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Comparing survival and growth among three different planting stocks of water oak (Quercus nigra) and white oak (Quercus alba) on lands damaged by Hurricane Katrina

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Comparing survival and growth among three different planting stocks of water oak (*Quercus nigra*) and white oak (*Quercus alba*) on lands damaged by Hurricane Katrina

By

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Comparing survival and growth among three different planting stocks of water oak

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Bareroot, conventional containerized, and large potted EKOgrown® seedlings of water oak (*Quercus nigra*) and white oak (*Q. alba*) were planted on two Hurricane Katrina damaged sites in south Mississippi. After two growing seasons, white oak exhibited greater survival (61.1%) than water oak (48.8%) and greater height growth (WHO = 7.4 cm, WAO = 1.4 cm). Water oak had greater groundline diameter (GLD) growth (3.3 mm) and greater second-year height growth (WHO = 2.5 cm, WAO = 9.6 cm). Second-year development could lead to greater height growth by water oak. Bareroot seedlings outperformed other planting stocks in survival and height growth, but EKO seedlings exhibited greater GLD growth. Even though EKO seedlings had greatest GLD growth, they exhibited the least overall height growth of all planting stocks (1.9 cm). Based on seedling cost and performance in this study, planting bareroot seedlings are the most efficient method to artificially regenerate oak forests.

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CHAPTER I

INTRODUCTION

Bottomland hardwood forests are highly productive systems, normally growing on some of the better soils in an area. Oaks are a major contributor to diversity of the forest, improvement of water quality, and carbon sequestration (Taylor et al. 1990). They also provide habitat for many different species of wildlife and are sources of timber and other wood products (Gardiner et al. 2000, Kennedy 1992).

Natural regeneration of oaks requires practices that provide sunlight to seedlings. Midstory and understory control followed by partial overstory harvest is normally required to allow sufficient sunlight to reach the forest floor and to reduce competition for oak seedlings (Ezell et al. 1999). The timing of these practices is critical to produce successful regeneration due to the seeding nature of oaks. Oaks are heavy-seeded species that do not produce a good seed crop every year. The seed crop must be monitored to determine optimal timing of the regeneration practices (Peairs et al. 2004). Although this is the most economically attractive practice, it requires extensive planning and critical timing on execution, both of which are often difficult for the average non-industrial private landowner (NIPL).

Artificial regeneration is an alternative for oaks. This can be supplemental planting in gaps, or planting an entire clearcut area after harvest, or a retired agricultural field. The different options for regenerating an oak stand include a variety of different planting stocks, numerous species to choose from, and different planting methods. It is necessary to match species with the appropriate site, high quality seedlings are required, appropriate planting practices must be utilized, competition control is often essential, and the importance of flooding or drought conditions must be recognized (Dey et al. 2007, Stanturf et al. 2004). Artificial regeneration can also be cost-prohibitive for the average NIPL, but it may be the only way to quickly regenerate or maintain the oak component of a forest (Dey et al. 2007).

Hurricane Katrina made landfall on the Gulf Coast on August 29, 2005, causing widespread damage to forty percent of Mississippi's forests (Oswalt et al. 2008). The most severely damaged areas were bottomland hardwood forests (Wang and Xu 2009). Oaks are a large component in these forests and Hurricane Katrina eliminated the seed source necessary to regenerate the heavy-seeded species in these areas. Since most of these lands are non-industrial private forests (NIPF), landowners may not have the funds to regenerate their oaks. Cost-share programs, such as the well known Wetland Reserve Program (WRP), exist within government agencies and non-profit organizations that can help landowners reforest their lands.

R.L. Johnson (1984) reported that large potted seedlings have the best chance for juvenile survival and growth because of the larger and more developed root system. They should have a greater leaf area, be more competitive against surrounding vegetation (Jacobs et al. 2005), and also be able to produce acorns much sooner than other planting stocks, but they are more expensive (Dey et al. 2006). In studies similar to this work, it was found that large potted seedlings did not express a clear advantage over the smaller, less expensive seedlings (Dowdy 2015, Conrad 2013). Some studies reported comparable or greater growth and greater survival by the smaller bareroot and conventional containerized seedlings (Conrad 2013, Dowdy 2015, Reeves 2016, Durbin 2018, Miles 2019). These more recent studies reported that the smaller, less expensive bareroot seedlings are the most cost-effective option for this area.

Objectives

This study is an effort to expand upon the knowledge base from previous artificial regeneration attempts on Hurricane Katrina-damaged lands. The objectives of this study are as follows:

I. Compare survival of three different planting stocks (bareroot, conventional containerized, and EKOgrown®) of water oak (*Quercus nigra*) and white oak (*Q. alba*).

II. Evaluate the average height and groundline diameter (GLD) growth of each species/planting stock combination.

III. Compare physiological parameters across species, planting stocks, sites, and months during the first growing season.

CHAPTER II

LITERATURE REVIEW

Impacts of Hurricane Katrina

Hurricane Katrina caused damage to an estimated 3.2 million hectares (ha) of Mississippi's forests, which is slightly more than 40% of the state's total forestland (Oswalt et al. 2008). Wang and Xu (2009) stated that bottomland hardwood forests were the most severely affected landscape. With so much of the forest damaged, people consider the options of converting to agriculture or replanting forests, especially oaks. People tend to favor oaks for planting because of their nutritional value to wildlife, timber value, and because light-seeded species typically re-seed these sites naturally (Ouchley et al. 2000, Schoenholtz et al. 2001). Also, these areas may require planting if desirable seed sources are lacking, especially those of heavy-seeded species (Schoenholtz et al. 2001).

Seedling Mortality

Successfully regenerating oak species can be a difficult task for private landowners. Many factors may contribute to seedling mortality according to Stanturf et al. (1998). These factors may include, but are not limited to: drought or flooding after planting, poor seedling quality, poor planting practices, overwhelming competition, herbicide drift, and not properly matching species to site. The first step of reforestation is knowing which species to plant on the site. Lockhart et al. (2003) stated that correctly matching species to site conditions was essential for establishment success. Every species has a niché in which it can best compete against other species. Familiarity with the site and an understanding of species characteristics such as light requirements and flood tolerance is important when determining which species to plant in an area (Hodges and Switzer 1997). Along with site selection, site preparation may be needed to reduce compaction on the site and to make the area more accessible to planters by clearing debris. Seedling quality is also an important factor in successful artificial hardwood regeneration (Mattson 1996, Dey and Parker 1997). A high quality oak seedling has been defined as a seedling that is 45-61 centimeters tall with a minimum of 6 first order lateral roots (FOLR) (Jacobs et al. 2005, Kennedy 1992). High quality seedlings are typically more competitive once planted and usually exhibit higher survival rates than those of lower quality.

