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Assessing Two Year Growth and Survival of Two Oak Species and Three Planting Stocks on Hurricane Katrina Damaged Land

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Assessing two year growth and survival of two oak species and three planting stocks on Hurricane Katrina damaged land

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Assessing two year growth and survival of two oak species and three planting stocks on Hurricane Katrina damaged land

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Hurricane Katrina made landfall in 2005 damaging 1.2 billion cubic meters of timber including 48 million cubic meters of hardwood. An economically efficient method of artificial oak regeneration is necessary in many areas to restore this high value resource. Bareroot, conventional containerized, and EKOgrown® seedlings of *Quercus shumardii* and *Q. texana* were planted on two sites in south Mississippi. Growth and survival were evaluated for two years. Survival was assessed monthly and at the end of each growing season. Height and groundline diameter were assessed initially after planting and the end of each growing season. After two growing seasons, *Q. Nuttallii* exhibited superior performance generally when compared to *Q. Shumardii*. Conventional containerized had poor survival and initial growth likely caused by freeze damage in the nursery. EKOgrown® seedlings performed better than other planting stocks, however, high seedling cost makes them less cost-effective than bareroot seedlings which exhibited acceptable performance overall.

DEDICATION

I dedicate this thesis to my mom, Cheryl Evans Hall, and dad, Orlyn Craye Hall Jr., for the incredible love and support that has given me the freedom to pursue my dreams.

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CHAPTER I

INTRODUCTION

Hurricane Katrina made landfall on August 29, 2005, as a Category III hurricane causing an estimated 1,200 deaths and 108 billion dollars in damages to the Gulf Coast region of the United States (U.S.) (Blake et al. 2011). Hurricane Katrina is the third deadliest and the most costly hurricane in recorded U.S. history.

An estimated 1.2 billion cubic meters of timber volume was estimated to be damaged by Hurricane Katrina including 48 million cubic meters of hardwood volume (USDA 2005). Often after large scale destructive weather events, timber supply is significantly increased by timber needing to be salvaged (Prestemon and Holmes 2010). Demand for this timber is also sometimes reduced due to mills being temporarily shut down because of damage incurred to the facilities. Increases in supply and decreases in demand lead to reduction in timber value resulting in landowners receiving little or no money for salvaged timber.

In addition to the damage to standing timber, regeneration on these lands can be problematic. Oak regeneration is often more difficult to secure than other less desirable species. Natural regeneration of oaks requires considerable advanced planning. A plentiful acorn crop, sufficient advanced regeneration, and ability to plan multiple, well timed timber removals from the stand are essential for successful natural regeneration (Larsen and Johnson 1998). Depending on the maturity of the stand and time of year when destructive weather occurs, these factors will often not be favorable. Therefore, artificial regeneration may be the only viable option to reestablish an oak dominated stand in some situations.

Artificial regeneration of oaks does not come without its own set of constraints. For successful artificial regeneration of oak, it is important to obtain high quality seedlings, achieve proper seedling handling and planting, and implement herbaceous weed control to ensure adequate survival and growth (Self et al. 2011). These factors can be hard to accomplish for some landowners with a relative lack of available information about artificial oak regeneration as compared to other species.

With as much as 40 percent of the damage occurring in hardwood forests during Hurricane Katrina, it is important to restore the ecological benefits provided by this cover type. Oak dominated stands are important to southern forests because of their high value for wildlife, timber, and water and air quality (Shaw et al. 2003). However, reduced or eliminated revenue from timber harvest, unavailable natural regeneration, and the constraints to artificial regeneration are all areas of concern for many landowners. This combination of factors often contributes to the conversion of these storm damaged lands to non-forest uses or to a forest dominated by less desirable species. While artificial or natural regeneration of less desirable species is often the more efficient option, it does not provide the same ecological benefits offered by an oak dominated forest. Therefore, it is important to provide landowners with the most economically efficient method possible of artificial oak regeneration to reduce the loss of these benefits.

Objectives

The primary goal of this study is to evaluate the two year performance of three different planting stocks of two species of oaks on Hurricane Katrina disturbed sites. The secondary goal is to evaluate how photosynthesis relates to the two year performance of these planting stocks and species.

The objectives are to:

I. Compare the two year survival, height growth, and groundline diameter growth of Nuttall oak (*Q. texana*) and Shumard oak (*Q. shumardii*).

II. Compare the two year survival, groundline diameter growth, and height growth of three planting stocks:

a. High-quality 1-0, bareroot seedlings

b. Conventional containerized seedlings

c. EKOgrown® seedlings

III. Determine the degree of relationship between first growing season average seasonal photosynthetic rate to the two year groundline diameter and height growth.

CHAPTER II

LITERATURE REVIEW

Impacts of Hurricane Katrina on Forestland

On August 29, 2005, Hurricane Katrina became the third most powerful storm to make landfall in the United States (Chapman et al. 2008). It is estimated that 125 billion dollars of damages were incurred. Every state in the Gulf Coast was affected; however, the bulk of the damage occurred in Alabama, Louisiana, and Mississippi. A Category III Hurricane at landfall, Katrina traveled northward through Mississippi, being reduced to a tropical storm roughly 50 km northwest of Meridian, Mississippi, and a tropical depression near Clarksville, Tennessee. However, wind gusts in excess of 129 km hr^{-1} were recorded throughout Mississippi (Graumann et al. 2005).

Initially, reports indicated that most of the damage was done to softwood species (USDA 2005). Later studies concluded that the most heavily damaged areas were bottomland hardwood forests that were frequently flooded (Chapman et al. 2008, Oswalt and Oswalt 2008, Wang and Xu 2009). An estimated 49 million cubic meters of hardwood timber were damaged, including 35 million cubic meters in Mississippi (USDA 2005). By creating large canopy gaps and dispersing seed from light-seeded species across the range of the hurricane, the landscape was left with open areas now growing less desirable species (Chapman et al. 2008). Some landowners chose to regenerate such sites artificially with more desirable species such as oaks in order to improve wildlife habitat, promote native biodiversity, enhance hunting opportunities, produce forest products and restore ecosystem processes and functions (Shaw et al. 2003).

Oak Regeneration

Oaks, predominantly, are moderately shade intolerant, exhibit a slow response to release, and have delayed shoot growth in their juvenile stage (Hodges and Gardiner 1993, Janzen and Hodges 1987, Loftis 1990, Smith 1993). Such qualities as early root growth, expansive root systems, high water use efficiency, and stomatal closure only at very negative water potentials allow oaks to compete successfully on drier sites (Clark 1993, Hodges and Gardiner 1993). However, these characteristics do not serve them well for competing in moist soils such as those found in bottomland systems. This reduced competitiveness in moist soil areas poses a problem when dealing with undesirable species that exhibit rapid shoot growth. Typically, only oak seedlings that have established root systems will be able to survive multiple seasons when faced with competition from species with rapid shoot growth (Meadows and Hodges 1997).

Advanced regeneration possesses competitive qualities, such as large root systems and superior height, needed to survive multiple seasons, and when present in adequate numbers, can be a reliable indication that oaks will persist to become a major component of the canopy in the succeeding stand (Clatterbuck and Meadows 1992, Hodges 1987, Loftis 1990, Meadows and Hodges 1997, Meadows and Stanturf 1997). However, advanced regeneration establishment necessitates the presence of a good seed source, proper light and moisture levels, and control of non-desirable species (Hodges and Gardiner 1993). These components must be monitored and careful planning is required for success. While there are multiple detriments to acorn survival, such as losses due to insects, mammals, birds, flooding, and extreme temperature, seed source over time is typically not limiting (Hodges and Gardiner 1993). Proper light and competition reduction can be accomplished prior to a harvest operation by the implementation of stem injection. Mechanical operations have been used in the past; however, are not economically viable at the present time (Janzen and Hodges 1987, Meadows and Stanturf 1997).

In order to provide the proper amount of light to favor oak seedlings, the appropriate harvesting system and procedure must be implemented (Clatterbuck and Meadows 1992, Hodges 1987). Clearcutting, shelterwood, and patch cutting are considered to be reliable systems to accomplish this task (Meadows and Hodges 1997). The most cost-effective of these harvest methods is clearcutting, when implemented in conjunction with natural regeneration (Clatterbuck and Meadows 1992, Dey et al. 2008). However, without adequate advanced regeneration source or potential, clearcutting is unlikely to provide the preferred results. A modified shelterwood method, proposed by Hodges (1987), may be employed to develop the required level of advanced regeneration.

Artificial Oak Regeneration

Artificial oak regeneration is often considered a viable option when attempting to reestablish an oak stand. Obtaining natural regeneration can be problematic when the desired seed source is not available or when fast growing competitors are present (Hollis et al. 2011). Artificial regeneration is typically considered a quicker and easier way to establish desired species. For these reasons, artificial regeneration has been used extensively to establish oak stands (Haynes 2004, King and Keeland 1999, Schoenholtz et al. 2001). Good initial growth and survival rates can be attributed to proper species and planting stock selection, as well as site quality (Baker and Broadfoot 1979, Dey et al. 2008, Kennedy 1992, Moree et al. 2010). However, artificial regeneration does not come without problems: poor seedling quality from the nursery, inadequate care of seedlings in transport and storage, or improper planting practices can lead to poor survival and growth of seedlings (Hollis et al. 2011, Moree et al. 2010). Other concerns when dealing with artificial regeneration include herbaceous competition, herbivory, drought, and flooding (Moree et al. 2010, Stanturf et al. 2004,). Some of these can be mitigated using various site preparation methods and competition control measures (Hannah 1987, Kennedy 1992, Stanturf et al. 2004).

Artificial regeneration can be accomplished through direct seeding or by planting seedlings. Direct seeding often provides relatively higher species diversity compared to planting seedlings, which appeals to land managers concerned with wildlife due to the inherent benefits provided by having a more diverse stand (Allen 1990, Haynes 2004). Conversely, planted seedlings typically have better survival, growth, and timber quality which are desired by most landowners in the southern United States who are generally concerned more with timber production than wildlife value (Allen 1990, Lockhart et al. 2005).

Bareroot Seedlings

Bareroot seedlings are less expensive than other types of hardwood seedlings, and provide some flexibility in planting because they can be planted by machine or by hand. Bareroot seedlings have been the preferred selection for artificial regeneration of bottomland hardwood sites for many years (Dey et al. 2008 and King and Keeland 1999).

While there is a range of size classes available when selecting bareroot seedlings; a common selection in the South is a high-quality seedling that has spent one year in the nursery bed and no time as a nursery outplant which is known as a 1-0 seedling. Criteria that must be met to be considered a high-quality 1-0, bareroot seedling include basal diameter between 6mm and 8mm, total height between 50cm and 70cm, and minimum of eight first order lateral roots (FOLR) (Allen et al. 2004, Dey et al. 2010, Gardiner et al. 2002, Kormanik et al. 1987). Research has shown that taller seedlings which have a larger diameter and a more extensive lateral root system outperform those having smaller diameters and less extensive root systems (Kormanik et al. 1995, Kormanik and Ruehle 1987, Teclaw and Isebrands 1993).

Three major factors dictate bareroot seedling performance in the early years of establishment: precipitation, vegetative competition, and proper handling of seedlings. Allen (1990) conducted a study that evaluated bareroot hardwood seedlings planted on federal lands which had received little or no post-planting treatments after an average of 7.5 years, and found survival varied from 50 percent to 90 percent. It was concluded that variability in survival rates was caused by differences in soil moisture and competing vegetation among sites. This study provided evidence that bareroot seedlings are sensitive to stress caused by inadequate moisture and vegetative competition; however, they are a viable option for artificial regeneration of oaks. Seedlings planted between January and mid-March exhibit less planting shock and better survival than those planted outside of this range (Stanturf et al. 1998). For optimal performance, species-site relationships need to be considered and proper storage, handling, and planting protocol need to be followed.

Conventional Containerized Seedlings

Conventional containerized seedlings offer the benefits of being relatively easy to plant and possessing a well-developed root system. The trade-off between root systems of containerized and bareroot seedlings is that bareroot seedlings often have a larger tap root while containerized seedlings have more extensive fibrous root systems. Having a fibrous root system bound to media from the nursery to the planting site reduces the chance of root damage or loss during planting (Humphrey et al. 1993). Conventional containerized seedlings are also shorter, on average, than 1-0 bareroot seedlings which, in conjunction with their more fibrous root system, provides a more balanced root-to-shoot ratio (Burkett and Williams 1998, Humphrey 1994, Williams and Craft 1998). Humphrey et al. (1993) suggested that containerized seedlings are often a better choice than bareroot seedlings as they abate some of the problems that can occur with establishing oak seedlings. It was also noted that they could potentially be planted later in the season and provide better drought resistance compared to bareroot seedlings (Allen et al. 2004, Humphrey et al. 1993). Williams and Craft (1998) found that, on average, containerized seedlings exhibited survival in excess of 80 percent regardless of planting date. In order to avoid seedlings being "heaved" out of the planting slit, containerized seedlings should be planted sufficiently late in the season to avoid freezing temperatures, especially in high shrink-swell clay soils (Stroupe and Williams 1999).

Conventional containerized seedlings often exhibit good survival and initial growth which is critical to establishing oak plantations. These attributes were observed by Johnson et al. (1984) who found greater shoot growth, leaf area, and root elongation for containerized northern red oak (*Q. rubra*) after one growing season compared to small and large 1-0 and 1-1 bareroot seedlings. After one growing season, conventional containerized water oak (*Q. nigra*) and willow oak (*Q. phellos*) seedlings exhibited over twice the height growth compared to 1-0 bareoot seedlings (Williams and Stroupe 2002). Survival was 25 percent greater and positive height growth was observed in containerized seedlings in contrast to 1-0 bareroot seedlings which had negative overall height growth due to dieback as reported in a study with northern red oak in Canada (Wilson et al. 2007). Similar results were reported by Williams and Craft (1998) comparing Nuttall oak containerized and 1-0 bareroot seedlings when planted late in the growing season. These studies provide evidence that containerized seedlings are more apt to overcome transplant shock and have earlier height growth than bareroot seedlings.

Hollis (2011) found evidence contradictory to studies reporting superior performance of conventional containerized seedlings compared to other planting stocks when conducting a study with Nuttall oak and swamp chestnut oak (*Q. michauxii*). In that study, 1-0 bareroot seedlings exhibited an advantage in survival and height growth over containerized seedlings during the first and second growing seasons when pre-emergent herbaceous weed control was applied over bareroot seedlings. Alkire (2011) found height growth was significantly better for Nuttall oak and cherrybark oak (*Q. pagoda*) large potted seedlings than the same species of conventional containerized after one growing season. A study conducted by Conrad (2013) comparing bareroot and containerized seedlings found that height growth for live oak (*Q. virginiana*) and Nuttall oak was not significantly different after two growing seasons. Dowdy (2015) conducted a similar study on swamp chestnut and water oak whose results showed that height growth was not significantly different after two growing seasons when pre-emergent herbaceous weed control was applied both years to both containerized and bareroot seedlings. This evidence suggests that advantages proposed for containerized seedlings are minimized or eliminated when favorable growing conditions are present for bareroot seedlings.

