growth between bareroot and conventional containerized live oak seedlings at the end of the second growing season (41.8cm and 42.0cm, respectively). RPM™ seedlings did not increase in height during the second growing season, and decreased by an average of 42.0cm total. Despite being on average approximately 20% shorter than their initial height, RPM™ live oak seedlings remained taller than bareroot and containerized live oak seedlings through the end of the second growing season. However, the vast majority of RPM™ live oak seedlings were sparsely foliated, leaning, and had multiple sprouts originating from the root collar.

Height Growth Differences among live oak Planting Stocks by Site

The statistical ranking of live oak planting stocks varied by site (Table 19). Results on the Guiles site were consistent with overall results: there were no significant differences between bareroot and containerized seedlings after either growing season, and height growth of both of these planting stocks was significantly greater than that of RPM™ seedlings, which exhibited severe dieback.

Table 19 Average initial height and height growth of live oak seedlings by site, planting stock, and time of evaluation.

	Initial	Height growth					
		2012		2012		Cumulative	
	--- cm ---	cm					
Guiles							
BRT[1]	45.5	2.2	A[2]	32.6	A	34.8	A
CON	74.7	6.4	A	27.9	A	34.3	A
RPM™	186.8	-32.1	B	-9.7	B	-41.8	B
Morgan							
BRT	42.2	15.3	B	31.8	A	47.0	A
CON	72.6	29.4	A	19.1	B	48.5	A
RPM™	212.2	-41.9	C	-0.2	C	-42.2	B

[1]BRT = 1-0 bareroot; CON = conventional containerized; RPM™ = Root Production Method.
[2]Means followed by the same uppercase letter in a column within a site do not differ significantly
($\alpha = 0.05$).

However, on the Morgan site, conventional containerized live oak seedlings exhibited significantly greater height growth than bareroot live oak seedlings during the first growing season (29.4cm and 15.3cm, respectively) (Table 19). Similar to the Guiles site, dieback of RPM™ live oak seedlings was severe. During the second growing season, bareroot live oak seedlings exhibited significantly greater height growth than conventional containerized seedlings. RPM™ live oak seedlings did not increase in height during the second growing season on the Morgan site. Similar to the Guiles site, there was no significant difference in cumulative height growth between bareroot and conventional containerized live oak seedlings (47.0cm and 48.5cm, respectively).

Height growth Differences Among Nuttall oak Planting Stocks

During the first growing season, conventional containerized Nuttall oak seedlings exhibited significantly greater height growth than bareroot or RPM™ Nuttall oak seedlings (20.3cm, 11.2cm, and 5.8cm, respectively) (Table 20). Bareroot Nuttall oak seedlings exhibited slightly greater height growth than RPM™ seedlings, but the difference was not significant. Alkire (2011) observed similar first year height growth of bareroot Nuttall oak seedlings in a previous trial (13.0cm), but he observed much lower height growth in conventional containerized stock (6.3cm) than observed in this study, likely because conventional containerized seedlings in his study did not receive herbaceous weed control. Also in contrast to results in this study, Alkire (2011) reported that RPM™ Nuttall oak seedlings exhibited 23.8cm height growth during the first growing season.

Table 20 Average initial height and height growth of Nuttall oak seedlings by planting stock (all sites).

	Initial	Height Growth 2011		Height Growth 2012		Cumulative	
	--- cm ---	------------ cm -----------					
BRT[1]	50.2	11.2	B[2]	24.0	A	35.2	A
CON	50.0	20.3	A	14.3	B	34.5	A
RPM	196.7	5.8	C	-3.2	C	2.6	B

[1]BRT = 1-0 bareroot; CON = conventional containerized; RPM™ = Root Production Method.
[2]Means followed by the same uppercase letter in a column do not differ significantly (α = 0.05).

During the second growing season, bareroot Nuttall oak seedlings exhibited significantly greater height growth than conventional containerized seedlings (24.0cm and 14.3cm, respectively) (Table 20). Similar to live oak, RPM™ Nuttall oak seedlings did not exhibit an increase in height during the second year (-3.2cm). Hollis (2011) also observed greater second year height growth of bareroot seedlings compared to conventional containerized Nuttall oak seedlings, as well as a lack of height growth of RPM™ seedlings. Henderson et al. (2009) reported 7-8% decrease in height of RPM™ pin oak seedlings during the first two growing seasons, despite receiving fertilization during the second growing season.

After two years, cumulative height growth of bareroot Nuttall oak seedlings was slightly greater than conventional containerized seedlings, but differences between these planting stocks were not significant (Table 20). RPM™ Nuttall oak seedlings exhibited negligible cumulative height growth, which was significantly less than that of bareroot or containerized seedlings. Despite a lack of growth, RPM™ seedlings maintained their height advantage over both bareroot and conventional containerized seedlings after the second year.