Bareroot Seedlings

Bareroot seedlings are the most commonly used planting stock in artificial regeneration of oaks in the South (King and Keeland 1999). When using bareroot stock, high quality seedlings should be used. Performance of these seedlings is dependent on the level of competing vegetation as well as the amount of precipitation that occurs on the site during the early growing seasons. Best survival is observed if planting takes place while seedlings are dormant and the soil is moist (Stanturf et al. 1998). Bareroot seedlings are more sensitive to handling practices such as: lifting from the seed bed, storage, transport, and planting. If not taken care of properly, these things can negatively affect their performance (Grossnickle and El-Kassaby 2016).

Conventional Containerized Seedlings

Container stock seedlings have a growth advantage compared to bareroot seedlings due to decreased planting shock (Johnson, P.S. 1984). They also tend to exhibit greater leaf area, root elongation, and shoot growth (R.L. Johnson 1984, Grossnickle and El-Kassaby 2016, Humphrey 1993) and can be planted later in the planting season. The well-developed root system and shorter initial shoot increases a seedling's ability to withstand drought (Grossnickle and El-Kassaby 2016). As a result, the planting season can be extended, and containerized oaks may have higher survival rates on sites that are considered to be harsh. In a study by Williams and Craft (1998), seedlings of different planting stocks were planted at different times of the year and were flooded for roughly two months early in the growing season. At the end of the first growing season, containerized seedling survival nearly doubled that of bareroot and direct-seeded seedlings. Containerized seedlings also exhibited more growth. A trade-off for these benefits, though, is the increased expense of containerized seedlings and greater difficulty in transport (Stanturf et al. 1998).

Large Potted Seedlings

Large containerized (i.e. potted) seedlings are an option for planting oaks. These seedlings have the best chance for juvenile survival and growth due to a larger and more developed root system (Johnson, R.L. 1984). It should be noted that these seedlings are much more expensive than the smaller containerized or bareroot seedlings, but are expected to produce acorns much sooner. Subsequently, it is the landowner's choice as to whether he/she wishes to encumber the additional expense (Dey et al. 2006). Self et al. (2010) conducted a study on a retired row-crop field with different planting stocks. Flooding occurred on the site during the growing season. The study showed that the potted seedlings exhibited greater survival than bareroot and containerized stocks, likely due to the developed root system being able to support the seedlings during the flooded and later drought conditions.

McLeod (2000) reported that bareroot seedlings can perform just as well or better than larger and more expensive planting stocks. Oak survival can be further improved by planting bareroot seedlings that are larger and have higher quality (Thompson and Schultz 1995). This is evidenced in several studies that demonstrated that high-quality bareroot seedlings can outperform the more expensive planting stocks (Conrad 2013, Dowdy 2015, Reeves 2016, Durbin 2018).

Prioritization of Growth

Gardiner et al. (2010) stated that natural oak seedlings may appear inactive because there is such little shoot growth due to the seedling allocating resources to its roots instead of the shoot. They build their root system before favoring shoot growth (Gardiner et al. 2010). Canham et al. (1996) found that red oak seedlings exhibited 58-75% growth allocation to their root system in the first year. This characteristic gives large-potted seedlings an advantage over containerized and bareroot planting stocks due to a more developed root system.

Herbaceous Weed Control

Since oak seedlings are typically more expensive and take longer to grow than pine, it is essential to take the necessary steps to ensure acceptable survival rates (Ezell and Hodges 2002). Herbaceous weed control (HWC) is a critical step to ensure the survival of established seedlings. In old fields, oak reproduction can quickly become suppressed by competing vegetation, being subject to extremely low light levels in the first summer (Dey et al. 2007). If oak seedlings are overtopped by surrounding vegetation, mortality rates of the oak seedlings tend to be high (Lorimer 1993). Adequate weed control is needed for successful establishment of red oak plantations (Jacobs et al. 2005) because water and nutrients become more available (Dubois et al. 2000). Ezell et al. (2007) stated that a HWC application can result in 20-25% greater survival of seedlings during the first year of growth and 30-35% better during the second year. Many different chemicals are available for HWC applications. Factors such as time of year, vegetative composition, and crop species may determine which chemicals should be used. Sulfometuron methyl, the active ingredient in Oust XP, is a potent sulfonylurea herbicide commonly used for broadleaf control in forestry applications. This herbicide inhibits growth by blocking the activity of acetolactate synthase, which is vital in the building of branched-chain amino acids (Yadav et al. 1986). Oust XP can control many plants including pokeweed (*Phytolacca americana L.*), ragweed (*Ambrosia spp.*), goldenrod (*Solidago spp.*), honeysuckle (*Lonicera japonica*), and many herbaceous plants that are competitive towards oak seedlings (Michael 1985), but it tends to release broomsedge (*Andropogon spp.*) (Miller 1993, Ezell and Catchot 1998). Timing of application is important to ensure no damage occurs to non-target stems. In a study by

Ezell and Nelson (2001), they concluded that total safety of oaks occurs if sulfometuron methyl is applied prior to bud break of the seedlings. It can also be applied post-emergence but can cause mortality to white oak (*Quercus* alba) seedlings. Herbaceous weed control is an added expense to hardwood plantations, but it is worth the extra cost. Grebner et al. (2003) conducted a study using different competition control methods used in hardwood plantations, including mechanical and chemical practices. Mechanical practices were successful in obtaining desirable survival rates, but the use of herbicides-only yielded the best results to control competition and maximize returns.

White Oak

White oak is an important tree species across the eastern United States. It is a large, slow-growing, long-lived tree that often reaches 24 to 30 meters in height and 91 to 122 cm in diameter at breast height (DBH). It occurs from southwestern Maine, west to central Michigan, to southeastern Minnesota; south to eastern Texas; and east to northern Florida (Rogers 1990, Hodges et al. 2004). White oaks produce valuable lumber, such as staves for barrels, and its acorns provide valuable hard mast for wildlife. It grows well on most soils with a pH of 4.5-6.8 except for the driest and shallowest soils. On very sandy soils, mineral nutrition is a limiting factor on growth. It does grow well on shallow, dry ridges, poorly drained flats, or wet bottomlands. Its best growth occurs on moderately dry slopes with shallow soils (Rogers 1990, Hodges et al. 2004). It has intermediate shade tolerance and moderate drought tolerance (Hodges et al. 2004)

Water Oak

Water oak (*Quercus nigra*) is found along watercourses and lowlands on silty clay and loamy soils throughout the southeast along the Coastal Plain from southern New Jersey and Delaware south to southern Florida; west to eastern Texas; and north in the Mississippi Valley to southeastern Oklahoma, Arkansas, Missouri, and southwestern Tennessee (Vozzo 1990, Hodges et al. 2004). It appears on a wide variety of sites ranging from wet bottomlands to well-drained uplands (Schummer et al. 2011, Vozzo 1990, Hodges et al. 2004) with a soil pH range of 4.8-5.8 (Hodges 2004). It is a medium to large, shade intolerant canopy tree that normally reaches 27 meters at maturity and can grow to 9 meters in 20 years (Schummer et al. 2011, Hodges et al. 2004). Higher quality water oaks tend to occur on better-drained silty clay or loamy soils on high flats in alluvial stream bottoms. It can grow to 38 meters and can grow quickly on favorable sites. This shade intolerant species exhibits slow early growth, therefore it does not compete well with other species (Vozzo 1990).