Studies have shown that performance of containerized seedlings can be related to container size (Howell and Harrington 2002, Moorhead 1978). When comparing conventional containerized seedlings to larger potted seedlings, Self et al. (2010) observed that larger containers lead to improved height growth and survival. Cost of larger potted seedlings is much greater than that of conventional containerized seedlings and this can be prohibitive to some land managers as benefits may not be cost-effective. A similar situation is found when considering use of conventional containerized which typically cost at least five times as much as high quality 1-0 bareroot seedlings.

Large Potted Seedlings

Both conventional containerized and bareroot seedlings are subject to stress caused by vegetative competition, flooding, and large mammal herbivory. These limitations to growth and survival may be abated by larger potted seedlings such as those developed by Forest Keeling Nursery in Elsberry, Missouri, grown using the Root Production Method™ (RPM™), and those grown using the EKOgrown® system created by RootMaker®. Both of these systems generate seedlings that often exceed 1.5m in height at the time of planting and have a much larger root system than a 1-0 bareroot or conventional containerized seedling (Dey et al. 2006, Dey et al. 2004).

The argument for larger potted seedlings is that they are more drought and competition resistant than seedlings with less developed root systems and shorter initial height (Dey et al. 2006, Dey et al. 2004, Pinto et al. 2011). It is also suggested that because of increased size and potting medium, transplant shock will be mitigated or eliminated. However, they are not always effective or practical when one considers the additional cost and effort associated with planting (Howell and Harrington 2002). When comparing small, medium, and large containerized seedlings, Howell and Harrington (2002) found that while larger seedlings showed potential to offset costs, small and medium seedlings actually were the more economical choice. RPM™ seedlings have had limited study conducted on their performance, and most information comes from a long-term case study implemented on two retired agricultural fields in Missouri (Dey et al. 2006, Dey et al. 2004, Kabrick et al. 2005, Shaw et al. 2003), which compared their performance to 1-0 bareroot seedlings. Similar studies have been implemented in south Mississippi (Alkire 2011, Conrad 2013, Dowdy 2015, Hollis 2011, Reeves 2016).

A study by Dowdy (2015), comparing EKOgrown® to bareroot and conventional containerized seedlings, found height growth of EKOgrown® was significantly less over two growing seasons. These findings were not consistent with other studies conducted on larger potted seedlings, and excessive dieback exhibited by the EKOgrown® seedlings was attributed to being planted in October rather than the optimal planting range of January to mid-March.

The additional cost of large potted seedlings could prove to be economically inefficient; however, Dey et al. (2006) suggests that planting fewer large seedlings would offset the costs when compared to planting more, smaller seedlings. It is suggested that these seedlings could fill a niche that differs from that of smaller planting stocks by being used in common agroforestry practices such as riparian buffers, wind breaks, alley cropping, or silvopastural systems (Dey et al. 2006, Dey et al. 2004). It is also suggested by Dey et al. (2006) that land managers concerned more with producing hard mast for wildlife could consider additional benefits that would help justify the additional cost.

Herbaceous Weed Control

A major concern when regenerating oaks on high-quality bottomland sites is competing vegetation. Slower growing oak seedlings are often outcompeted for resources such as moisture, direct sunlight, and growing space by both woody and herbaceous vegetation. Ezell et al. (2007) concluded that forbs and other herbaceous species are often the source of limited moisture availability. However, through proper application of herbicides, many of these herbaceous species can be controlled (Haynes 2004). Seedling mortality can be attributed to many factors. However, competition control through the application of chemicals can drastically improve survival, particularly when herbaceous weeds are controlled during the first year of establishment (Ezell et al. 2007). Grebner et al. (2003) found that implementing herbaceous weed control practices was a better decision economically than using the “plant and walk away” method.

Sulfometuron methyl (Oust® XP)

Sulfometuron methyl, the active ingredient in Oust® XP, is a broad spectrum herbicide that is effective in controlling many species of forbs and some grasses. While suitable for tank mixing, it is normally applied alone for control of herbaceous competition in oak seedling establishment. Post-plant, pre-emergent applications are most effective for controlling competition, and in order to minimize crop damage to oaks, applications should be made prior to bud-break (Ezell and Cachot 1998). A rate of 140g of Oust® XP per ha is effective for many problematic species; however, it is only marginally effective against goldenrod (*Solidago* spp.), dogfennel (*Eupatoorium capillifolium*), broomsedge (*Andropogon* spp.), johnsongrass (*Sorghum halepense*), and is unsuccessful at controlling woody species (Miller 1993). Residual effects of herbaceous weed control have been observed when a tank mix including sulfometuron methyl was used for site preparation (Ezell 2002). Plots treated in September with site preparation tank mixes containing 210 g/ha Oust® or 529g/ha Oustar® exhibited 80 percent bareground ten months later, whereas control plots only exhibited 15 percent bareground.

In a study conducted by Ezell and Cachot (1998) examining post-plant, pre-emergent application of two rates of Oust® (140g/ha and 281g/ha), a 20-25 percent increase in survival was reported across six oak species and green ash (*Fraxinus pennsylvanica*), compared to control areas. Two trials with cherrybark oak and Nuttall oak resulted in similar increases (ranging from 31-44 percent greater) in average survival in areas that received treatment compared to untreated areas, in years that precipitation was below average during the growing season (Ezell et al. 2007). In all three trials, average survival exceeded 80 percent in treated areas (Ezell et al. 2007). When timber production is an objective, Grebner et al. (2003) found that less than 75 percent stocking was undesirable. These studies, in conjunction, provide evidence that the application of chemicals such as Oust® XP is an economically efficient means of controlling herbaceous competition.

Nuttall oak

Nuttall oak is a rapidly growing species in the red oak family (Hodges et al. 2008). It is an important wildlife species and its timber is considered suitable for lumber and veneer. Nuttall oak is shade intolerant; however, it is moderately flood tolerant

(Clatterbuck and Meadows 1992). Mature specimens can grow to approximately 30 to 36 meters in height on preferred sites (Burns and Honkala 1990). Preferred soil characteristics for the species include wet, fine textured soils (Hodges et al. 2008) with a pH ranging from 3.6 to 6.8 (Londo et al. 2006).

Shumard oak

Shumard oak is a moderate growth species in the red oak family (Hodges et al. 2008). Its acorns are eaten by a wide variety of wildlife species and serves as an important wildlife species. Timber quality is excellent and is suitable for making high value products such as flooring, furniture, trim, veneer and cabinetry. Shumard oak is shade intolerant and weakly flood tolerant at maturity but relatively intolerant as seedlings (Clatterbuck and Meadows 1992). At maturity, Shumard oak can reach 30 meters in height on preferred sites (Burns and Honkala 1990). Preferred soil characteristics include well drained, medium to coarse textured soils (Hodges et al. 2008) with a pH of 4.2-7.6 (Londo et al. 2006).

CHAPTER III

MATERIALS AND METHODS

Site Description

This study was conducted on two sites in southern Mississippi. The first and southernmost site was on land owned by Mr. Len O'Neal in Stone County, Mississippi. This site was approximately 10 kilometers west of Wiggins, Mississippi, and ½ kilometer west of Red Creek (30.861245, -88.43260), and was approximately 1.2 hectares in size. Two soil series are found at this site: Harleston fine sandy loam and Smithton fine sandy loam (USDA Web Soil Survey 2015). The site was relatively flat and flood potential has been minimized by a drainage ditch immediately south of the study area. Previous cover was different annual crops established for wildlife habitat. The site was bush hogged in preparation for planting by Mississippi State personnel.

The second study site was located on land owned by Mr. Larry Wozencraft in George County, Mississippi. This site was approximately 16 kilometers southeast of Lucedale, Mississippi, (30.861245, -89.234198), and was approximately 1.6 hectares in size. Three soil series are present on this site: Alaga loamy sand, Bennedale fine sandy loam, and Leaf-Lenior association (USDA Web Soil Survey 2015). The research area was relatively flat and is bordered to the north by Rocky Creek and reportedly rarely floods. This area had been bush hogged annually to prevent an undesirable cover type from establishing.

Plot Demarcation

Plots were laid out prior to planting establishing a 2.4 meter by 2.4 meter spacing for each seedling. Each planting row was designated by a piece of rebar marked with flagging and a metal tag denoting the treatment, block, and row number. A piece of rebar with flagging only was used to mark the end of the row. A 100 meter tape was utilized to establish spacing of the trees; and a pin flag was used to mark each planting location. Each treatment utilized a different color pin flag and the rebar was flagged with similar colored flagging.

Seedling Establishment

Seedlings used for this study included high quality 1-0 bareroot seedlings from Plum Creek nursery in Hazelhurst, Mississippi, 240mL conventional containerized seedlings from Mossy Oak Nativ Nursery™ located in West Point, Mississippi, and EKOgrown® seedlings grown in a 3.8L Rootmaker® pot from RES Native Tree Nursery in Montegut, Louisiana. All planting stocks were utilized for both Nuttall oak and Shumard oak.

Conventional containerized seedlings were received two days prior to planting and were stored in a walk-in cooler until transportation to study areas. Bareroot seedlings were acquired the day prior to planting and stored outside the night prior to planting due to mild temperatures. Conventional containerized and bareroot seedlings were planted on February 7, 2015, by Mississippi State University graduate research assistants and student workers. No culling was implemented for conventional containerized seedlings. The bareroot seedlings were culled for quality control in accordance with specified parameters including minimum seedling height of 50 centimeters and a minimum of 8 first order lateral roots. While culling occurred for bareroot seedlings, no root trimming occurred. If seedling roots were excessively long and protruded from the planting hole they were allowed to air prune. Seedling care on the day of planting consisted of keeping the seedlings in the shade until planted and ensuring that root systems stayed moist.

EKOgrown® seedlings were planted by a contract crew. The O'Neal site was planted on February 24, 2015, and the Wozencraft site was planted on March 24, 2015. Mississippi State University personnel were present during these plantings to ensure proper seedling care, placement, and general quality control of planting.

Pre-Emergent Herbicide and Ground Cover Evaluation

Herbaceous weed control was applied after establishment efforts were completed. A banded application of 140 grams of Oust® XP per sprayed hectare (ha) was completed on March 27-28, 2015, over all conventional containerized and some bareroot seedlings at each site. All conventional containerized and bareroot seedlings received this treatment on March 4, 2016. An 11.4 liter (L) Solo® 425 diaphragm-pump backpack sprayer equipped with a TeeJet® XR8003 nozzle was used to apply the herbicide solution as a 1.5m band over the top of seedlings at 93L per treated ha. A herbicide study was implemented on the remaining portion of bareroot seedlings which consisted of over-the-top applications of various rates of indaziflam on April 2, 2015. This latter study was implemented on 1,097 linear meters of the 1,463 linear meters of planting rows. The 366 linear meters not used in the herbicide study had the same herbaceous weed control (Oust XP) as the conventional containerized seedlings. EKOgrown® seedlings received no herbaceous weed control because EKOgrown® seedlings are promoted by the producer of these seedlings as not requiring competition control due to their height and more fully developed root system at the time of planting. To evaluate efficacy of herbaceous weed control, percent coverage was recorded by grass, broadleaf, vine, and shrub competition categories by plot monthly from May through September, 2015.

Seedling Survival and Measurements

Seedling height and groundline diameter (GLD) were recorded three times. Initial measurements were taken on March 27-28, 2015. End of growing season measurements were repeated on October 10-11, 2015, and September 3-4, 2016. Meter sticks were used to record total height in whole centimeters. When seedlings exhibited a split stem, the taller of the two stems was measured. If dieback was present, it was noted and height was recorded only to the point of highest live tissue. When complete dieback and resprouting occurred, the new sprout was measured and reported as a resprout. Mitutoyo® digital calipers were used to measure GLD which was recorded in tenths of a millimeter. Ground line diameter was measured directly above the root collar.

Survival was recorded monthly throughout the first growing season, at the end of the first growing season, and at the end of the second growing season. Trees were considered alive if they exhibited green leaves or green cambium tissue when bark was scraped from the base of the stem.

Rainfall Collection

Rainfall data were collected at each site using a Rainwise™ tipping bucket gauge in conjunction with a Hobo Pendant data logger. Data were uploaded to a computer with HOBOWare™ Plus software. Rainfall was assessed monthly during each growing season in order to determine if a relationship between precipitation and growth and survival was present.

Soil Sampling

Soil samples were collected randomly from each site using a soil probe on July 28, 2015. Samples were analyzed for nutrient content and texture by the Mississippi State University Extension Service Plant and Soil Sciences Soil Testing Lab in Mississippi State, Mississippi on August 6, 2015.

Photosynthesis Measurements

A LI-6400XT Portable Photosynthesis System (LI-COR Biosciences Inc. Lincoln Nebraska, USA) was used to measure gas exchange and calculate photosynthetic (A) and transpiration (E) rates in order to analyze the relationship of carbon uptake and water use to growth and survival of the seedlings. Measurements were made at a photosynthetic photon flux density (PPFD) of 1,500µmol m^{-2} s^{-1} from a red-blue LED light source and a CO_2 concentration of 400 parts per million (ppm). Measurements were made monthly during the first growing season on May 19-20, June 20-21, July 20-21, August 21-22, and September 18-19, 2015. During May and June, two individuals from each treatment were randomly selected and marked with a labeled pin flag. This resulted in four trees per treatment and 72 trees total after the June measurements. Rounds of gas exchange measurements were made every 1.5 hours from 9:00 a.m. to 3:00 p.m. until five sets were recorded or until inclement weather stopped measurements from being taken. Individuals were measured in the same order each time to ensure an equal time interval was established. If dew was present, leaves were dried with a paper towel prior to taking a measurement. In July, two seedlings in each treatment were randomly selected to be measured in the July, August, and September periods. These trees were measured using the same procedure as the May and June periods except that measurements were started at 7:00 a.m. instead of 9:00 a.m.

Statistical Analysis

A complete block design was used for this study. Three blocks were established on each site. Each block was subdivided into six treatments. A treatments consisted of unique species and planting stock combination and contained 100 seedlings. The treatment was considered the experimental unit for all analysis. No significant difference between blocks was detected, therefore they were combined for the following analysis.