Height growth differences among Nuttall oak Planting Stocks by Site

The ranking of height growth in Nuttall oak planting stocks differed by site. First year results were consistent between sites, but second year results varied by site (Table 21). On the Guiles site, bareroot seedlings exhibited significantly greater second year height growth than conventional containerized seedlings. The difference in second year height growth between bareroot and conventional containerized seedlings on the Morgan site was not significant. RPM™ seedlings exhibited significantly less height growth than both bareroot and conventional containerized seedlings on both sites.

Cumulative height growth results also differed by site. On the Guiles site, bareroot seedlings exhibited greater cumulative height growth than conventional containerized seedlings, but the opposite was observed on the Morgan site.

Table 21 Average height measurements and height growth of Nuttall oak by planting stock and site.

	Initial	Height growth 2011		Height growth 2012		Height growth Cumulative	
	--- cm ---	------------------------ cm ------------------------					
Guiles							
BRT[1]	51.0	10.2	B[2]	30.6	A	40.9	A
CON	51.7	13.8	A	13.2	B	27.0	B
RPM™	191.4	3.8	C	-3.8	C	0.1	C
Morgan							
BRT	49.0	12.1	B	18.3	A	30.4	B
CON	49.0	25.2	A	15.1	A	40.3	A
RPM™	201.9	7.4	C	-2.7	B	4.7	C

[1]BRT = 1-0 bareroot; CON = conventional containerized; RPM™ = Root Production Method.

[2] Means followed by the same uppercase letter in a column within a site do not differ significantly ($\alpha = 0.05$).

Groundline Diameter and Height Growth Summary and Discussion

The results of this study are consistent with others that have reported rapid juvenile growth of Nuttall oak seedlings (Miwa et al. 1992). Few, if any trials existed documenting the growth performance live oak seedlings planted in clear-cut areas. With the exception of RPM™ seedlings, results showed that once live oak seedlings become established, they can exceed or match Nuttall oak in juvenile diameter and height growth during the second year.

Diameter growth is correlated with root growth (Dey and Parker 1997) and thus, is indicative of seedlings' acclimatization to a site. Containerized seedlings have been shown less susceptible to transplant stress compared to bareroot seedlings (Johnson et al. 1984, Wilson et al. 2007). This, in combination with the root system architecture of containerized seedlings, having more roots near the soil surface than bareroot seedlings, may explain why conventional containerized seedlings exhibited greater average GLD growth than bareroot seedlings during both growing seasons (Table 10). Several studies have reported similar results with various oak species (Johnson et al. 1984, Williams and Craft 1998, Wilson and Stroupe 2002, Wilson et al. 2007). Cumulative GLD growth was comparable between bareroot and containerized seedlings. Sweeney et al. (2002) observed similar results after the fourth growing season comparing bareroot and containerized pin oak and Northern red oak.

RPM™ and bareroot seedlings exhibited comparable GLD growth after the first and second growing seasons (Table 10). Close et al. (2005) stated that seedlings typically exhibit a decrease in height growth but increase in diameter growth near the root collar in response to wind damage. Thus, it is thought that GLD growth is a less useful measurement compared to height growth for comparing RPM™ seedlings to other planting stocks in this study.

Results were consistent with others who observed greater first-year height growth of containerized seedlings compared to bareroot seedlings (Dixon et al.1981a, Johnson et al.1984a, Burkett and Williams 1998, Sweeney et al. 2002, Rathfon et al. 2005). Teclaw and Isebrands (1993) reported greater total height growth of conventional containerized seedlings after the second and third growing seasons compared to bareroot seedlings. In this study, the height growth advantage containerized seedlings had during the first year did not persist into the second growing season. In both species, height growth of bareroot seedlings during the second year exceeded that of conventional containerized seedlings. At the end of two years, there was no significant difference in height growth between conventional containerized seedlings and bareroot seedlings in terms of cumulative growth. Mullins et al. (1998) observed similar results comparing height growth of bareroot and containerized cherrybark oak seedlings.

Some research has shown greater first-year height growth of RPM™ seedlings compared to 1-0 bareroot or conventional containerized seedlings (Shaw et al. 2005, Alkire 2011). Height growth of RPM™ seedlings in this study was thwarted by strong winds. Live oak RPM™ seedlings were severely impacted and decreased approximately 20% from their initial height (Table 16). The impact to Nuttall oak RPM™ seedlings was less severe, and they exhibited negligible average height growth. Although the severity of wind damage to these seedlings was considered atypical, others have observed wind damage as problem using RPM™ seedlings (Damon Hollis, personal communication) and other large planting stocks (Adams 1982). In addition to their tall height and large canopy size, several characteristics of large containerized seedlings make them susceptible to wind damage. Rapid growth of seedlings in the nursery may not allow seedlings to become adequately lignified (Close et al. 2005). Also, the root system architecture and course consistency of the planting medium (4:4:2 mixture of rice hulls, pine bark, and sand), does not offer much stability once planted. Finally, the amount of above ground biomass is difficult to support in strong with 11.9L root system.