Similar Studies

Seedling attributes such as height and diameter are used as response variables because they associate well with field success (Jacobs et al. 2005). Groundline diameter is the best indicator of several physical characteristics of seedling root systems (Dey and Parker 1997, Guan and Cheng 2003). This is likely an outcome of the adjustment of balancing the root-shoot ratios after planting. Seedlings with larger initial heights when planted will typically be able to compete better with surrounding vegetation compared to smaller seedlings (Jacobs et al. 2005). A study by Hollis et al. (2012) showed that large potted seedlings exhibited the most height growth compared to bareroot seedlings, which had the next greatest height growth, and conventional containerized seedlings. This supports the statement made by Jacobs et al. (2005). Some recent studies have produced differing results. Dowdy (2015) and Conrad (2013) found that large potted seedlings did not have a clear advantage over the smaller bareroot and containerized seedlings. Both studies observed that bareroot and conventional containerized seedlings can produce comparable growth and greater survival. Reeves (2016) reported that bareroot seedlings can even surpass large potted seedlings in growth and survival. Durbin (2018) observed survival of large potted seedlings to be unacceptable and best results were from bareroot seedlings after two years. Since large potted seedlings are exceedingly expensive, it is recommended that bareroot seedlings, along with herbaceous weed control, is likely the most feasible option for the larger scale operations typified by private landowners (Hollis et al. 2012, Dowdy 2015, Alkire 2011, Conrad 2013, Reeves 2016, Hall 2017, Durbin 2018, Miles 2019).

A/C_i Curves

A/C_i curves are an interpretation of net CO_2 assimilation rate (A) versus calculated substomatal CO_2 concentration (C_i). This is used to estimate leaf photosynthesis under a wide variety of experimental conditions (Manter and Kerrigan 2004). Durbin (2018) conducted measurements in the month of June of the first growing season to determine if there was a relationship from the parameters of A/C_i curves to height growth and survival of planted oak seedlings. No significant relationships were found, but the measurements were only taken once early in the growing season. Hall

(2017) found a weak relationship between photosynthetic rates and growth, meaning seedlings with higher photosynthetic rates exhibited higher growth rates. The weak relationship indicates that photosynthetic rates may be a poor indicator of growth during the first and second growing seasons, but further research may be needed to determine its worth in that regard.

CHAPTER III

MATERIALS AND METHODS

Site Description

This study was conducted on two privately owned tracts in southern Mississippi that were separated by 97 kilometers (km) latitudinally. Average annual rainfall for this area is 156.5 centimeters (cm), and average annual temperature is 18.9 ºC (U.S. Climate Data 2019).

The first and westernmost site was located in Pearl River County, Mississippi on land owned by Mr. Chris Reinike. This site was located approximately 5 km east of Hillsdale, Mississippi and 0.2 km northeast of Hillsdale-Gumpond Rd (Latitude 30º 55' 18.50" N Longitude 89º 26' 42.92" W). The research site consisted of 1.2 hectares (ha) of land with only one soil series: Ruston fine sandy loam (Web Soil Survey 2019), which is a well-drained soil. A slight 2-5% slope was present across the site, with the highest elevation located on the southwestern border. Previous cover was an assortment of grasses that were cut as hay prior to the planting of the research plots.

The second site was located in George County, MS on land owned by Mr. Dennis Baxter. The site was located approximately 9.7 km northeast of Agricola, Mississippi and 0.5 km south of Agricola-Latonia Rd (Latitude 30º 51' 30.41" N Longitude 88º 26' 11.29" W). The site also consisted of 1.2 ha of land with two soil series, Atmore fine sandy loam and Dorovan-Johnston association (Web Soil Survey 2019). Atmore fine sandy loam is poorly drained with a 0-2% slope and Dorovan-Johnston is very poorly drained, consisting of muck and sand in a 0-1% slope. This site was very prone to ponding water during the growing season. Previous cover is unknown and the site was burned prior to planting the research plots.

Experimental Design

A randomized complete block (RCB) design with three replications was used in this study. Each replication was separated into six treatments. A treatment was composed of 600 seedlings of a different species and planting stock combination. The six treatments were: 1) bareroot white oak, 2) conventional containerized white oak, 3) EKOgrown® white oak, 4) bareroot water oak, 5) conventional containerized water oak, 6) EKOgrown® water oak. Individual seedlings were the experimental unit from which all growth and survival measurements were recorded and analyzed.

Site Demarcation

Plots were laid out three weeks prior to planting by Mississippi State University (MSU) personnel. Each site was marked using a 2.1m x 3m spacing for tree planting due to limited area. Each planting row was designated by a piece of rebar marked with flagging and metal tag denoting the replication and treatment, with each treatment also being assigned a specific color. Two 100 meter tapes and a compass were used to lay out plots and spacing of seedlings. Colored pin flags assigned to specific treatments were used to designate planting locations of each seedling. One hundred seedlings were planted in each treatment area per replication, except for EKOgrown® white oak seedlings on replication “A” on the Reinike site. This was due to a seedling shortage by the nursery, reducing the number of seedlings on that block to 19 seedlings, resulting in a total of 219 EKOgrown® white oak seedlings planted on the Reinike site. With the exception of that treatment, 300 seedlings were planted per treatment per site.

Seedling Establishment

White oak and water oak seedlings were evaluated in this study. Three planting stocks of each species were utilized including: 1) high quality 1-0 bareroot, 2) 240 milliliter (ml) conventional containerized, and 3) 3.8 liter (L) potted seedlings. ArborGen tree nurseries in Bluff City, Arkansas, produced the bareroot stock, conventional containerized seedlings were produced by Mossy Oak's Nativ Nurseries in West Point, Mississippi, and EKOgrown® seedlings were provided by Resource Environmental Services (RES) Native Tree and Coastal Marsh Nursery in Montegut, Louisiana.

Bareroot seedlings were obtained 10 days prior to planting and conventional containerized seedlings were obtained two days prior to planting. Both planting stocks were stored in a walk-in cooler until transportation to the study sites. Bareroot seedlings were culled for quality control to meet specifications of having a minimum of 8 first order lateral roots and a shoot height equal to or greater than 50 centimeters (cm). No culling was implemented on the conventional containerized or EKOgrown® seedlings. Seedling care on the day of planting consisted of keeping seedlings in the shade and ensuring the root systems remained moist. Student workers and supervising graduate research assistants from MSU planted bareroot and conventional containerized seedlings of both species on February 17 and 18, 2018. EKOgrown® seedlings were planted at the

Reinike site on March 5, 2018 and at the Baxter site on March 20, 2018 by a commercial planting crew under the supervision of a MSU graduate research assistant.