Data were analyzed using Statistical Analysis System (SAS™) software version 9.4®. Differences were considered significant at α=0.05 level. PROC GLM was used to perform an analysis of variance to determine if groups were significantly different in terms of GLD growth, height growth, photosynthesis, and survival of seedlings for each main effect and possible interactions. When significant differences were detected, a multiple comparison procedure was used to determine significance using the LSMEANS statement with the Tukey-Kramer method. PROC GLM, LSMEANS, and Tukey-Kramer were implemented because sample populations were not equal due to mortality. Additionally, the Tukey-Kramer method was used over other methods because it accounts for all pairwise comparisons.

PROC REG was used to perform simple linear regression analysis on average seasonal photosynthetic rate, and height and GLD versus height growth and GLD growth in order to determine if differences in photosynthetic rates explained variation in GLD and height growth data.

CHAPTER IV

RESULTS AND DISCUSSION

Analysis of variance

Analysis of variance (ANOVA) was utilized to determine if the effects of site, species, and planting stock were statistically significant for average groundline diameter growth (Table 4.1), average height growth (Table 4.2), and survival (Table 4.3). ANOVA testing is limited to reporting significance among groups and further testing is required to determine significance within groups for which a Tukey-Kramer multiple comparisons procedure (MCP) was performed. Results from the ANOVA and MCP analyses for each variable are explained subsequently in the proper section for site, species, planting stock, and their interactions.

Table 4.1 ANOVA results for average groundline diameter growth by year and overall.

		Growing Season					
		2015		2016		Overall	
Source	DF	F	P>F	F	P>F	F	P>F
(A) Species	1	80.72	<0.0001	8.87	0.0029	110.56	<0.0001
(B) Stock	2	139.97	<0.0001	38.50	<0.0001	4.60	0.0101
(C) Site	1	33.85	<0.0001	138.12	<0.0001	343.56	<0.0001
A * B	2	2.05	0.1284	0.21	0.8108	0.53	0.5599
B * C	2	0.52	0.5947	36.18	<0.0001	46.14	<0.0001
A * C	1	0.36	0.5497	10.42	0.0013	19.07	<0.0001
A * B * C	2	8.61	0.0002	5.97	0.0026	4.80	0.0083

Table 4.2 ANOVA results for average height growth by year and overall.

		Growing Season					
		2015		2016		Overall	
Source	DF	F	P>F	F	P>F	F	P>F
(A) Species	1	5.29	0.0284	43.38	<0.0001	28.20	<0.0001
(B) Stock	2	221.17	<0.0001	131.77	<0.0001	21.98	<0.0001
(C) Site	1	40.86	<0.0001	508.70	<0.0001	611.71	<0.0001
A * B	2	29.31	<0.0001	25.71	<0.0001	51.93	<0.0001
B * C	2	1.18	0.4067	125.89	<0.0001	115.94	<0.0001
A * C	1	0.12	0.5482	24.65	<0.0001	26.16	<0.0001
A * B * C	2	0.40	0.6995	10.30	<0.0001	10.34	<0.0001

Table 4.3 ANOVA results for survival by year.

		Growing Season			
		2015		2016	
Source	DF	F	P>F	F	P>F
(A) Species	1	162.10	<0.0001	194.70	<0.0001
(B) Stock	2	787.33	<0.0001	577.52	<0.0001
(C) Site	1	11.47	0.0007	42.92	<0.0001
A * B	2	117.56	<0.0001	79.45	<0.0001
B * C	2	6.32	0.0018	5.77	0.0031
A * C	1	0.12	0.7260	0.12	0.7263
A * B * C	2	0.12	0.8845	4.09	0.0168

Monthly precipitation and survival during first growing season

Monthly precipitation and survival evaluations were conducted during the first growing season to determine the impact of transplant shock and precipitation on survival. Survival for conventional containerized seedlings was unexpectedly low for this study. However, all seedlings were planted during late winter or early spring while dormant and did not appear abnormal or damaged.

Monthly precipitation during first growing season

Precipitation during the 2015 growing season was similar across sites (Table 4.4) and to monthly averages in the area (NOAA 2016b). Rainfall was observed as below long term average July and August for each site and September for the O'Neal site (Table 4.4). Precipitation exceeded long term average during April, May, and June, on both sites and during September for the Wozencraft site.

Table 4.4 Monthly precipitation at each site during the first growing season and long term regional precipitation.

Site	April	May	June	July	Aug.	Sept.
	Centimeters					
O'Neal	18.9	24.6	12.4	10.2	6.6	9.1
Wozencraft	27.2	19.5	12.1	11.4	8.3	14.6
Long Term Average*	13.4	11.8	11.0	15.2	11.4	9.8

*20th Century Average Mississippi Climate Division Nine (NOAA 2016a)

Monthly survival during first growing season

Survival was unexpectedly low for conventional containerized seedlings of the species in this study. The poor survival was noticed early in the growing season when approximately 30 percent of the seedlings failed to break bud (Table 4.5). Similar results were observed by Reeves (2016) when both Nuttall and Shumard oak conventional containerized seedlings had almost complete failure to break bud. The cause was determined to most likely be an unusually low temperature in the growing region and lack of sufficient protection at the nursery leading to freeze damage. Conventional containerized seedlings for this study were obtained from the same nursery used by Reeves (2016) and the region experienced unusually low temperatures during the winter prior to planting in both studies. November 2014 was an unusually cold month for the region and January 2015 had multiple consecutive days that minimum temperatures in the teens were observed (NOAA 2016b). Similar survival was observed across sites for each treatment and no drastic decreases in monthly survival for any treatment were detected after the initial evaluation in May (Table 4.5). No relationship was observed between monthly precipitation and survival during the first growing season.

Table 4.5 Monthly survival per treatment by site during the first growing season.

Site	Treatment	May	June	July	Aug.	Sept.	Oct.
		Percentage					
O'Neal	Bareroot Nuttall oak	100.0	99.3	99.0	99.0	99.0	99.6
	Bareroot Shumard oak	97.0	97.0	97.0	97.0	96.3	96.3
	Containerized Nuttall oak	83.3	79.0	79.0	79.0	79.0	79.3
	Containerized Shumard oak	61.3	58.0	53.0	47.3	45.0	45.0
	EKO Nuttall oak	100.0	100.0	100.0	100.0	100.0	100.0
	EKO Shumard oak	99.7	99.7	99.3	99.0	99.0	99.0
Wozencraft	Bareroot Nuttall oak	99.7	99.0	99.0	99.0	99.0	98.6
	Bareroot Shumard oak	97.3	96.7	96.7	96.7	96.7	95.3
	Containerized Nuttall oak	76.0	75.0	72.0	71.0	70.7	70.3
	Containerized Shumard oak	57.0	50.7	44.7	43.3	44.0	38.3
	EKO Nuttall oak	100.0	100.0	99.0	99.0	99.0	99.3
	EKO Shumard oak	99.7	99.3	99.3	99.3	99.0	99.0

Soil Nutrient and Texture Analysis

The O'Neal site had a higher nutrient content for five of the seven nutrients (P, K, Ca, Mg, S, Na) analyzed for this study compared to the Wozencraft site (Table 4.6). Both sites had identical pH values at 4.8, which is considered acidic but within the acceptable range for these species. The O'Neal site had a higher percentage of organic matter (3.07 percent) than the Wozencraft site (1.65 percent).

Table 4.6 Nutrient content in kilograms per hectare, pH, and percent organic matter by site.

Site	P	K	Ca	Mg	Zn	S	Na	pH	OM
	Kilograms per Hectare								Percent
O'Neal	38	168	472	135	1.0	495	13	4.8	3.07
Wozencraft	13	57	207	61	1.3	267	15	4.8	1.65

*OM = Organic matter

Clay, silt, and sand composition was similar for the O'Neal site (2.50 percent, 47.25 percent, and 50.25 percent, respectively) when compared to the Wozencraft site (3.75 percent, 30.75 percent, and 65.50 percent, respectively) (Table 4.7). Both soils are classified as sandy loams.

Table 4.7 Percent Clay, Silt, and Sand, and Texture by Site.

Site	Clay	Silt	Sand	Texture Class
	Percent			
O'Neal	2.50	47.25	50.25	Sandy Loam
Wozencraft	3.75	30.75	65.50	Sandy Loam

Species comparison

Interactions were detected within species for average GLD growth, average height growth, or survival. Therefore, significance of the main effect species could not be validly determined.

GLD growth variation between species

Analysis of variance revealed an effect of species on average GLD growth during the first growing season ($F = 80.72$, $p < 0.0001$), the second growing season ($F = 8.87$, $p = 0.0029$), and overall ($F = 110.56$, $p < 0.0001$) (Table 4.1).

Overall, average GLD growth of Nuttall Oak was greater than Shumard oak during the first growing season (3.13mm and 2.01mm, respectively), second growing season (1.91mm and 1.36mm, respectively), and overall (5.06mm and 3.43mm, respectively) when all planting stocks and both sites were considered (Table 4.8).

Table 4.8 Average groundline diameter growth by species, growing season, and overall. (All planting stocks and both sites)

	Growing Season		
Species	2015	2016	Overall
	Millimeters		
Nuttall oak	3.13	1.91	5.06
Shumard oak	2.01	1.36	3.43

Height growth variation between species

Analysis of variance revealed an effect of species on average height during the first growing season ($F = 5.29$, $p = 0.0284$), the second growing season ($F = 43.38$, $p < 0.0001$), and overall ($F = 28.20$, $p < 0.0001$) (Table 4.2).

Shumard oak seedlings had greater average height growth than Nuttall oak seedlings during the first growing season when all planting stocks at both sites were considered (3.8cm and 2.8cm, respectively) (Table 4.9). Nuttall oak seedlings had greater average height growth than Shumard oak seedlings during the second growing season (12.4cm and 5.8cm, respectively) and overall (15.2cm and 9.7cm, respectively) when all planting stocks at both sites were considered.

Table 4.9 Average height growth by species, growing season, and overall. (All planting stocks and both sites)

Species	Growing Season 2015	Growing Season 2016	Overall
	Centimeters		
Nuttall oak	2.8	12.4	15.2
Shumard oak	3.8	5.8	9.7

Survival variation between species

Analysis of variance revealed an effect of species on survival at the end of the first growing season (F = 162.10, $p < 0.0001$), and the second growing season (F = 194.70, $p < 0.0001$) (Table 4.3).

Nuttall oak seedlings had greater survival than Shumard oak seedlings at the end of the first growing season (91.2 percent and 79.1 percent, respectively), and the second growing season (87.9 percent and 72.4 percent, respectively) when all planting stocks at both sites were considered (Table 4.10).

Table 4.10 Survival by species and growing season. (All planting stocks and both sites)

Species	Growing Season 2015	Growing Season 2016
	Percent	
Nuttall oak	91.2	87.9
Shumard oak	79.1	72.4

Species comparison discussion

Nuttall oak seedlings maintained greater GLD growth and survival throughout this study when compared to Shumard oak. Shumard oak had greater height growth during the first growing season when compared to Nuttall oak but that trend reversed during the second growing season and overall. Shumard oak exhibiting greater height growth during the first growing season is unexpected, because Nuttall oak is a more rapidly growing species than most other oaks (Burns and Honkala 1990). When studying different oaks over multiple growing seasons, Mercker et al. (2011) found that Nuttall oak exhibited superior survival compared to Shumard oak on soils of various drainage classes. Reeves (2016) conducted a study on two planting stocks of Nuttall and Shumard oak and reported Nuttall oak had superior height growth, GLD growth, and survival over a two-year study. A study conducted by Self (2011) revealed superior performance from Nuttall oak seedlings compared to Shumard oak seedlings (among others) when comparing different site preparation methods for oak regeneration. Soil texture for both sites in this study was more favorable for Shumard oak, which prefer coarser textured soils (Hodges et al. 2008), compared to Nuttall oak but this advantage was not mirrored in the data (Table 4.7).

First growing season height growth was unexpectedly low for both species in this study (Table 4.9). When comparing three nursery stocks of Nuttall oak bareroot seedlings in the Lower Mississippi Alluvial Valley, Gardiner et al. (2007), reported first year height growth being approximately 20 cm. Two studies investigating three planting stocks of Nuttall oak (among other species) found similar results reporting twice the height growth in the first year compared to this study (Alkire 2011 and Conrad 2013). Self (2011) reported greater first year height growth for both Nuttall and Shumard oak than was recorded in this study. Less height growth in this study is in part due to dieback exhibited by both species during the first growing season. Growth was also inhibited by the previously mentioned freeze damage that occured in the nursery for conventional containerized seedlings. Height growth inhibited by dieback was reported by Reeves (2016) who found first growing season height growth of Nuttall oak similar to that of this study and negative overall growth in Shumard oak seedlings due to dieback also reported.

Survival of Shumard oak being approximately 12 and 15 percent less than Nuttall oak in the first and second growing season, respectively, can be partly attributed to especially high mortality of Shumard oak conventional containerized seedlings (Table 4.5). Survival of Nuttall oak decreased by approximately 3 percent between the first and second growing seasons. Shumard oak survival decreased by almost 7 percent in the same time span. This result may be explained by Burns and Honkala (1990) characterizing Shumard oak as reacting poorly to competition, and Clatterbuck and Meadows (1992) listing Nuttall oak as being able to withstand most competition. HWC was applied over bareroot and conventional containerized seedlings; however, some level of vegetative competition developed in all treatments during each growing season.

Planting stock comparison

Interactions were detected within planting stock for average GLD growth, average height growth, or survival. Therefore, significance of the main effect planting stock could not be validly determined.

GLD growth variation among planting stocks

Analysis of variance revealed an effect of planting stock on average GLD growth during the first growing season ($F = 139.97$, $p < 0.0001$), the second growing season ($F = 38.50$, $p < 0.0001$), and overall ($F = 4.60$, $p = 0.0101$) (Table 4.1).

EKOgrown® seedlings' average GLD was greater than bareroot and conventional containerized seedlings. Significant differences were not observed for the latter two during the first growing season (3.88mm, 1.76mm, and 2.09mm, respectively) when both species and sites were considered (Table 4.11). Conventional containerized and bareroot seedlings were not different in the second growing season (2.00mm and 2.27mm, respectively) but both were different than EKOgrown® seedlings (0.62mm). Overall, bareroot seedlings (4.05mm) were different than EKOgrown® seedlings (4.53mm) but neither differed from conventional containerized seedlings (4.15mm). After two growing seasons, bareroot seedling GLD growth was almost identical (<0.5 mm difference) to the more expensive containerized or potted seedlings.

Table 4.11 Average groundline diameter growth by planting stock, growing season, and overall. (Both species and both sites)

	Growing Season		
Planting Stock	2015	2016	Overall
	Millimeters		
Bareroot	1.76	2.27	4.05
Conventional Containerized	2.07	2.00	4.15
EKOgrown®	3.88	0.62	4.53

Height growth variation among planting stocks

Analysis of variance revealed an effect of planting stock during the first growing season ($F = 221.17$, $p < 0.0001$), the second growing season ($F = 131.77$, $p < 0.0001$), and overall ($F = 21.98$, $p < 0.0001$) (Table 4.2).