Hollis (2011) reported greater two year height growth of bareroot swamp chestnut oak and Nuttall oak seedlings compared to RPM™ seedlings on clear-cut sites in southern Mississippi. In a study conducted on retired agricultural lands in Missouri, Dey et al. (2006) reported no significant difference in third year height growth of RPM™ swamp white oak and pin oak seedlings compared to bareroot seedlings after both planting stocks were severely damaged by rabbits during the second growing season.

Height growth of undamaged RPM™ and bareroot pin oak seedlings in red-top grass (*Agrostis gigantea*) fields was the same (9.1cm) (Dey et al. 2006). They suggested that the lack of height growth in RPM™ seedlings was possibly the result of weak epinastic control, because their crowns were above competing vegetation when they were planted. In another study using pin oak, Henderson et al. (2009) reported that although RPM™ seedlings were taller than bareroot seedlings initially, bareroot seedlings had a faster growth rate and were able to catch up to RPM™ seedlings in height by the eighth year. The authors also noted that RPM™ seedlings may have received more browse pressure by white-tailed deer.

In this study, wind damage curtailed the possibility of observing any growth advantages large containerized seedlings potentially had over conventional containerized or bareroot seedlings. Others observed similarly severe dieback of large containerized seedlings due to herbivory (Burkett et al. 2005, Dey et al. 2006). Results support the work of others who have shown that once bareroot seedlings overcome transplant stress, they can match or exceed containerized planting stocks in growth (Mullins et al. 1998, Sweeney et al. 2002, Burkett et al. 2005, Henderson et al. 2009, Hollis 2011).

CHAPTER V

CONCLUSIONS

Although seedlings may be subject to many detrimental factors during the first few growing seasons, competing vegetation is widely accepted as the most consistent factor (Russell et al.1998). The level of competition differed greatly between sites in this study during the first growing season and this was reflected by site differences in survival and growth.

Nuttall oak bareroot and conventional containerized seedlings exhibited good growth and survival and have performed well on other sites in southern Mississippi (Alkire 2011, Hollis 2011). Live oak conventional containerized seedlings also performed well. As reflected by low survival, some difficulty was experienced establishing live oak bareroot seedlings. As previously mentioned, this may have been a result of loss of moisture through transpiration prior to planting.

Much of the early research investigating oak seedling performance affirmed planting stock type and seedling size as important influences on survival and growth performance (Dixon et al. 1981a, Johnson et al. 1984, Kormanik et al 1995, 1998, Dey and Parker 1997). Generally, it was reported that containerized seedlings out-performed bareroot seedlings and “bigger is better” with respect to seedling morphological traits (Johnson et al. 1984, Kormanik et al. 1995, Dey and Parker 1997, Schultz and Thompson 1997). While this may be true to an extent, larger seedlings don’t necessarily always perform better than smaller ones, largely because they are extremely difficult to plant properly. Moree et al. (2010) found no significant differences in survival between large, enhanced bareroot Nuttall oak and white oak seedlings compared to nursery run seedlings. Large seedlings may also not perform well if their root systems cannot uptake enough moisture to make up for transpirational losses (Jacobs et al. 2012).

Despite being over twice as large, RPM™ seedlings did not exhibit a clear advantages in survival or growth over conventionally-sized containerized or bareroot seedlings. The results of this study, along with others (Burkett et al. 2005, Hollis 2011, Sweeney et al. 2002), demonstrated that conventional containerized and bareroot seedlings can exhibit survival and growth comparable or better than large containerized seedlings.

The potential growth advantages of large containerized seedlings are likely not great enough to justify their cost in large-scale operational plantings, especially when extraneous factors such as wind damage may eliminate them. In other studies, severe rodent herbivory has resulted in extreme dieback (Shaw et al. 2005, Burkett et al. 2005). This is not to say that large containerized seedlings have no role in reforestation operations. Some landowners may prefer large containerized seedlings for small-scale plantings in which more intensive management techniques would be financially feasible (Dey et al. 2003).

Results of this study supported others who have found that when measures are taken to control competition during the first growing season, high-quality 1-0 bareroot seedlings can exhibit satisfactory survival and growth that is comparable with containerized seedlings (Mullins et al. 1998, Sweeney et al. 2002, Ezell et al. 2007, Hollis

2011). Containerized seedlings may be a more suitable choice when circumstances require planting operations to be conducted outside of the traditional planting season (Stanturf et al. 1998). However, cost-effectiveness is typically important in reforestation efforts. For this reason, high-quality 1-0 bareroot seedlings are likely the most suitable planting stock for most large-scale reforestation operations.

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