Herbaceous Weed Control

Herbaceous weed control (HWC) was applied as a 1.5 meter wide banded application of 140 grams of Oust® XP per sprayed ha on March 2, 2018 and March 7, 2019 to all treatments that included bareroot or conventional containerized planting stocks. An 11.4 L Solo® 425 diaphragm-pump backpack sprayer equipped with a TeeJet® XR8004 nozzle was used to apply herbicide over the center of rows at a rate of 93L per treated ha. No HWC treatment was applied to EKOgrown® seedlings in accordance with their promotion by the producer as not requiring competition control due to their height and more fully developed root system. Due to standing water on reps B and C of the Baxter site, a HWC application was not performed, as it would not have properly controlled target vegetation. In addition, such an application is prohibited by Oust® XP label restrictions.

Field Data Collection

Survival

Survival data were collected monthly throughout the first growing season, and at the end of the second growing season. Determination of seedling survival involved scraping the bark to check for live cambium tissue if green foliage was not present. They were recorded as dead if no remaining green tissue was observed throughout the main stem.

Precipitation

Rainfall data were collected from both sites using a Rainwise® 111 tipping bucket rain gauge connected to a Hobo® UA-003-64 pendant event data logger. The tipping bucket rain gauge measured precipitation in 0.25 mm increments and stored data on the data logger with a date and time stamp. A Hobo® U-DTW-1 waterproof shuttle was used to extract and transport information stored on the data logger. The shuttle was then connected with HOBOWare™ Plus software on a computer to display rain data with times, dates, and measurements. Precipitation and survival data were separated by month in order to determine if a relationship existed between precipitation, growth, and survival.

Measurements

Initial height and groundline diameter (GLD) measurements were collected after planting on March 24, 2018. First growing season measurements were collected on September 22-23, 2018, with final measurements recorded September 28-29, 2019, at the end of the second growing season. Dieback, herbivory, and resprouts were noted at each measurement timing for use in data analysis.

Height

Aluminum meter sticks were used to measure total height of seedlings. Total height was measured from the ground to the tip of the terminal bud. If the seedling was taller than a meter, it was marked at 100cm, then measured from that mark to the tip of the terminal bud. The second measurement was then added to obtain the total seedling height. When seedlings exhibited a split stem, the taller stem was measured. If dieback was present, it was noted and height was measured to the point of highest green cambial tissue. When complete dieback and resprouting occurred, the new sprout was measured and reported as a resprout. Total height measurements were recorded to the nearest centimeter.

Groundline diameter

Mitutoyo® digital calipers were used to measure GLD. Calipers were held level, parallel to the ground, immediately above the root collar. Measurements were recorded in tenths of a millimeter, and calibration was checked after each measurement.

Photosynthesis

Photosynthesis measurements were taken during the first growing season to create CO_2 response curves (A/Ci Curves). Measurements were collected June 6-7, July 19-20, and September 8-9, 2018. A Li-Cor LI-6400XT portable photosynthesis system (Li-Cor Biosciences Inc.) was used to obtain measurements to compare the maximum Rubisco carboxylation rate (V_{cmax}), maximum electron transport rate (J_{max}), and triose phosphate utilization rate (TPU) in the different species and planting stocks. Measurements were obtained from two seedlings per treatment per site at each timing. A/Ci curves were created by setting light levels to 1500 μmol m^{-2} s^{-1} and CO_2 concentration to 400 ppm. CO_2 concentration was sequentially lowered to 300 ppm, 200 ppm, 100 ppm, and 50 ppm. CO_2 concentration was then returned to 400 ppm and raised to 600 ppm, and 800 ppm. Photosynthesis, transpiration, and water use efficiency were estimated at saturating light and ambient CO_2 conditions. Measured leaves were collected, returned to the lab, and fresh leaf area was estimated using a Li-Cor LI 3100 leaf area meter (Li-Cor

Biosciences Inc). Leaves were then dried at 70ºC for at least 3 days and their dry weights were obtained to estimate leaf mass per unit area (LMA).

Soil Sampling

Soil samples were collected randomly from the top 25.4 centimeters at each site on March 7, 2019. Samples were thoroughly mixed and a 3L amount of the soil was analyzed for nutrient content and texture by the Mississippi State University Extension Plant and Soil Sciences Soil Testing Lab in Mississippi on March 18, 2019.

Statistical Analysis

Survival and Growth

Statistical Analysis System 9.4 (SAS) software was used to perform data analysis on the data collected. 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 height growth, GLD growth, and survival of seedlings for each main effect and possible interactions. When significant interactions were detected, a multiple comparisons procedure was used to determine significance using the LSMEANS statement with the Tukey-Kramer method. PROC GLM, LSMEANS, and Tukey-Kramer were utilized because sample populations differed due to mortality, and the lower sample size of one treatment. Additionally, the Tukey-Kramer method was used over other tests because it accounts for all pairwise interactions.

Photosynthesis analysis

A Microsoft Excel solver function developed by Sharkey et al (2007) was used to estimate V_{cmax}, J_{max}, and TPU from the CO_2 assimilation rates (A) and CO_2 concentration

(C_i) measurements obtained in the field on a tree by tree basis (Figure 3.1). Averages of V_{cmax}, J_{max}, and TPU were then calculated in a normal Excel spreadsheet and separated by species, planting stock, site, and month. The ANOVA function in R version 3.2.5 was used to determine significant differences of the variables among the previously stated groups at α=0.05. If a significant relationship was revealed, then a Tukey-Kramer multiple comparisons procedure (MCP) was used to determine significance within the groups.