Average height growth was greatest for EKOgrown® seedlings, bareroot seedlings had the second highest growth, and conventional containerized exhibited the lowest growth due to dieback (9.5cm, 3.0cm, and -2.6cm, respectively) during the first growing season when both species and sites were considered (Table 4.12). Average height growth for conventional containerized seedlings (20.2cm) during the second growing season was greater than bareroot seedlings (7.8cm), and EKOgrown® seedlings had the lowest height growth (-0.6cm). Average height growth was greatest overall for conventional containerized seedlings (17.6cm), and bareroot and EKOgrown® seedlings' height growth was not significantly different (10.9cm and 8.9cm, respectively).

Table 4.12 Average height growth by planting stock, growing season, and overall. (Both species and both sites)

	Growing Season		
Planting Stock	2015	2016	Overall
	Centimeters		
Bareroot	3.0	7.8	10.9
Conventional Containerized	-2.6	20.2	17.6
EKOgrown®	9.5	-0.6	8.9

Survival variation among planting stocks

Analysis of variance revealed an effect of planting stock on survival for the first growing season ($F = 787.33$, $p < 0.0001$), and the second growing season ($F = 577.52$, $p < 0.0001$) (Table 4.3).

Conventional containerized seedling survival was lower than EKOgrown® and bareroot seedling survival. The latter two were similar in the first growing season (58.3 percent, 99.5 percent, and 97.5 percent, respectively) when both species and sites were considered (Table 4.13). EKOgrown® seedling survival (97.6 percent) was greater in the second growing season than bareroot seedling survival (88.9 percent), and conventional containerized seedlings exhibited the lowest survival (53.9 percent).

Table 4.13 Survival planting stock and growing season. (Both species and both sites)

	Growing Season	
Planting Stock	2015	2016
	Percent	
Bareroot	97.5	88.9
Conventional Containerized	58.5	53.9
EKOgrown®	99.5	97.6

Planting stock comparison discussion

Resources are allocated to root growth in oak seedlings until a sufficient root system has been developed to supply nutrients for rapid shoot growth (Johnson et al. 2009). EKOgrown® seedlings have a greater root surface area than conventional containerized seedlings and both have greater root surface area than bareroot seedlings. Bareroot and conventional containerized seedlings were likely able to increase height growth from the first growing season to the second because sufficient root systems were development. EKOgrown® seedlings having a root system with more surface area at the time of planting allows them to have greater initial growth. First year growth of EKOgrown® seedlings being greater when compared to conventional containerized and bareroot seedlings is similar to results reported by other studies (Alkire 2011 and Shaw et al. 2003).

Reduced growth of EKOgrown® seedlings in the second growing season compared to conventional containerized and bareroot seedlings' is also consistent with findings of a number of studies (Conrad 2013, Dowdy 2015, Reeves 2016). The producers of EKOgrown® and other large potted seedlings claim that benefits inherent to larger potted seedling allows them to better withstand competition compared to other seedlings. These results indicate that EKOgrown® seedlings may be able to better withstand competition in the first growing season compared to other planting stocks. However, this advantage was absent during the second growing season resulting in comparatively lower GLD growth and dieback.

When both first and second year growth was considered, EKOgrown® seedlings performed slightly better compared to both of the other planting stocks in GLD growth, height growth, or survival. These results are inconsistent with many recent studies comparing large potted seedlings versus conventional containerized or bareroot seedlings for longer than one year. Conrad (2013), Dowdy (2015), and Reeves (2016) reported poorer overall two year performance from large potted seedlings. The superior performance of EKOgrown® seedlings in this study compared to that of large potted seedlings in other studies may be explained by proper seedling handling (Dowdy 2015) and lack of weather impediments such as damage caused by flooding and wind (Conrad 2013 and Reeves 2016). However, any growth advantage in these trees was only slight.

EKOgrown® seedlings exhibited greater survival than bareroot seedlings after two growing seasons. This is consistent with results reported by Grossman et al. (2003) and Shaw et al. (2003). These results differ from numerous other studies comparing planting stocks of various oaks. Hollis (2011) reported survival of bareroot and large potted seedlings of two oak species to be statistically similar across two growing seasons. Conrad (2013) found survival of bareroot seedlings to be similar or greater to that of large potted seedlings when comparing two oak species over two growing seasons.

Dowdy (2015) reported superior survival of bareroot seedlings in two oak species when compared to EKOgrown® seedlings over two growing seasons. Conventional containerized exhibited poor survival which is attributed to the lack of sufficient protection in the nursery leading to root freeze damage which can cause increased mortality and decreased growth (Bigras and Dumais 2005). Barney (1991) noted that seedlings that incur freeze damage in the nursery often go without notice until after they are planted.

Survival of bareroot seedlings decreased from the first growing season to the second by nearly 9 percent. This decrease is due to Shumard oak bareroot seedlings exhibiting over 10 percent less survival than Nuttall oak bareroot seedlings. These differences can be attributed to Shumard oak not being able to withstand competition as well as Nuttall oak as discussed previously. Grass competition was especially severe on the Wozencraft site.

Site comparison

Significance could not be validly determined for average GLD growth or survival for the main effect site because interactions were detected within site. Significance of average GLD growth during the first growing season is presented because no interaction was detected within site. Significance could not be validly determined for average GLD growth during the second growing season and overall because interactions were detected within site.

GLD growth variation between sites

Analysis of variance revealed an effect of site on average GLD growth during the first growing season ($F = 33.85$, $p < 0.0001$), the second growing season ($F = 138.12$, $p < 0.0001$), and overall ($F = 343.56$, $p < 0.0001$) (Table 4.1).

Average GLD growth of seedlings planted at the O'Neal site was greater than those at the Wozencraft site during the first growing season (2.93mm and 2.21mm, respectively), the second growing season (2.72mm and 0.55mm, respectively), and overall (5.68mm and 2.81mm, respectively) when both species and all planting stocks were considered (Table 4.14).

Table 4.14 Average groundline diameter growth by site, growing season, and overall. (Both species and all planting stocks).

	Growing Season		
Site	2015	2016	Overall
	Millimeters		
O'Neal	2.93	2.72	5.68
Wozencraft	2.21	0.55	2.81

Height growth variation between sites

Analysis of variance revealed a significant effect of site on average height growth during the first growing season ($F = 40.86$, $p <0.0001$) (Table 4.2). An effect of site on average height growth was also detected for the second growing season ($F = 508.70$, $p < 0.0001$), and overall ($F = 611.71$, $p < 0.0001$), but significance could not be validly determined. MCP analysis was then used to determine which interactions were significant.

Average height growth of seedlings at the O'Neal site was greater than at the Wozencraft site during the first growing season (4.8cm and 1.8cm respectively), the second growing season (20.4cm and -2.2cm, respectively), and overall (25.2cm and -0.3cm, respectively) when both species and all planting stocks were considered (Table 4.15).

Table 4.15 Average height growth by site, growing season, and overall. (Both species and all planting stocks).

	Growing Season		
Site	2015	2016	Overall
	Centimeters		
O'Neal	4.8b*	20.4	25.2
Wozencraft	1.8a	-2.2	-0.3

*Values in a column followed by the same letter are not significantly different (α=0.05)

Survival variation between sites

Analysis of variance revealed an effect of site on survival at the end of the first growing season ($F = 11.47$, $p = 0.0007$), and the second growing season ($F = 42.92$, $p < 0.0001$) (Table 4.3).

Survival at the O'Neal site was greater than at the Wozencraft site during the first growing season (86.8 percent and 83.6 percent, respectively) and the second growing season (83.8 percent and 76.5 percent, respectively) when both species and all planting stocks were considered (Table 4.14).

Table 4.16 Survival by site and growing season. (Both species and all planting stocks).

Site	Growing Season 2015	Growing Season 2016
	Percent	
O'Neal	86.8	83.8
Wozencraft	83.6	76.5

Site comparison discussion

The O'Neal site maintained higher GLD growth, height growth, and survival throughout this study when compared to the Wozencraft site. Seedlings at the Wozencraft site exhibited negative height growth in the second growing season and overall which can be attributed to dieback.

Survival for both sites, only being in the 80 percent range, is lower than expected. This is caused by poor survival of conventional containerized stock which incurred freeze damage in the nursery. When conventional containerized are excluded, survival for both sites is 90 percent or greater.

Overall variation in seedling survival and growth between sites may be explained in large part by differences in vegetative competition. Competition on the Wozencraft site was composed heavily of grasses mostly comprised of *Andropogon* spp., panicgrass (*Panicum* spp.), and cogongrass (*Imperata cylindrica* L.). Competition on the O'Neal site was comprised mostly of ragweed (*Ambrosia* spp.) and sicklepod (*Senna obtusifolia* L.). Miller and Zutter (1987) found that herbaceous competitors such as panicum grasses, bluestems, and asteraceae forbs had a more negative effect than woody competition on the success of loblolly pine seedlings. Thompson (2005) reported similar results when studying white spruce (*Picea glauca* (Moench) Voss) in Alaska, observing that grass inhibited early growth by competing for resources in the rooting area greater than shrub species. A study conducted by Jensen et al. (2012) in Sweden found that shrubs acted as both direct competitors and indirect facilitators of growth for English oak (*Q. robur*) seedlings planted in an open field. Jensen et al. (2012) explained that shrubs reduced light availability enough to completely eliminate herbaceous competition subsequently increasing growth and survival of oak seedlings. The growth habit of sicklepod can be classified as subshrub (USDA 2016) and was observed eliminating understory herbaceous competition similarly to shrubs in the study by Jensen et al. (2012). Cogongrass has been described as exhibiting allelopathy and reported to reduce productivity and survival in loblolly pine (*Pinus taeda*) and longleaf pine (*P. palustris*) (Kaufman and Kaufman 2013). It would be expected that cogongrass would have negative effects on other tree species as well and could be partially responsible for decreased growth and survival observed at the Wozencraft site.

Soil tests conducted on the sites indicate that soils on the O'Neal site had greater nutrient content for five of seven nutrients tested (Table 4.6). The difference in overall nutrient content of the soils on each site may have had some effect on growth between sites; however, the extent of this effect on survival is believed to be very limited.

Interaction of species and planting stock

GLD growth variation by species and planting stock interaction

Analysis of variance revealed that significant interactions between species and planting stock were not detected indicated by lack of variation in average GLD growth during the first growing season ($F = 2.05$, $p = 0.1284$), the second growing season ($F = 0.21$, $p = 0.8108$), and overall ($F = 0.53$, $p = 0.5599$) (Table 4.1).

First Growing Season – Average GLD growth was observed to be greater for Nuttall oak EKOgrown® seedlings (4.61mm) and Shumard oak EKOgrown® exhibited the second greatest growth (3.16mm) when both sites were considered (Table 4.17). Average GLD growth for Nuttall oak bareroot and conventional containerized seedlings was not found to be significantly different (2.26mm and 2.51mm, respectively). Shumard oak conventional containerized GLD growth (1.67mm) was significantly less than Nuttall oak conventional containerized. Shumard oak bareroot seedlings GLD growth (1.25mm) was not observed as being significantly different from Shumard oak conventional containerized seedlings.

Second Growing Season – Average GLD growth similar for Nuttall oak bareroot and conventional containerized seedlings (2.56mm and 2.33mm, respectively) and Shumard oak bareroot and conventional containerized seedlings (1.98mm and 1.66mm, respectively). Nuttall oak EKOgrown® seedlings (0.82mm) were not observed to be different than Shumard oak conventional containerized or Shumard oak EKOgrown® seedlings (0.43mm).

Overall – Average GLD growth was not found to be different for bareroot, conventional containerized, and EKOgrown® Shumard oak seedlings (3.26mm, 3.43mm, and 3.61mm, respectively) or Nuttall oak seedlings (4.48mm, 4.87mm, and 5.46mm, respectively). All planting stocks of Nuttall differed from comparable Shumard oak seedlings.

Table 4.17 Average groundline diameter growth by species and planting stock by growing season and overall. (Both sites).

Species/Planting Stock	Growing Season 2015	Growing Season 2016	Overall
	Millimeters		
Nuttall oak Bareroot	2.26bc*	2.56c	4.84b
Nuttall oak Conventional Containerized	2.51c	2.33c	4.87b
Nuttall oak EKOgrown®	4.61e	0.82ab	5.46b
Shumard oak Bareroot	1.25a	1.98c	3.26a
Shumard oak Conventional Containerized	1.63ab	1.66bc	3.43a
Shumard oak EKOgrown®	3.16d	0.43a	3.61a

*Values in a column followed by the same letter are not significantly different (α=0.05)

Height growth variation by species and planting stock interaction

Analysis of variance revealed that significant interactions between species and planting stock were present as indicated by variation in average height growth during the first growing season ($F = 29.31$, $p < 0.0001$), the second growing season ($F = 25.71$, $p < 0.0001$), and overall ($F = 51.93$, $p < 0.0001$) (Table 4.2). MCP analysis was then used to determine which interactions were significant.

First Growing Season – When both sites were considered Shumard oak EKOgrown® seedlings exhibited the greatest height growth (12.4cm), followed by Nuttall oak EKOgrown® seedlings (6.6cm) (Table 4.18). Nuttall and Shumard oak bareroot seedling height growth (3.1cm and 3.0cm respectively) was not significantly different. However, height growth of both species were significantly less than both species of EKOgrown® seedlings and significantly greater than both species of conventional containerized seedlings. Nuttall and Shumard oak conventional containerized height growths (-1.4cm and -3.8cm respectively) was not significantly different , but was significantly less than other species-planting stock combinations.

<u>Second Growing Season</u> – Average height growth of Nuttall oak conventional containerized seedlings (25.7cm) was greatest when both sites were considered. Shumard oak conventional containerized seedlings (14.7cm) did not differ from Nuttall oak bareroot seedlings (13.5cm). EKOgrown® Nuttall oak and Shumard oak seedlings (-1.9cm and 0.7cm respectively) were not different than Shumard oak bareroot seedlings (2.1cm).

<u>Overall</u> – Average height growth of Nuttall oak conventional containerized seedlings (24.2cm) was greatest. Average height growth for Nuttall oak bareroot seedlings (16.7cm) was greater but not significantly different than Shumard oak EKOgrown® or Shumard oak conventional containerized seedlings (13.0cm and 11.0cm respectively). Shumard oak bareroot seedlings height growth (5.2cm) did not differ from that of Shumard oak conventional containerized or Nuttall oak EKOgrown® seedlings (4.8cm).

Table 4.18 Average height growth by species and planting stock by growing season and overall. (Both sites)

	Growing Season		
Species/Planting Stock	2015	2016	Overall
	Centimeters		
Nuttall oak Bareroot	3.1b*	13.5b	16.7c
Nuttall oak Conventional Containerized	-1.4a	25.7c	24.2d
Nuttall oak EKOgrown®	6.6c	-1.9a	4.8a
Shumard oak Bareroot	3.0b	2.1a	5.2ab
Shumard oak Conventional Containerized	-3.9a	14.7b	11.0bc
Shumard oak EKOgrown®	12.4d	0.7a	13.0c

*Values in a column followed by the same letter are not significantly different (α=0.05)

Survival variation by species and planting stock interaction

Analysis of variance revealed that a significant interaction between species and planting stock was present as indicated by variation in survival during the first growing season ($F = 117.56$, $p < 0.0001$) and the second growing season ($F = 79.45$, $p < 0.0001$) (Table 4.3). MCP analysis was then used to determine which interactions were significant.

First Growing Season – Average survival was not detected to be significantly different for Nuttall oak bareroot, Nuttall oak EKOgrown®, Shumard oak bareroot, or Shumard oak EKOgrown® seedlings (99.2 percent, 99.7 percent, 95.8 percent, and 99.3 percent respectively) when both sites were considered (Table 4.19). Nuttall oak conventional containerized seedling survival was significantly greater than survival of Shumard oak conventional containerized (74.8 percent and 41.7 percent respectively). Conventional containerized seedlings of both species exhibited significantly lower survival than bareroot and EKOgrown® seedlings of the same species.

Second Growing Season – Average survival for Nuttall oak bareroot, Nuttall EKOgrown®, and Shumard oak EKOgrown® seedlings (94.3 percent, 98.2 percent and 97.0 percent, respectively) was significantly greater than Shumard oak bareroot seedlings (83.5 percent), Nuttall oak conventional containerized seedlings (71.2 percent) and Shumard oak conventional containerized seedlings (36.7 percent).

Table 4.19 Survival by growing season, species, and planting stocks. (Both sites).

Species/Planting Stock	Growing Season 2015	Growing Season 2016
	Percent	
Nuttall oak Bareroot	99.2c*	94.3d
Nuttall oak Conventional Containerized	74.8b	71.2b
Nuttall oak EKOgrown®	99.7c	98.2d
Shumard oak Bareroot	95.8c	83.5c
Shumard oak Conventional Containerized	42.2a	36.7a
Shumard oak EKOgrown®	99.3c	97.0d

*Values in a column followed by the same letter are not significantly different (α=0.05)

Interaction of species and planting stock discussion

Bareroot and conventional containerized seedlings generally exhibited an increase in GLD and height growth. This is likely caused by the development of a sufficient root system in bareroot and conventional containerized seedlings. This served to increase growth, especially shoot growth where large increases were observed. Similar results were reported by Reeves (2016) who found a large increase in height growth of Nuttall oak bareroot seedlings. Conrad (2013) found height growth of Nuttall oak bareroot seedlings to increase in the second growing season, while conventional containerized and large potted seedlings of the same species exhibited a reduction in height growth. Reduced GLD growth was also reported by Conrad (2013) in the second growing season for all planting stocks of Nuttall oak seedlings. EKOgrown® seedlings of both species exhibited a reduction in growth during the second growing season compared to the first. This can probably be attributed to initital benefits of the larger pot size no longer abating negative effects of competition in the second growing season. The combination of these two factors are likely the reason no statistical difference was detected in planting stocks of the same species for GLD growth when both growing seasons are considered. Overall, these factors can also be used to explain why bareroot and conventional containerized seedlings exhibited much greater height growth compared to EKOgrown® seedlings of the same species generally.

Nuttall oak seedlings generally exhibited greater GLD and height growth in the second growing season and overall when compared to Shumard oak seedlings. This can likely be explained by rapid initial growth and the ability to better withstand competition. This is a typical characteristic of Nuttall oak seedlings.

Poor first growing season height growth and survival of both species of conventional containerized seedlings was likely caused by freeze damage incurred in the nursery. This is consistent with Reeves (2016) who reported Nuttall and Shumard oak were affected similarly by freeze damage that occurred in the nursery. It appears that Shumard oak was more heavily affected based on the fact that they exhibited lower GLD and height growth, and survival, although only GLD growth and survival were significantly lower. Conventional containerized seedlings that survived were able to overcome this damage to exhibit statistically equal or greater height and GLD growth than other planting stocks of the same species when both growing seasons were considered.

Survival declined at a higher rate for Shumard oak seedlings when compared to Nuttall oak seedlings of the same planting stock from the first growing season to the second. This phenomenon is likely related to the ability of Nuttall oak to better withstand competition than Shumard oak (Burns and Honkala 1990, and Clatterbuck and Meadows

1992). This is consistent with other studies comparing these two species (Mercker et al. 2011 and Reeves 2016).

Interaction of planting stock and site

GLD growth variation by planting stock and site interaction

Analysis of variance revealed that there were significant interactions between planting stock and site present as indicated by variation in average GLD growth during the second growing season ($F = 36.18$, $p < 0.0001$), and overall ($F = 46.16$, $p < 0.0001$) but not during the first growing season ($F = 0.52$, $p = 0.5947$) (Table 4.1). MCP analysis was then used to determine which interactions were significant.

<u>First Growing Season</u> – Average GLD growth was greatest for EKOgrown® seedlings on the O'Neal site (4.30mm), followed by EKOgrown® seedlings on the Wozencraft site (3.47mm). EKOgrown® seedling GLD growth on both sites was significantly greater compared to all other planting stocks on both sites when both species were considered (Table 4.20). Conventional containerized and bareroot seedlings on the O'Neal site, and conventional containerized seedlings on the Wozencraft site did not have significantly different GLD growth (2.33mm, 2.16mm, and 1.81mm, respectively). GLD growth was observed to be lowest for bareroot seedlings on the Wozencraft site (1.36mm), but was not significantly different than GLD growth of conventional containerized seedlings on the Wozencraft site.

<u>Second Growing Season</u> – Average GLD growth was greatest for bareroot and conventional containerized seedlings on the O'Neal site (3.82mm and 3.64 mm, respectively). Average GLD growth for EKOgrown® seedlings on the O'Neal site and

bareroot, conventional containerized, and EKOgrown® seedlings on the Wozencraft site were not significantly different (0.69mm, 0.73mm, 0.35mm, and 0.56mm, respectively).

Overall – Average GLD growth was greatest for bareroot and conventional containerized seedlings on the O'Neal site (5.99mm and 6.03mm, respectively). EKOgrown® seedlings on the O'Neal site (5.01mm) exhibited the next highest GLD growth, followed by EKOgrown® seedlings on the Wozencraft site (4.06mm). Bareroot and conventional containerized seedlings on the Wozencraft site had the lowest GLD growth (2.12mm and 2.26mm, respectively).

Table 4.20 Average groundline diameter by planting stock and site, by growing season and overall. (Both species).

	Growing Season		
Planting Stock/Site	2015	2016	Overall
	Millimeters		
Bareroot O'Neal	2.16b*	3.82b	5.99d
Bareroot Wozencraft	1.36a	0.73a	2.12a
Conventional Containerized O'Neal	2.33b	3.64b	6.03d
Conventional Containerized Wozencraft	1.81ab	0.35a	2.26a
EKOgrown® O'Neal	4.30d	0.69a	5.01c
EKOgrown® Wozencraft	3.47c	0.56a	4.06b

*Values in a column followed by the same letter are not significantly different (α=0.05)

Height growth variation by planting stock and site interaction

Analysis of variance revealed that significant interactions between planting stock and species were present as indicated by variation in average height growth during the second growing season ($F = 125.89$, $p < 0.0001$), and overall ($F = 115.94$, $p < 0.0001$), but not during the first growing season ($F = 1.18$, $p = 0.4067$) (Table 4.2). MCP analysis was then used to determine which interactions were significant.

First Growing Season – Average height growth was significantly different for each planting stock and site combination when both species were considered (Table 4.21). EKOgrown® seedlings on the O'Neal site exhibited the greatest average height growth (11.0cm) followed by EKOgrown® seedlings on the Wozencraft site (8.1cm), bareroot seedlings on the O'Neal and Wozencraft site (4.1cm and 2.0cm, respectively), and conventional containerized on the O'Neal and Wozencraft site (-0.7cm and -4.6cm, respectively).

Second Growing Season – Average height growth was greatest for conventional containerized seedlings on the O'Neal site (35.1cm). Bareroot seedlings on the O'Neal site (25.4cm) exhibited the next greatest height growth. EKOgrown® seedlings on the O'Neal site (0.8cm) were not significantly different than conventional containerized or EKOgrown® seedlings on the Wozencraft site (5.3cm and -2.0cm, respectively) although the latter two were different from one another. Bareroot seedlings on the Wozencraft site (-9.8cm) had the lowest growth.

Overall – Bareroot and conventional containerized seedlings on the O'Neal site (29.5cm and 34.4cm, respectively) had the greatest height growth. EKOgrown® seedlings on the O'Neal site (11.7cm) had the next greatest growth, and were significantly greater than height growth of conventional containerized and EKOgrown® seedlings on the Wozencraft site (0.7cm and 6.1cm, respectively). Bareroot seedlings on the Wozencraft site (-7.6cm) had the lowest height growth.

Table 4.21 Average height growth by planting stock and site, by growing season and overall. (Both species).

Planting Stock/Site	Growing Season 2015	2016	Overall
	Centimeters		
Bareroot O'Neal	4.1d*	25.4d	29.5d
Bareroot Wozencraft	2.0c	-9.8a	-7.6a
Conventional Containerized O'Neal	-0.7b	35.1e	34.4d
Conventional Containerized Wozencraft	-4.6a	5.3c	0.7b
EKOgrown® O'Neal	11.0f	0.8bc	11.7c
EKOgrown® Wozencraft	8.1e	-2.0b	6.1b

*Values in a column followed by the same letter are not significantly different (α=0.05)

Survival variation by planting stock and site interaction

Analysis of variance revealed that significant interactions between planting stock and site were present as indicated by variation in survival during the first growing season (F = 6.32, p = 0.0018) and the second growing season (F = 5.77, p = 0.0031) (Table 4.3). MCP analysis was then used to determine which interactions were significant.

First Growing Season – Survival was not significantly different for bareroot seedlings at the O'Neal and Wozencraft sites (98.0 percent and 97.0 percent, respectively) and EKOgrown® seedlings at the O'Neal and Wozencraft sites (99.8 percent and 99.2 percent, respectively) when both species were considered (Table 4.22). Bareroot and EKOgrown® seedlings on both sites had significantly greater survival than conventional containerized seedlings on both sites. Conventional containerized seedlings at the O'Neal site had significantly greater survival (62.5 percent) than conventional containerized seedlings on the Wozencraft site (54.5 percent).

Second Growing Season – Bareroot and EKOgrown® seedlings on the O'Neal site (94.5 percent and 98.7 percent, respectively) and EKOgrown® seedlings on the

Wozencraft site (96.5 percent) had the greatest survival. Survival of bareroot seedlings on the Wozencraft site (83.3 percent) was significantly greater than conventional containerized seedling survival on both sites (49.7 percent and 58.2 percent, respectively).

Table 4.22 Survival by growing season, planting stock, and site. (Both species).

Planting Stock/Site	Growing Season 2015	Growing Season 2016
	Percent	
Bareroot O'Neal	98.0c*	94.5d
Bareroot Wozencraft	97.0c	83.3c
Conventional Containerized O'Neal	62.5b	58.2b
Conventional Containerized Wozencraft	54.5a	49.7a
EKOgrown® O'Neal	99.8c	98.7d
EKOgrown® Wozencraft	99.2c	96.5d

*Values in a column followed by the same letter are not significantly different (α=0.05)

Interaction of planting stock and site discussion

As discussed previously, competition was mostly comprised of grasses on the Wozencraft site. Thus those seedlings were at a competitive disadvantage when compared to those on the O'Neal site. EKOgrown® seedlings are also believed to exhibit decreased growth in the second growing season due to their larger root system no longer lessening effects of competing vegetation, which was not controlled with HWC. Having HWC and less aggressive competition may explain why bareroot and conventional containerized seedlings on the O'Neal site exhibited statistically greater GLD and height growth in the second growing season and overall when compared to EKOgrown® seedlings on the same site.

Height growth for bareroot seedlings on the Wozencraft site was lower than expected. This is likely caused by vegetation on the Wozencraft site being more competitive. Significantly greater height growth of conventional containerized and EKOgrown® seedlings when both growing seasons are considered could suggest that increasing container size may provided some advantage in the first or the second growing season compared to bareroot seedlings. Greater GLD growth of EKOgrown® seedlings on the Wozencraft site over both growing seasons may also indicate this advantage of increasing pot size. Williams and Stroupe (2002) found greater growth in oak species in conventional containers seedlings when compared to bareroot seedlings. Similar results were reported by Williams and Craft (1998) who found conventional containerized had increased height growth and survival when compared to bareroot Nuttall oak seedlings. In a Canadian study, Wilson et al. (2007) reported greater height growth in northern red oak (*Q. rubra* L.) conventional containerized seedlings as compared to bareroot. These studies (Williams and Craft 1998, Williams and Stroupe 2002, and Wilson et al. 2007) concluded that containers allowed seedlings to overcome harsh conditions that caused reduced performance in bareroot seedlings. Alkire (2011) reported superior growth and survival in large potted seedlings of two oak species after one growing season. Other studies have also reported that containerized seedlings may have an advantage when compared to bareroot seedlings (Allen et al. 2004 and Humphrey et al. 1993).

Survival declined at a greater rate for seedlings on the Wozencraft site (approximately 3-13 percent) than the O’Neal site (approximately 1-4 percent) for the same planting stock. This variation in survival is likely due to the more competitive vegetation present on the Wozencraft compared to that at the O’Neal site.

Interaction of species and site

GLD growth variation by species and site interaction

Analysis of variance revealed that significant interactions between species and site were present as indicated by variation in average GLD growth during the second growing season ($F = 10.42$, $p = 0.0013$), and overall ($F = 19.07$, $p < 0.0001$), but not during the first growing season ($F = 0.31$, $p = 0.5497$) (Table 4.1). MCP analysis was then used to determine which interactions were significant.

First Growing Season – Average GLD growth was observed to be greatest for Nuttall oak seedlings on the O'Neal site (3.52mm) when all planting stocks were considered (Table 4.23). GLD growth of Nuttall oak seedlings on the Wozencraft site and Shumard oak seedlings on the O'Neal site was not significantly different (2.73mm and 2.34mm, respectively), but was significantly greater than that of Shumard oak seedlings on the Wozencraft GLD growth (1.71mm).