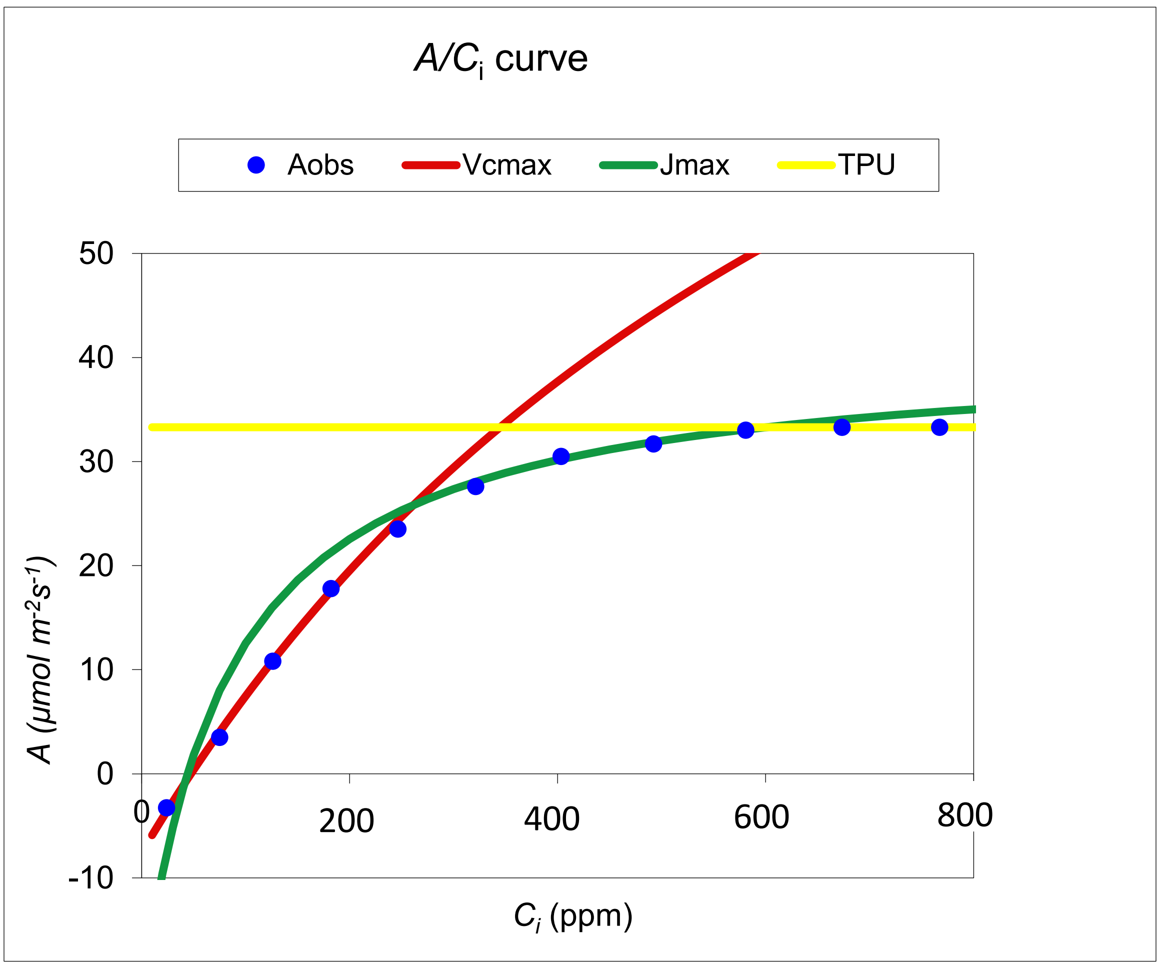

Figure 3.1 Example A/C_i curve showing photosynthetic capacity parameters including V_{cmax}, J_{max}, and TPU.

CHAPTER IV

RESULTS AND DISCUSSION

Survival comparison

Analysis of variance

Analysis of variance (ANOVA) was used to determine if there was observable statistical significance for survival (Table 4.1) due to effects of site, species, and planting stock. ANOVA is limited to reporting significance among groups, therefore a Tukey-Kramer multiple comparisons procedure (MCP) was performed to determine significance within groups. ANOVA and MCP analyses results for each variable are explained subsequently in the proper section for site, species, planting stock, and their interactions.

Table 4.1 ANOVA results for survival rates by year

		Growing Season			
		2018		2019	
Source	DF	F	P>F	F	P>F
(A) Species	1	74.82	<.0001	71.70	<.0001
(B) Stock	2	485.97	<.0001	401.65	<.0001
(C) Site	1	2.39	0.1219	85.85	<.0001
A*B	2	35.37	<.0001	44.51	<.0001
B*C	2	31.65	<.0001	61.35	<.0001
A*C	1	71.88	<.0001	69.45	<.0001
A*B*C	2	2.28	0.1028	4.23	0.0146

Monthly precipitation and survival during first growing season

Precipitation and seedling survival were evaluated monthly during the first growing season. Survival was recorded and precipitation data were retrieved at the middle of each month during the first growing season. These data were used to determine the impact of transplant shock and precipitation on seedling survival.

Monthly precipitation during first growing season

Although the Baxter site did not experience a deficit of rainfall, the Reinike site consistently received more rainfall throughout the year, except for the month of July (Table 4.2). The Baxter site experienced rainfall similar to monthly averages for the area (NOAA 2019), while the Reinike site exceeded the averages in most months. Both sites experienced less than average rainfall during the months of September and October, but it was not considered lacking to the point of causing mortality.

Table 4.2 Monthly precipitation at each site during the 2018 growing season and long term regional precipitation

Site	April	May	June	July	Aug.	Sept.	Oct.
	---------------------------Centimeters----------------------------						
Reinike	17.2	16.8	18.2	13.4	15.4	10.1	8.3
Baxter	11.6	12.4	10.3	19.0	13.5	8.2	6.9
Long Term Average*	11.5	12.5	14.5	17.2	13.5	11.8	9.5

*20th Century Average Mississippi Climate Division Nine (NOAA 2019)

Monthly survival during first growing season

Survival of conventional containerized seedlings was unexpectedly low across both sites and species. Survival was lower in April than the other planting stocks, dropped an average of 19.5% between April and May, and continued at a steady decline throughout the first growing season (Table 4.3). All conventional containerized seedlings exhibited a similar rate of decline over the next four months. No treatments with conventional containerized seedlings exceeded 50% survival at the end of the first growing season. White oak and water oak had similar overall survival rates (37.3% and 31.8% respectively) (Table 4.9) and conventional containerized seedlings as a whole had 34.6% survival at the end of the first growing season (Table 4.7).

All EKOgrown® (hereafter EKO) treatments had high survival rates in April. Significant declines of water oak EKO survival became noticeable in June while white oak EKO survival remained relatively steady throughout the growing season (Table 4.3). At the end of the first growing season, white oak EKO seedlings exhibited 88.2% survival (Table 4.9) across both sites while water oak EKO seedlings exhibited less than desirable survival (59.3%) (Table 4.9) and the planting stock as a whole had 73.7% survival (Table 4.7).

Bareroot seedlings exhibited significantly higher survival compared to other planting stocks during the first growing season. Bareroot seedling survival on the Reinike site (89.8%) was greater than on the Baxter site (80.1%) (Table 4.10). This could be attributed to failure to obtain adequate weed control and persistent wet conditions on the Baxter site due to its topographical bottom location. There were no detectable differences in survival of bareroot seedlings between species, but white oak bareroot seedlings on the Reinike site exhibited the greatest survival (95%) (Table 4.3) at the end of the first growing season. Bareroot planting stock outperformed other planting stocks with an overall survival rate of 84.9% at the end of the first growing season and 71.8% after two growing seasons (Table 4.7).

Most of the large declines in first year survival occurred from June to August. This could be due to increased vegetative competition occurring after effects of the Oust XP application expired. This would be more plausible on the Baxter site since most of the study area had not received an Oust XP application due to standing water at the time of application.

Table 4.3 Survival of all treatments during the first growing season after planting

Site	Treatment	April	May	June	July	Aug.	Sept.
		------------------------Percentage------------------------					
Reinike	Bareroot white oak	100	100	99	97	96	95
	Containerized water oak	93	67	45	35	19	16
	EKO white oak	100	100	100	97	95	95
	Bareroot water oak	100	99	96	92	87	85
	Containerized white oak	88	70	51	44	39	36
	EKO water oak	100	95	69	57	54	53
Baxter	Bareroot white oak	100	100	96	89	85	77
	Containerized water oak	98	84	68	55	52	47
	EKO white oak	100	99	95	89	87	81
	Bareroot water oak	99	98	94	91	86	83
	Containerized white oak	93	73	55	46	42	39
	EKO water oak	98	93	87	85	75	66

Percentages rounded to the nearest whole number

Soil nutrient and texture analysis

The Reinike site had significantly higher nutrient content for all five nutrients analyzed (P, K, Ca, Mg, Zn) compared to the Baxter site (Table 4.4). Both sites had pH levels within the acceptable range for white oak, but the Baxter site pH level lies outside of the preferred range for water oak (Reinike 5.7, Baxter 4.5) (Rogers 1990). It is possible that the lower nutrient content contributed to lower overall survival at the Baxter site after two years.

Table 4.4 Nutrient content and pH level by site

Site	P	K	Ca	Mg	Zn	pH
	-----------------Kilograms per Hectare-------------					
Reinike Site	43	133	996	170	1.23	5.7
Baxter Site	10	49	18	20	0.11	4.5

Both sites had the same overall sandy loam texture. The Reinike site consisted of 25% more sand, whereas the Baxter site consisted of 25% more silt. Both sites consisted of 8% clay (Table 4.5). The Reinike site is well-drained, but the Baxter site is poorly drained (Web Soil Survey 2019). Poor drainage at the Baxter site could also have contributed to overall lower survival.

Table 4.5 Sand, silt, and clay composition by percentage and soil texture

Site	Sand	Silt	Clay	Texture
	--------------------------Percent------------------			
Reinike Site	75	17	8	Sandy loam
Baxter Site	50	42	8	Sandy loam

Survival variation between species

ANOVA indicated significant differences between species in seedling survival at the end of the first growing season ($F= 74.82$, $p<.0001$) and the end of the second growing season ($F= 71.70$, $p<.0001$) (Table 4.1).

White oak (WHO) had significantly higher survival than water oak (WAO) at the end of the first (WHO= 70.5%, WAO= 58.4%) and second growing seasons

(WHO= 61.1%, WAO= 48.8%) when both sites and all planting stocks were considered (Table 4.6). Survival of both species declined approximately 9.5% between the first and second growing seasons. Both overall averages were decreased by the significantly lower survival of conventional containerized seedlings (Table 4.9).

Table 4.6 Survival by species at the end of each growing season for both sites and all planting stocks

	End of Growing Season	
Species	2018	2019
	----------------Percent-------------	
White oak	70.5a*	61.1a
Water oak	58.4b	48.8b

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

Survival variation among planting stocks

ANOVA detected significant differences among planting stocks in seedling survival at the end of the first growing season (F= 485.97, p<.0001) and second growing season (F= 401.65, p<.0001) (Table 4.1).

Bareroot seedlings exhibited the best survival (84.9% in 2018, 71.8% in 2019) compared to EKO (73.7% in 2018, 66.9% in 2019) and conventional containerized (34.6% in 2018, 26.1% in 2019) when both sites and species were considered (Table 4.7).

Table 4.7 Survival by planting stock at the end of each growing season for both sites and species.

Planting Stock	End of Growing Season 2018	2019
	--------------Percent-------------	
Bareroot	84.9a*	71.8a
Conventional Containerized	34.6c	26.1c
EKOgrown®	73.7b	66.9b

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

Survival variation between sites

ANOVA did not indicate significant differences between sites in seedling survival at the end of the first growing season (F= 2.39, p= 0.1219), but significant differences were detected at the end of the second growing season (F= 85.85, p<.0001) (Table 4.1).

At the end of the first growing season, there was no detectable difference in overall survival between the two sites (Reinike= 63.4%, Baxter= 65.5%) (Table 4.8). At the end of the second growing season, the Baxter site had significantly lower survival than the Reinike site (Reinike= 61.7%, Baxter= 48.2%).

Table 4.8 Survival by site at the end of each growing season for both species and all planting stocks.

Site	End of Growing Season 2018	2019
	---------------Percent--------------	
Reinike site	63.4a*	61.7a
Baxter site	65.5a	48.2b

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

Survival variation by species and planting stock interaction

ANOVA indicated significant interactions between species and planting stock in seedling survival at the end of the first growing season (F= 35.37, $p<.0001$), and at the end of the second growing season (F= 44.51, $p<.0001$) (Table 4.1).

No significant difference in survival was evident between species of conventional containerized seedlings at the end of the first (WHO= 37.3%, WAO= 31.8%) and second growing seasons (WHO= 27.0%, WAO= 25.3%), with both species displaying poor survival (Table 4.9). EKO white oak seedlings had the highest survival of all treatments while EKO water oak seedlings exhibited poor survival rates during the first growing season (WHO= 88.2%, WAO= 59.3%) and second growing season (WHO= 82.9%, WAO= 50.8%). No significant difference was evident between species of bareroot seedlings during the first growing season (WHO= 85.9%, WAO= 84.0%), or the second growing season (WHO= 73.4%, WAO= 70.2%).

Table 4.9 Survival by species and planting stock at the end of each growing season for both sites.

Species/Planting Stock	End of Growing Season 2018	2019
	-----------Percent-----------	
White oak Bareroot	85.9a*	73.4b
White oak Conventional Containerized	37.3c	27.0d
White oak EKOgrown®	88.2a	82.9a
Water oak Bareroot	84.0a	70.2b
Water oak Conventional Containerized	31.8c	25.3d
Water oak EKOgrown®	59.3b	50.8c

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

Survival variation by planting stock and site interaction

ANOVA indicated significant differences in interactions between planting stock and site at the end of the first ($F= 31.65$, $p<.0001$) and second growing seasons ($F= 61.35$, $p<.0001$) (Table 4.1). MCP analysis was used to further determine significant interactions.

Significant difference in survival at the end of the first growing season was evident in all planting stock and site interactions, except for EKO seedlings. Conventional containerized seedlings exhibited low survival at both sites, but survival was significantly higher at the Baxter site than the Reinike site (Reinike= 26.2%, Baxter= 42.9%) (Table 4.10) after the first growing season. EKO seedlings had intermediate survival across both sites and species (Reinike= 74.1%, Baxter= 73.4%). Survival was highest for bareroot seedlings across both sites and species. While bareroot seedlings on the Baxter site had higher survival (Baxter= 80.1%) than EKOgrown® seedlings (Baxter= 73.4%), the difference was not significant. Bareroot seedlings on the Reinike site displayed the greatest survival of all planting stock and site interactions (Reinike= 89.8%) after the first growing season.