Second Growing Season – Average GLD growth was significantly greater for Nuttall oak seedlings on the O'Neal site (3.29mm) than Shumard oak seedlings on the O'Neal site (2.14mm) when all planting stocks were considered. Nuttall and Shumard oak seedling GLD growth on the Wozencraft site (0.52mm and 0.57mm, respectively) was significantly lower than both species on the O'Neal site.

Overall – Average GLD growth was greatest for Nuttall oak seedlings on the O'Neal site (6.83mm) followed by Shumard oak seedlings on the O'Neal (4.53mm) when all planting stocks were considered. Nuttall oak seedlings on the Wozencraft site (3.29mm) exhibited significantly greater GLD growth than Shumard oak seedlings on the

Wozencraft site (2.34mm). Both species on the O'Neal site exhibited greater GLD growth than either species on the Wozencraft site.

Table 4.23 Average groundline diameter by species, site, growing season and overall. (All planting stocks).

	Growing Season		
Species/Site	2015	2016	Overall
	Millimeters		
Nuttall oak O'Neal	3.52c*	3.29c	6.83d
Nuttall oak Wozencraft	2.73b	0.52a	3.29b
Shumard oak O'Neal	2.34b	2.14b	4.53c
Shumard oak Wozencraft	1.69a	0.57a	2.34a

*Values in a column followed by the same letter are not significantly different (α=0.05)

Height growth variation by species and site interaction

Analysis of variance revealed that significant interactions between species and site were present as indicated by variation in average height growth during the second growing season ($F = 24.65$, $p < 0.0001$), and overall ($F = 26.16$, $p < 0.0001$), but not during the first growing season ($F = 0.12$, $p = 0.5482$) when all planting stocks were considered (Table 4.2). MCP analysis was then used to determine which interactions were significant.

First Growing Season – Average height growth was not observably different on the O'Neal site for Nuttall oak and Shumard oak seedlings (4.3cm and 5.2cm respectively); however, it was greater than both species on the Wozencraft site (Table 4.24). Height growth of Nuttall oak and Shumard oak seedlings was not detected to be significantly different on the Wozencraft site as well (1.2cm and 2.4cm, respectively). However, growth on the O'Neal site (both species) was significantly greater than that on the Wozencraft site (both species).

Second Growing Season – Average height growth was significantly greater for Nuttall oak seedlings (26.2cm) compared to Shumard oak seedlings (14.7cm) on the O'Neal site. Height growth of Nuttall oak seedlings (-1.4cm) and Shumard oak seedlings (-3.0cm) on the Wozencraft site was significantly lower than that of seedlings on the O'Neal site but not different from one another.

Overall – Average height growth was significantly greater for Nuttall oak seedlings (30.6cm) compared to Shumard oak seedlings (19.8cm) on the O'Neal site. Height growth of Nuttall oak seedlings (-0.2cm) and Shumard oak seedlings (-0.4cm) on the Wozencraft site was significantly lower than that on the O'Neal site but were not different from one another.

Table 4.24 Average height growth by species, site, growing season and overall. (All planting stocks).

Species/Site	Growing Season 2015	Growing Season 2016	Growing Season Overall
	Centimeters		
Nuttall oak O'Neal	4.3b*	26.2c	30.6c
Nuttall oak Wozencraft	1.2a	-1.4a	-0.2a
Shumard oak O'Neal	5.2b	14.7b	19.8b
Shumard oak Wozencraft	2.4a	-3.0a	-0.4a

*Values in a column followed by the same letter are not significantly different (α=0.05)

Survival variation by species and site interaction

Analysis of variance revealed no significant interactions between species and site as indicated by lack of variation in survival during the first growing season (F = 0.12, p = 0.7260), or the second growing season (F = 0.12, p = 0.7263) (Table 4.3).

First Growing Season – Survival was greatest for Nuttall oak seedlings on the O'Neal site (93.0 percent) followed closely by Nuttall oak seedling survival on the

Wozencraft site (89.4 percent) when all planting stocks were considered (Table 4.25) Nuttall oak survival was greater than Shumard oak survival on both sites. Shumard oak survival on the O'Neal and Wozencraft sites was not obervably different (80.6 percent and 77.7 percent, respectively).

Second Growing Season – Survival of Nuttall oak seedlings on the O'Neal site (91.3 percent) was greater than all other species and site comparisons. Nuttall oak seedlings on the Wozencraft site (84.4 percent) exhibited greater survival compared to Shumard oak seedlings on the O'Neal site (76.2 percent) or Shumard oak seedlings on the Wozencraft site (68.6 percent).

Table 4.25 Survival at the end of each growing season by species and site. (All planting stocks).

	Growing Season	
Species/Site	2015	2016
	Percent	
Nuttall oak O'Neal	93.0d*	91.3d
Nuttall oak Wozencraft	89.4c	84.4c
Shumard oak O'Neal	80.6b	76.2b
Shumard oak Wozencraft	77.7a	68.6a

*Values in a column followed by the same letter are not significantly different (α=0.05)

Interaction of species and site discussion

Nuttall oak is characterized as having more rapid initial growth and being able to withstand similar competition better than Shumard oak (Burns and Honkala 1990, and Clatterbuck and Meadows 1992. The competing vegetation on the O'Neal site, being comprised of forbs and shrubs, is believed to have affected growth and survival of seedlings less negatively than the vegetative competition on the Wozencraft site. These factors are likely the reason that Nuttall oak seedlings exhibited greater growth and survival compared to Shumard oak seedlings on the same site. They can also be considered largely responsible for the greater growth and survival of seedlings on the O'Neal site compared to those on the Wozencraft site of the same species.

Interaction of species, planting stock, and site

GLD growth variation by species, planting stock, and site interaction

Analysis of variance revealed that significant interactions between species, planting stock, and site were present as indicated by variation in average GLD growth during the first growing season (F = 8.61, p = 0.0002), second growing season (F = 5.91, p = 0.0026), and overall (F = 4.80, p = 0.0083) (Table 4.1). MCP analysis was then used to determine which interactions were significant.

<u>First Growing Season</u> – Nuttall oak EKOgrown® seedlings on the O'Neal site (4.74mm) and Wozencraft site (4.45mm) exhibited significantly greater GLD growth compared to all other treatments on both sites (Table 4.26). Shumard oak EKOgrown® seedlings on the Oneal site (3.84mm) had significantly greater GLD growth compared to Shumard oak EKOgrown® seedlings on the Wozencraft site (2.48mm), but not Nuttall oak EKOgrown® seedlings on the Wozencraft site. GLD growth of Nuttall oak bareroot seedlings on the Oneal site (2.95mm) and conventional containerized seedlings on the Oneal and Wozencraft site (2.85mm and 2.17mm, respectively) were not detected to be significantly different from each other but were significantly greater than that of bareroot seedlings on the Wozencraft site of the same species (1.57mm). Shumard oak bareroot and conventional containerized seedlings on the O'Neal site (1.36mm and 1.81mm respectively) and Wozencraft site (1.14mm and 1.45mm, respectively) did not exhibit significantly different GLD growth.

<u>Second Growing Season</u> – Average GLD growth of Nuttall and Shumard oak bareroot seedlings (4.41mm and 3.23mm, respectively) and conventional containerized seedlings (3.87mm and 3.40mm, respectively) at the O'Neal site were significantly greater than Nuttall oak and Shumard oak EKOgrown® seedlings on the O'Neal site (1.58mm and -0.21mm, respectively) and all treatments on the Wozencraft site. GLD growth was not detected to be significantly different on the Wozencraft site for Nuttall and Shumard oak bareroot seedlings (0.72mm and 0.74mm, respectively), conventional containerized seedlings (0.79mm and -0.09mm, respectively), and EKOgrown® seedlings (0.06mm and 1.06mm, respectively).

<u>Overall</u> – Nuttall oak bareroot seedlings on the O'Neal site exhibited greater GLD growth (7.38mm) than all other treatments on both sites excluding conventional containerized and EKOgrown® Nuttall seedlings on the same site (6.73mm, and 6.38, respectively). GLD growth of Nuttall oak conventional containerized and EKOgrown® seedlings on the O'Neal site did not differ from Shumard oak conventional containerized seedlings on the O'Neal site (5.33mm), but were greater than GLD growth of Shumard oak bareroot and EKOgrown® seedlings on the O'Neal site (4.60mm and 3.65mm, respectively). Nuttall and Shumard oak EKOgrown® seedlings on the Wozencraft site (4.54mm and 3.58mm, respectively) did not exhibit different GLD growth. Bareroot and conventional containerized Nuttall oak seedlings on the Wozencraft site (2.32mm and 3.01mm, respectively) and bareroot and conventional containerized Shumard oak seedlings on the Wozencraft site (1.92mm and 1.52mm, respectively) had the lowest GLD growth.

Table 4.26 Average groundline diameter by species, planting stock, and site per growing season and overall.

Species	Planting Stock/Site	Growing Season 2015	2016	Overall
		Millimeters		
Nuttall oak	Bareroot O'Neal	2.95e*	4.41d	7.38f
Nuttall oak	Bareroot Wozencraft	1.57ab	0.72abc	2.32a
Nuttall oak	Conventional Containerized O'Neal	2.85de	3.87d	6.73ef
Nuttall oak	Conventional Containerized Wozencraft	2.17bcde	0.79abc	3.01ab
Nuttall oak	EKOgrown® O'Neal	4.76g	1.58c	6.38ef
Nuttall oak	EKOgrown® Wozencraft	4.45fg	0.06ab	4.54cd
Shumard oak	Bareroot O'Neal	1.36ab	3.23d	4.60cd
Shumard oak	Bareroot Wozencraft	1.14a	0.74abc	1.92a
Shumard oak	Conventional Containerized O'Neal	1.81abcd	3.40d	5.33de
Shumard oak	Conventional Containerized Wozencraft	1.45acd	-0.09ab	1.52a
Shumard oak	EKOgrown® O'Neal	3.84f	-0.21a	3.65bc
Shumard oak	EKOgrown® Wozencraft	2.48cde	1.06bc	3.58bc

*Values in a column followed by the same letter are not significantly different (α=0.05)

Height growth variation by species, planting stock, and site interaction

Analysis of variation revealed that significant interaction between species, planting stock, and site were present as indicated by variation in height growth during the second growing season (F = 10.30, p < 0.0001), and overall (F 10.34, p < 0.0001), but not during the first growing season (F = 0.40, p = 0.6995) (Table 4.2). MCP analysis was then used to determine which interactions were significant.

First Growing Season – Height growth was not detected to be significantly different for Shumard oak EKOgrown® seedlings on the O'Neal and Wozencraft sites (14.0cm and 10.7cm, respectively) (Table 4.27). Nuttall oak EKOgrown® seedlings on the O'Neal site (7.9cm) did not exhibit significantly different height growth from Shumard oak or Nuttall oak (5.4cm) EKOgrown® seedlings on the Wozencraft site.

Nuttall and Shumard oak bareroot seedlings on the O’Neal site (4.3cm and 3.9cm, respectively), and Nuttall and Shumard oak bareroot seedlings on the Wozencraft site (1.9cm and 2.1cm, respectively) did not differ in height growth. Nuttall and Shumard conventional containerized seedlings on the O’Neal site (0.8cm and -2.2cm, respectively) did not have significantly different height growth detected. Nuttall and Shumard oak conventional containerized seedlings on the Wozencraft site (-3.7cm and -5.5cm, respectively) did not have significant difference detected, but exhibited lower height growth compared to all other treatments on both sites excluding Shumard oak conventional containerized seedlings on the O’Neal site.

Second Growing Season – Height growth for Nuttall oak bareroot seedlings on the O’Neal site (36.5cm) was not detected to be significantly different from Nuttall or Shumard oak conventional containerized seedlings on the O’Neal site (41.8cm and 28.4cm, respectively). Both species of conventional containerized seedlings on the O’Neal site were significantly different from each other and all other treatments on both sites, excluding Nuttall oak bareroot seedlings. Shumard oak bareroot seedlings on the O’Neal site (14.3cm) and Nuttall oak conventional containerized seedlings on the Wozencraft site (9.6cm) did not exhibit significantly different height growth from each other, but did for all other treatments on both sites. Shumard oak EKOgrown® seedlings on the O’Neal and Wozencraft sites (1.3cm and 0.1cm, respectively), Nuttall oak EKOgrown® seedlings on the O’Neal and Wozencraft sites (0.3cm and -4.2cm, respectively), and Shumard oak conventional containerized seedlings on the Wozencraft site (0.9cm) did not exhibit significantly different height growth from each other. Nuttall and Shumard oak bareroot seedlings on the Wozencraft site (-9.5cm and -10.0cm, respectively) did not differ in height growth from each other, or Nuttall oak bareroot seedlings on the Wozencraft site, but were significantly lower than all other treatments on both sites.

Overall – Height growth of Nuttall oak conventional containerized and bareroot seedlings on the O'Neal site (42.7cm and 40.8cm, respectively) was significantly greater than all other treatments on both sites. Shumard oak conventional containerized, bareroot, and EKOgrown® seedlings on the O'Neal site (26.2cm, 18.2cm, and 15.1cm respectively) did not exhibit significantly different height growth from each other. Shumard oak EKOgrown® seedlings on the Wozencraft site (10.9cm) and Nuttall oak EKOgrown® seedlings on the O'Neal site (8.3cm) did not exhibit significantly different height growth from each other. Height growth of Nuttall oak conventional containerized and EKOgrown® seedlings on the Wozencraft site (5.7cm and 1.3cm, respectively) was not significantly different. Nuttall and Shumard oak bareroot seedlings on the Wozencraft site (-7.5cm and -7.8cm, respectively) exhibited significantly lower height growth than all other treatments on both sites, except Shumard oak conventional containerized on the Wozencraft site (-4.2cm).

Table 4.27 Average height growth by species, planting stock, and site per growing season and overall.

Species	Planting Stock/Site	Growing Season 2015	Growing Season 2016	Growing Season Overall
		Centimeters		
Nuttall oak	Bareroot O'Neal	4.3cd*	36.5de	40.8f
Nuttall oak	Bareroot Wozencraft	1.9c	-9.5a	-7.5a
Nuttall oak	Conventional Containerized O'Neal	0.8bc	41.8e	42.7f
Nuttall oak	Conventional Containerized Wozencraft	-3.7a	9.6c	5.7bc
Nuttall oak	EKOgrown® O'Neal	7.9ef	0.3b	8.3cd
Nuttall oak	EKOgrown® Wozencraft	5.4de	-4.2ab	1.3bc
Shumard oak	Bareroot O'Neal	3.9cd	14.3c	18.2e
Shumard oak	Bareroot Wozencraft	2.1cd	-10.0a	-7.8a
Shumard oak	Conventional Containerized O'Neal	-2.2ab	28.4d	26.2e
Shumard oak	Conventional Containerized Wozencraft	-5.5a	0.9b	-4.2ab
Shumard oak	EKOgrown® O'Neal	14.0g	1.3b	15.1de
Shumard oak	EKOgrown® Wozencraft	10.7fg	0.1b	10.9cd

*Values in a column followed by the same letter are not significantly different (α=0.05)

Survival variation by species, planting stock, and site interaction

Analysis of variation revealed that significant interaction between species, planting stock, and site were present as indicated by variation in survival during the second growing season (F = 4.09, p = 0.0168), but not during the first growing season (F = 0.12, p = 0.8845) (Table 4.3). MCP analysis was then used to determine which interactions were significant.

First Growing Season – Survival was not significantly different for Nuttall oak bareroot on the O'Neal and Wozencraft site (99.7 percent and 98.7 percent, respectively), Nuttall oak EKOgrown® seedlings on the O'Neal and Wozencraft sites (100.0 percent and 99.3 percent, respectively), Shumard oak bareroot seedlings on the O'Neal site (96.3 percent and 95.3 percent, respectively), or Shumard oak and EKOgrown® seedlings on the O’Neal and Wozencraft site (99.7 percent and 99.0 percent, respectively) (Table 4.28). Nuttall oak conventional containerized seedling survial on the O’Neal site (79.3 percent) was significantly lower than Nuttall oak and Shumard oak bareroot and EKOgrown® seedlings on both sites. Nuttall oak conventional containerized seedling survival on the Wozencraft site (70.3 percent) was significantly lower than the same species-planting stock combination on the O’Neal site. Shumard oak conventional containerized seedling survival on each site was significantly lower than all other species-planting stock-site combinations.

Second Growing Season – Survival of Nuttall oak bareroot seedlings on the O’Neal and Wozencraft sites (98.0 percent and 90.7 percent, respectively), Nuttall oak EKOgrown® seedlings on the O’Neal and Wozencraft sites (98.7 percent and 97.7 percent, respectively), Shumard oak bareroot seedlings on the O’Neal site (91.0 percent), and Shumard oak EKOgrown® seedlings on the O’Neal and Wozencraft site (98.7 percent and 95.3 percent, respectively) were significantly greater than all other treatments on both sites. Nuttall oak conventional containerized seedlings on the O’Neal site and Shumard oak bareroot seedlings on the Wozencraft site (77.3 percent and 76.0 percent, respectively) were not detected to be significantly different from each other but were significantly greater than Nuttall oak conventional containerized seedlings on the Wozencraft site (65.0 percent). There was no significant difference observed between Shumard oak conventional containerized seedlings on the O’Neal and Wozencraft site (39.0 percent and 34.3 percent, respectively), but they were significantly lower than all other treatments on both sites.

Table 4.28 Survival by growing season, species, planting stock, and site.

Species	Planting Stock/Site	— Growing Season — 2015	2016
		— Percent —	
Nuttall oak	Bareroot O'Neal	99.7d*	98.0d
Nuttall oak	Bareroot Wozencraft	98.7d	90.7d
Nuttall oak	Conventional Containerized O'Neal	79.3c	77.3c
Nuttall oak	Conventional Containerized Wozencraft	70.3b	65.0b
Nuttall oak	EKOgrown® O'Neal	100.0d	98.7d
Nuttall oak	EKOgrown® Wozencraft	99.3d	97.7d
Shumard oak	Bareroot O'Neal	96.3d	91.0d
Shumard oak	Bareroot Wozencraft	95.3d	76.0c
Shumard oak	Conventional Containerized O'Neal	45.7a	39.0a
Shumard oak	Conventional Containerized Wozencraft	38.7a	34.3a
Shumard oak	EKOgrown® O'Neal	99.7d	98.7d
Shumard oak	EKOgrown® Wozencraft	99.0d	95.3d

*Values in a column followed by the same letter are not significantly different (α=0.05)

Interaction of species, planting stock, and site discussion

Variation found in GLD and height growth when comparing treatments can likely be attributed to the establishment of sufficient root systems during the first growing season, receiving HWC, and a difference in the competitive potential of vegetation. These factors generally allowed Nuttall oak seedlings, bareroot and conventional containerized seedlings to have greater growth.

Freeze damage incurred in the nursery is likely responsible for the poor height growth of conventional containerized in the first growing season. Conventional containerized Shumard oak seedlings had lower growth and survival compared to Nuttall oak seedlings on both sites when both growing seasons were considered. Similarly, conventional containerized seedlings of both species on the Wozencraft site exhibited lower growth and survival compared to the same seedlings on the O'Neal site when both growing season were considered. This lower growth and survival may demonstrate that more competitive vegetation or a lower ability to withstand competition may lower the ability of seedlings to overcome freeze damage over time.

EKOgrown® seedlings' larger root surface may have benefited these seedlings during the first growing season. However, without HWC, this advantage was not observed during the second growing season, or overall, when comparing similar species on the O'Neal site.

When both growing seasons are considered, bareroot Nuttall and Shumard oak seedlings on the Wozencraft site exhibited similar GLD growth to conventional containerized seedlings, but significantly less than EKOgrown® seedlings. The same pattern was present in height growth for bareroot Shumard oak seedlings on the Wozencraft site. Height growth of Nuttall oak bareroot seedlings on the Wozencraft site was significantly lower than conventional containerized and EKOgrown® seedlings of the same species, with the latter two not being detected as significantly different. Considering all of these relationships provides evidence that on sites with highly competitive vegetation (grass on Wozencraft) and/or when dealing with species less able to withstand competition (Shumard oak), increasing pot size (conventional containerized and EKOgrown® seedlings) may mitigate effects of competition in the short term. These results are consistent with studies that have reported increased pot size may mitigate some negative environmental effects such as competition (Alkire 2011, Allen et al. 2004, Humphrey et al. 1993, Williams and Craft 1998, Williams and Stroupe 2002, and Wilson et al. 2007).

Lower survival of conventional containerized seedlings can potentially be explained by freeze damage. Lower survival for Shumard oak may be attributed to it being less able to withstand competition when compared to Nuttall oak. Seedlings on the Wozencraft site grew with more aggressive competition and may be used to explain the lower survival of those seedlings. Seedlings on the Wozencraft site exhibited a decrease in survival between the first and second growing season which may be attributed to the advantage provided by containers in the first or second growing season.

Stem contraction has been reported in many species by a number of studies, Deslauriers et al. (2007), Devine and Harrington (2011), and Zweifel et al. (2005). Collectively these studies have concluded that stem contraction can be caused by soil water availability, vapor pressure deficit, and transpiration including other factors. These reports may explain the negative GLD growth reported during the second growing season for Shumard oak conventional containerized seedlings on the Wozencraft site and EKOgrown® seedlings on the O’Neal site.

Photosynthesis Measurements

Photosynthetic rate versus growth data

Average seasonal photosynthetic rate had a relatively weak relationship with GLD growth (R^2 = 0.2160) and the slope (p = 0.1279) that was not significantly different from zero (Figure 4.1). The strength of the relationship increased and slope became significant when examining GLD growth in the second growing season (R^2 = 0.3463 and p = 0.0441) versus first year average photosynthetic rate (Figure 4.2), and overall GLD growth (R^2 = 0.6433 and p = 0.0017) (Figure 4.3). When comparing GLD growth during the first growing season to GLD growth during the second growing season, no relationship was found ($R^2 = 0.0136$) and the slope ($p = 0.7177$) was not significantly different from zero (Figure 4.4).

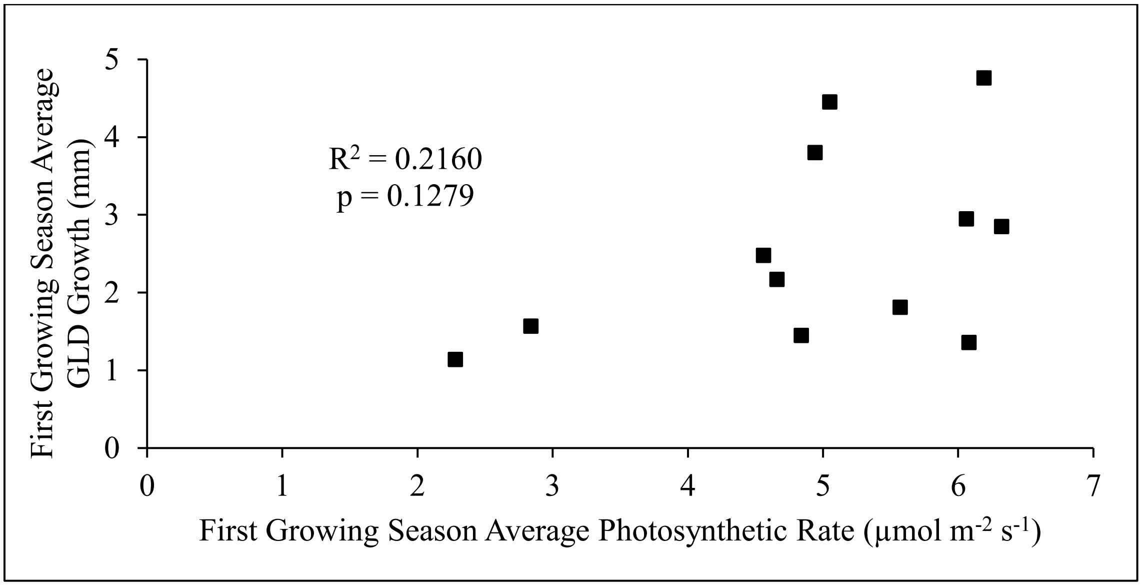

Figure 4.1 Average photosynthetic rate during the first growing season versus average GLD growth during the first growing season (All species, planting stocks, and sites).

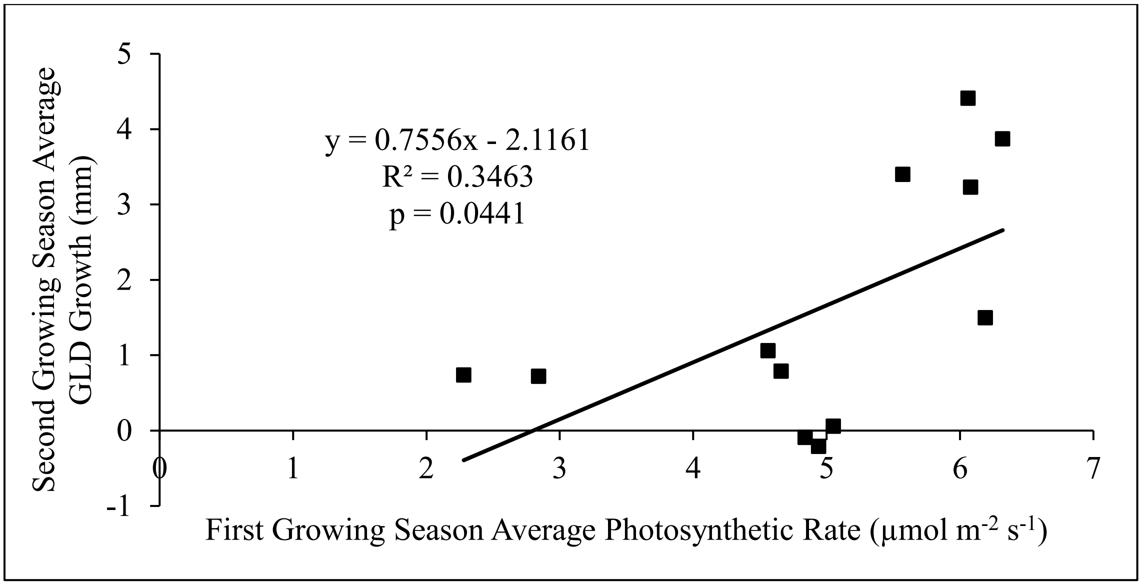

Figure 4.2 Average photosynthetic rate during the first growing season versus average GLD growth during the second growing season (All species, planting stocks, and sites).

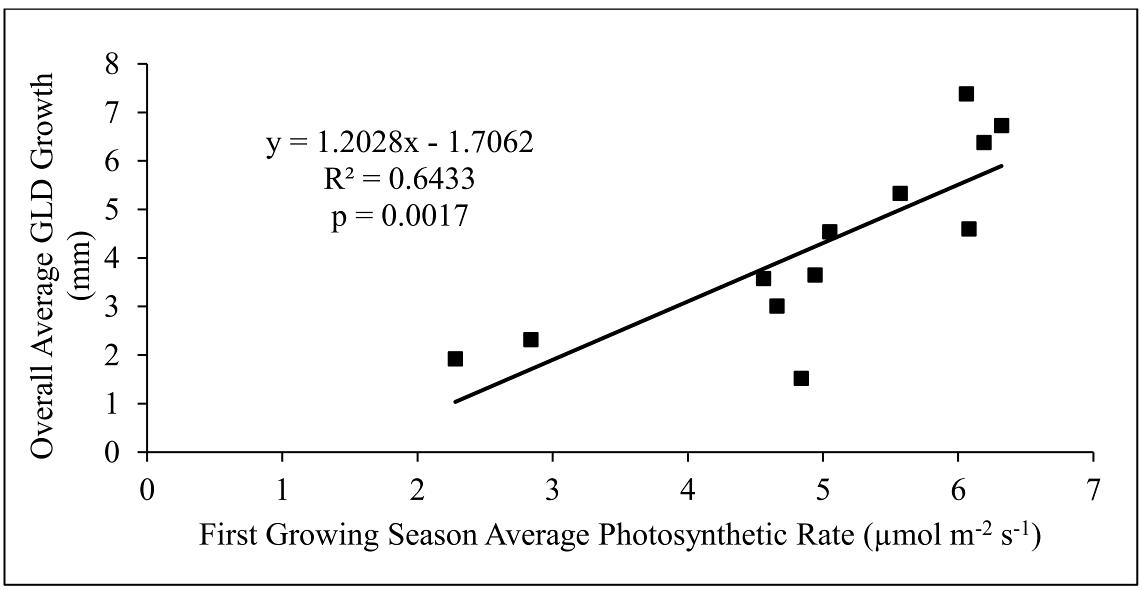

Figure 4.3 Average photosynthetic rate during the first growing season versus average overall GLD growth (All species, planting stocks, and sites).