At the end of the second growing season, it appears that site had an influence on survival. There were no large decreases (0-2.5%) in survival for any planting stock on the Reinike site, but survival decreases ranged from 11.2% to 25.7% in planting stocks on the Baxter site (Table 4.10). On the Reinike site, bareroot seedlings had the best survival followed by EKO and conventional containerized (89.2%, 71.6%, and 24.3%, respectively) with EKO having the largest decrease in survival (2.5%). On the Baxter site, EKO seedlings had the greatest survival, followed by bareroot and conventional containerized (62.2%, 54.4%, and 27.9%, respectively) with bareroot having the largest decrease in survival (25.7%).

Table 4.10 Survival by planting stock and site at the end of each growing season for both species.

Planting Stock/Site	End of Growing Season 2018	2019
	-----------Percent-----------	
Bareroot Reinike site	89.8a*	89.2a
Bareroot Baxter site	80.1b	54.4d
Conventional Containerized Reinike site	26.2d	24.3e
Conventional Containerized Baxter site	42.9c	27.9e
EKOgrown® Reinike site	74.1b	71.6b
EKOgrown® Baxter site	73.4b	62.2c

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

Survival variation by species and site interaction

ANOVA indicated significant differences in interactions between species and site at the end of the first (F= 71.88, p<.0001) and second growing seasons (F=69.45, p<.0001) (Table 4.1). MCP analysis was used to further determine significant interactions.

Significant differences were found in survival of species by site at the end of the first growing season. White oak had greater survival on the Reinike site (Reinike= 75.4%, Baxter= 65.6%) (Table 4.11), while water oak had better survival on the Baxter site (Reinike= 51.3%, Baxter= 65.4%). Survival was lowest for water oak on Reinike site (51.3%), due to poor survival of conventional containerized water oak seedlings during the first growing season. Survival was greatest for white oaks on Reinike site (75.4%)

and was significantly greater than other species/site combinations at the end of the first growing season, when all planting stocks are considered (Table 4.11).

At the end of the second growing season, white oak seedlings on the Reinike site (73.9%) had significantly greater survival than other species/site combinations. Survival of both species on the Baxter site (WHO= 48.3%, WAO= 48.1%) dropped to a level where it was no longer significantly different than water oak survival on the Reinike site (49.4%).

Table 4.11 Survival by species and site at the end of each growing season for all planting stocks.

Species/Site	End of Growing Season 2018	2019
	------------Percent------------	
White oak Reinike site	75.4a*	73.9a
White oak Baxter site	65.6b	48.3b
Water oak Reinike site	51.3c	49.4b
Water oak Baxter site	65.4b	48.1b

*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

ANOVA did not reveal evidence of significant differences in the overall interactions between treatment and site at the end of the first growing season (F= 2.28, p= 0.1028) (Table 4.1). Variation within treatment data sets may have produced this result. However, ANOVA did reveal evidence of significant differences in the overall interactions between treatment and site at the end of the second growing season (F= 4.23, p= 0.0146). MCP analysis was used to further determine significant interactions.

Bareroot was the only water oak planting stock that exhibited survival above 70% at the end of the first growing season, and it was consistent on both sites (Reinike= 85%, Baxter= 83%) (Table 4.12). EKO water oak seedlings exhibited significantly greater survival on the Baxter site (65.9%) compared to the Reinike site (52.7%). Conventional containerized water oak seedling survival was significantly greater on the Baxter site (47.3%) than the Reinike site (16.3%). White oak conventional containerized seedlings (36%) displayed significantly greater survival than water oak conventional containerized seedlings (16.3%) on the Reinike site, and lower survival on the Baxter site (WHO= 38.7%, WAO= 47.3%). White oak EKO seedlings (Reinike= 95.4%, Baxter= 81.0%) had significantly higher survival than water oak EKO seedlings (Reinike= 52.7%, Baxter= 65.9%) on both sites. White oak bareroot seedlings exhibited excellent (94.7%) survival on the Reinike site and intermediate (77.3%) survival on the Baxter site. White oak EKO and bareroot seedlings on the Reinike site exhibited the best overall survival of all treatments. Conventional containerized water oak seedlings on the Reinike site exhibited the worst survival of all treatments (Table 4.12).

At the end of the second growing season, both species of bareroot seedlings and white oak EKO seedlings on the Reinike site (WHO= 94.0%, WAO= 84.3%, WHO EKO= 94.5) exhibited the best survival. White oak EKO on the Reinike site (71.3%) displayed significantly greater survival than water oak EKO on either site (Reinike= 48.7%, Baxter= 53%). Bareroot seedlings on the Baxter site (WHO= 52.8%, WAO=56.0%) experienced the largest declines in survival (WHO= -24.5%, WAO= -27.0%), but still had significantly greater survival than conventional containerized seedlings (WHO Reinike= 33.3%, WAO Reinike= 15.3%, WHO Baxter= 20.7%, WAO Baxter= 35.2%).

Table 4.12 Survival by treatment and site at the end of each growing season for both species.

Species	Planting Stock/Site	End of Growing Season 2018	2019
		-------Percent--------	
White oak	Bareroot Reinike site	94.7a*	94.0a
	Bareroot Baxter site	77.3b	52.8c
	Conventional Containerized Reinike site	36.0f	33.3d
	Conventional Containerized Baxter site	38.7ef	20.7e
	EKOgrown® Reinike site	95.4a	94.5a
	EKOgrown® Baxter site	81.0b	71.3b
Water oak	Bareroot Reinike site	85.0ab	84.3a
	Bareroot Baxter site	83.0b	56.0c
	Conventional Containerized Reinike site	16.3g	15.3e
	Conventional Containerized Baxter site	47.3de	35.2d
	EKOgrown® Reinike site	52.7d	48.7c
	EKOgrown® Baxter site	65.9c	53.0c

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

Survival comparison discussion

Containerized seedlings exhibited poor survival beginning in May and EKO water oak seedlings exhibited poor survival beginning in June of the first growing season. All containerized seedling averages fell below 70% survival by June, with most falling to around 50% survival (Table 4.3). Containerized seedlings had identical transportation and planting as compared to that of bareroot seedlings. Consequently, those factors are not thought to have affected lack of success. Since containerized seedlings should be less prone to planting shock (Johnson, P.S. 1984), mortality may have resulted from damage while in the nursery. Bareroot seedlings exhibited the best overall survival. This can be attributed to proper planting and high quality seedlings. Previous studies have shown a similar trend in bareroot seedling survival. Conrad (2013), Dowdy (2015), Durbin (2018), and Miles (2019) all found that the bareroot seedling stock exhibited superior survival over the containerized and EKO planting stocks. For EKO water oak seedlings, seedling transportation may have been a factor in their lower survival. Although white oak EKO seedlings were transported the same way as water oak, placement on the trailer may have played a role. All seedlings were transported on a flat-bed trailer with plywood side walls, leaving the seedling tops exposed. Water oak seedlings were placed at the front of the trailer, receiving more wind impact than white oaks. It is possible that this resulted in more injuries leading to declining survival throughout the first growing season. Further examination would be needed to determine the true cause of different survival rates between species of EKO seedlings.