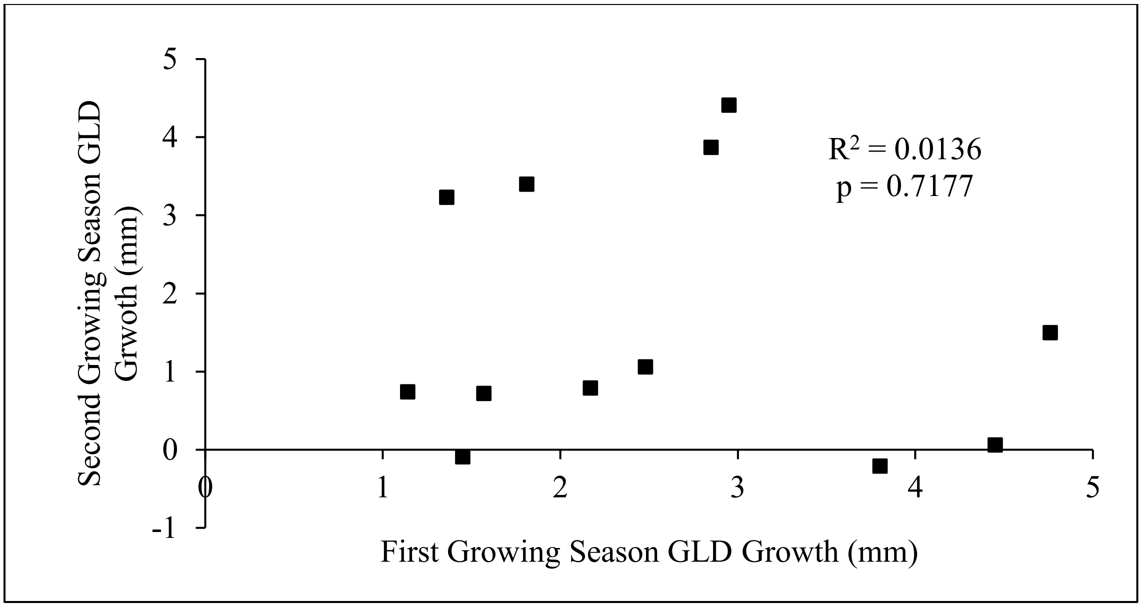

Figure 4.4 Average GLD growth during the first growing season versus average GLD growth during the second growing season (All species, planting stocks, and sites).

When comparing average photosynthetic rate to average height growth, a similar pattern was found. Average seasonal photosynthetic rate compared to height growth during the first growing season showed no relationship ($R^2 = 0.0075$) with a slope not statistically different from zero ($p = 0.7888$) (Figure 4.5). However, the relationship increased and slopes were significant for the second growing season height growth ($R^2 = 0.4995$ and $p = 0.0102$) compared with year one photosynthetic rate (Figure 4.6) and overall height growth data ($R^2 = 0.5676$ and $p = 0.0047$) (Figure 4.7). When comparing average height growth during the first growing season to height growth during the second growing season, no relationship was present ($R^2 = 0.0542$), and slope ($p = 0.4665$) was not significantly different from zero (Figure 4.8).

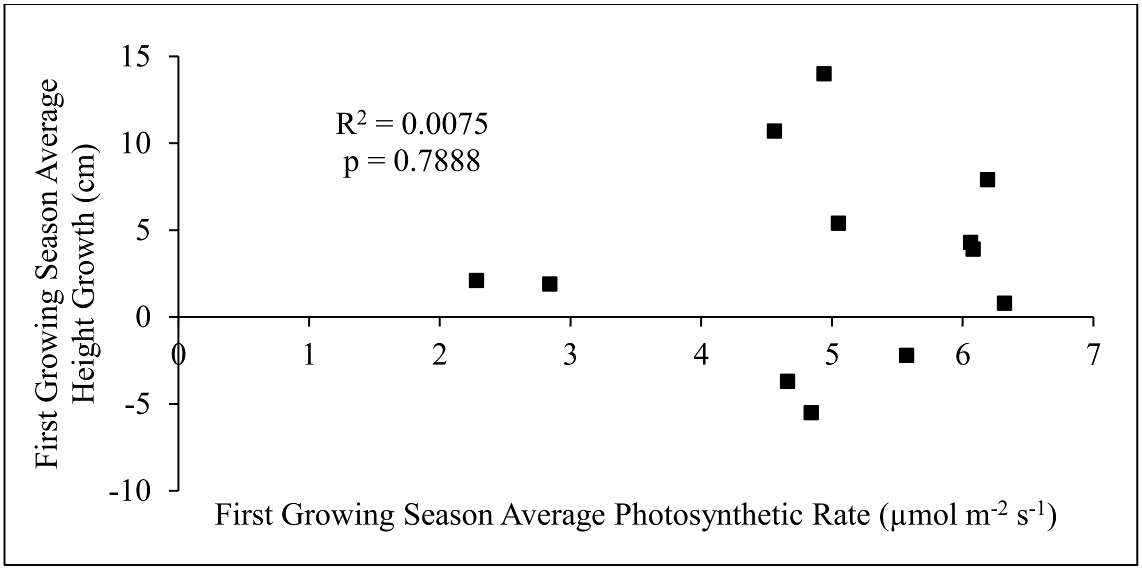

Figure 4.5 Average photosynthetic rate during the first growing season versus average height growth during the first growing season (All species, planting stocks, and sites).

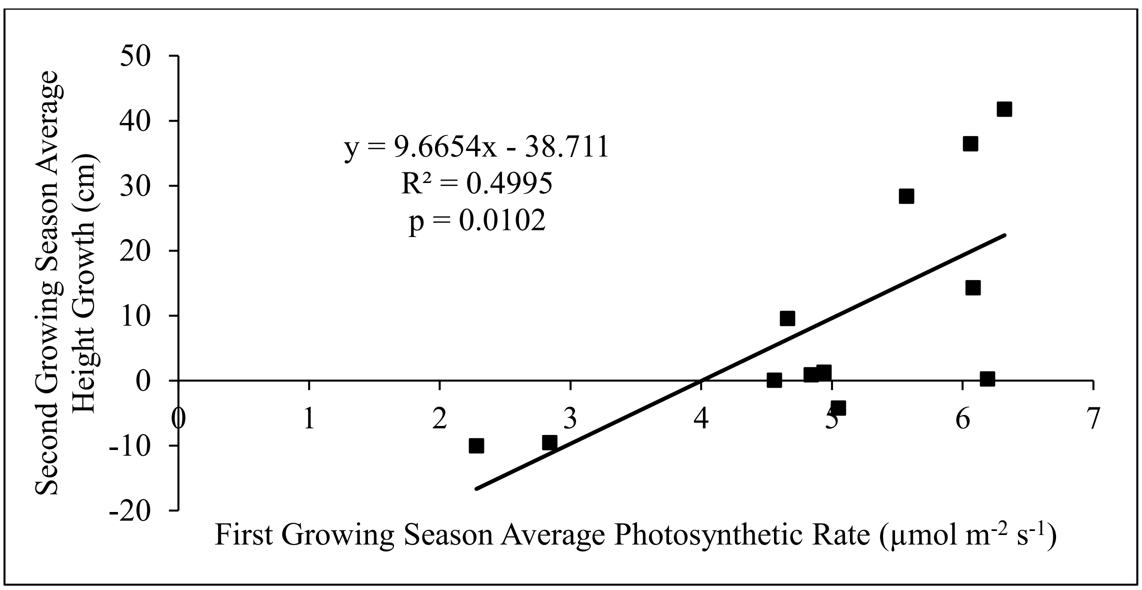

Figure 4.6 Average photosynthetic rate during the first growing season versus average height growth during the second growing season (All species, planting stocks, and sites).

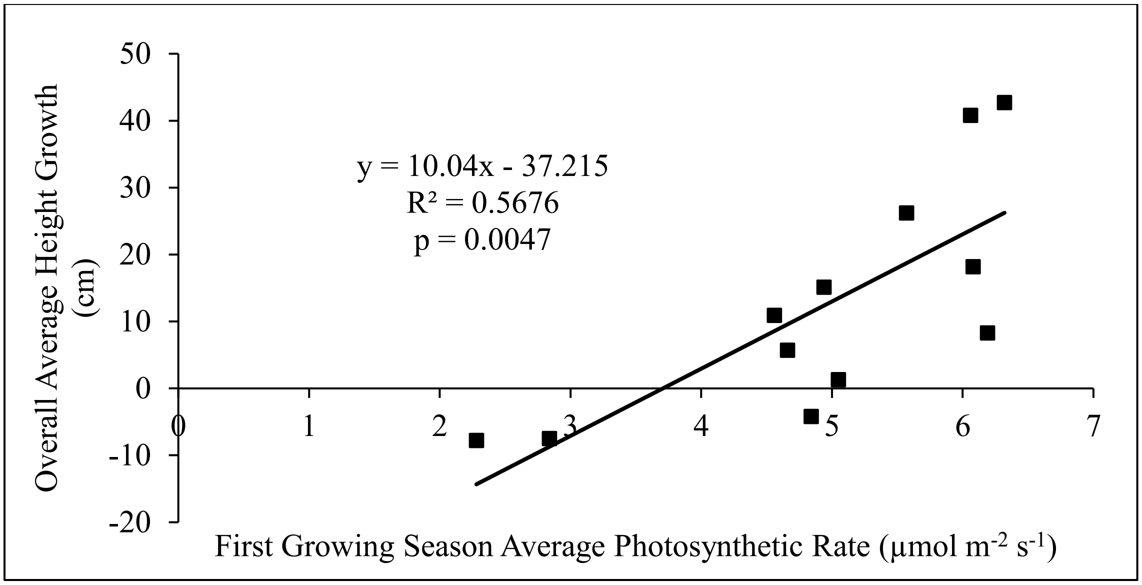

Figure 4.7 Average photosynthetic rate during the first growing season versus average overall height growth (All species, planting stocks, and sites).

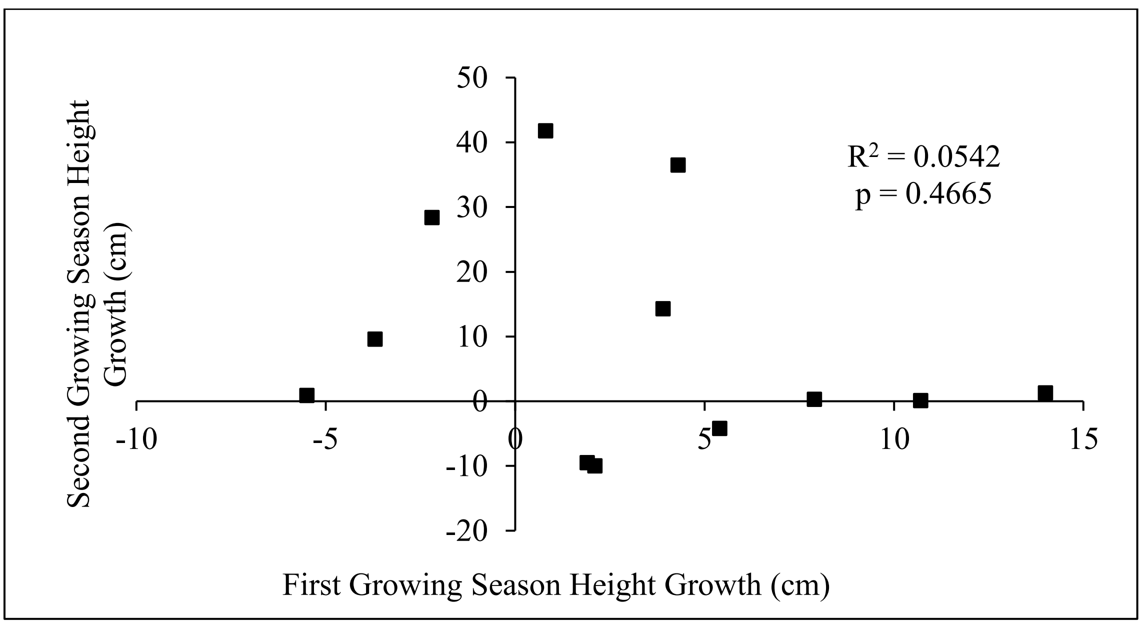

Figure 4.8 Average height growth during the first growing season versus average height growth during the second growing season (All species, planting stocks, and sites).

Photosynthetic rate versus growth data discussion

Relationships reported in this study indicate that photosynthetic rates may be a poor indicator of height and GLD growth during the first growing season. Dougherty et al. (1979), when conducting a study on mature white oak (*Q. alba*), reported resources were first allocated to root growth, then cambial stem growth, then leaf, flower, and branch growth. This pattern of resource allocation would explain the weak relationship between first growing season photosynthetic rate and first growing season growth parameters monitored during this study if allocation of resources to root development was emphasized over shoot growth. Other studies have indicated that there is a positive relationship between root and GLD growth. Dey and Parker (1997), when investigating underplanted red oak in Canada, reported second year stem diameter was highly correlated with root characteristics. GLD was found to be the best indicator of sapling structural root size in a study conducted by Guan and Cheng (2001) when investigating Taiwan yellow false cypress (*Chamaecyparis obtuse* Sieb & Zucc. var. *formosana* Rehder). Therefore a stronger, although still insignificant, relationship between first growing season photosynthetic rate and first growing season GLD growth when compared to first growing season height may be expected.

First growing season photosynthetic rate was a good predictor of GLD and height growth during the second growing season and overall. For both GLD and height growth, the relationship between photosynthetic rate and growth was strongest when both growing seasons were considered. This study found that photosynthetic rate during the first growing season is better than using growth during the first growing season to predict growth during second growing season. Recent studies on artificial oak regeneration by

Conrad (2013), Dowdy (2015), and Reeves (2016) have indicated that limited growth of some planting stocks can be explained by the previously mentioned allocation of resources to root development over shoot growth during the first growing season. These findings were supported by increases in growth during the second growing season compared to the first, indicating a sufficient root system had developed. The relationship observed in this study between seasonal photosynthetic rate during the first growing season and growth during the second growing season support these previous findings. However, further investigation would be needed into other factors affecting second year growth.

CHAPTER V

CONCLUSIONS

In this study, bareroot seedlings exhibited acceptable growth and survival and can be considered an economically viable option for artificial oak regeneration. EKOgrown® seedlings, while also displaying acceptable growth and survival, will be cost prohibitive for most landowners and not an economically efficient source of regeneration.

Unforeseeable factors, such as damage incurred in the nursery, have the potential to reduce survival of planting stock to a level which is unacceptable. However, surviving seedlings may have the ability to overcome early damage if HWC is applied.

Nuttall oak demonstrated greater growth and survival than Shumard oak and may be a better candidate for use in artificial oak regeneration. Variations in species and growth habit of competing vegetation can greatly influence the effect those competitors will have on oak regeneration. Both of these considerations should be involved in the planning of operational plantings.

Larger containers may have a positive influence on growth and survival in areas with highly competitive vegetation, or if the planted species is very susceptible to competition. However, without applying HWC, benefits of larger pots may be limited or diminished over time.

In very specific instances, conventional containerized or EKOgrown® seedlings may provide slight advantages in growth and survival. However, in the majority of situations, bareroot seedlings should provide equal or superior performance and will be found as the most cost effective solution for artificial oak regeneration.

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