Overall survival between sites only differed by two percent in the first growing season (Table 4.8). The Reinike site displayed a larger range in survival than the Baxter site (Reinike=16% to 95%, Baxter=39% to 83%) (Table 4.3). At the end of the second growing season, it became apparent that site had an influence on survival as there was a 13.5% difference in overall survival between the two sites (Reinike=61.7%, Baxter=48.2%) (Table 4.8). There was a 1.7% drop in survival on the Reinike site in the second growing season and a 17.3% drop on the Baxter site. Several factors could attribute to the difference in survival. Soils on both sites were classified as sandy loam, but the Reinike site was 75% sand compared to 50% for Baxter. Poor survival on the Reinike site is attributed to low survival of containerized seedlings of both species. High-quality bareroot seedlings have a larger root system prior to planting, allowing for access to more soil and water after planting, whereas conventional containerized seedlings would have to develop larger root systems in a short amount of time to exploit the same amount of resources. It is possible that the roots of these seedlings could be “bound”, meaning the root system may have grown too voluminous for the container. Once planted, these “bound” roots may not have been able to expand into the surrounding soil. This could explain the decrease in survival on the Reinike site, as seedlings were not able to exploit more of the well-drained soil to reach water. The persistent wet conditions of the Baxter site, being located in a depression, could explain the lower maximum of the survival range between the two sites. Neither species naturally occur on sites that are not consistently flooded during the growing season (Rogers 1990). The wet conditions could also explain the higher minimum survival at the Baxter site, due to less-developed or possibly “bound” roots still being able to obtain adequate water without the need to expand as far. Also, the majority of the Baxter site did not receive a HWC treatment either growing season due to the presence of standing water across the site at the desired time of application. This created a competition-rich environment on nutrient-poor soils in which seedlings were not able to compete well.

Although further examination is necessary to determine the exact cause of the decreased survival, similar trends were noted by Miles (2019) and Dowdy (2015). Over the course of two years, both studies observed lower survival of containerized and EKO seedlings. Greatest survival in the first growing season of this study was exhibited by bareroot seedlings of both species, followed by EKO and conventional containerized seedlings (Table 4.9). Greatest survival during the second growing season was exhibited by white oak EKO (82.9%), followed by both species of bareroot seedlings

(WHO= 73.4%, WAO= 70.2%), water oak EKO (50.8%), then conventional containerized seedlings (WHO= 27.0%, WAO= 25.3%) (Table 4.9).

Herbaceous weed control has been shown to be effective at increasing early survival of bareroot oak seedlings (Ezell and Hodges 2002, Ezell and Catchot 1998). Eliminating competing vegetation reduces competition for soil moisture for oak seedlings. Oust®XP was effective at reducing ground cover in the early months of the first growing season on the Reinike site. Mineral soil exposed by the HWC application was occupied by dogfennel (*Eupatoorium capillifolium*), sicklepod (*Senna obtusifolia*), and giant ragweed (*Ambrosia trifida*) by July of the first growing season on the Reinike site. By the end of the first growing season, a few small clusters of smallflower morningglory (*Jacquemontia tamnifolia*), and cypress-vine morningglory (*Ipomoea quamoclit*) had established and began to climb over seedlings. At the end of the second growing season, dogfennel, sicklepod, and giant ragweed were still the main competing species. Goldenrod (*Solidago* spp.) had become prevalent in the plots and cypress-vine morningglory had greatly expanded in replication "C", which is where most of the mortality occurred on the Reinike site in the second growing season. Oust®XP was able to control vegetation where it was applied on the Baxter site during the first growing season. However, bushy bluestem (*Andropogon glomeratus*), a perennial bunch grass not controlled by Oust®XP, was abundant on the drier portions of the Baxter site. A variety of different species occupied the Baxter site. The most common plants were *Juncus* spp., ten-angled pipewort (*Eriocaulon decangulare L.*), goldenrod, plumegrass (*Saccharum* giganteum), variable panicgrass (*Dichanthelium* spp.), and cinnamon fern (*Osmunda* *cinnamomea L.*). These plants were located in portions of the site that were too wet for application of Oust®XP and were the main competitors for the seedlings.

White oak displayed significantly greater overall survival than water oak at the end of the first and second growing seasons. Poor overall survival of water oak can be attributed to low survival of conventional containerized seedlings on the Reinike site (15.3%) and water oak EKO seedlings on both sites (Reinike= 48.7%, Baxter= 53.0%) (Table 4.12).

When comparing sites, neither species displayed better than intermediate overall survival at the end of the first growing season. By the end of the second growing season, both species on the Baxter site and water oak on the Reinike site had fallen below 50% survival. Sites did not differ in overall survival during the first growing season, but a significant difference was revealed in the second growing season. Reinike site survival only decreased 1.7% (63.4% to 61.7%) in the second growing season, where the Baxter site decreased 17.3% (65.5% to 48.2%) (Table 4.8). This difference in survival emphasizes the importance of competition control and appropriately matching species to site when artificially regenerating a forest. During the first growing season, white oak seedlings displayed significantly greater survival on the Reinike site, but water oak displayed significantly greater survival on the Baxter site. Soil conditions for the Reinike site were better suited for white oak and the Baxter site was better suited for water oak, although the Baxter site was not ideal for either species. During the second growing season, white oak had significantly greater survival on the Reinike site, but there was no significant difference in survival between species on the Baxter site. Vegetative competition was taller on the Reinike site, but more open area was present at ground-level, whereas the Baxter site had shorter competition, but possessed more of a ground cover mat around the seedlings, creating a more competitive environment than the Reinike site.

Height growth comparison

Analysis of variance

ANOVA was used to determine if there were any statistical differences observable for height growth (Table 4.13) considering the effects of site, species, and planting stock. ANOVA is limited to reporting significance among groups, therefore a Tukey-Kramer multiple comparisons procedure (MCP) was performed to determine significance within groups. The ANOVA and MCP analyses results for each variable are explained subsequently in the sections for site, species, planting stock, and their interactions.

Table 4.13 ANOVA results for average height growth by year and overall

		Growing Season					
		2018		2019		Overall	
Source	DF	F	P>F	F	P>F	F	P>F
(A) Species	1	185.83	<.0001	28.44	<.0001	14.32	0.0002
(B) Stock	2	0.91	0.4030	17.93	<.0001	8.25	0.0003
(C) Site	1	0.68	0.4108	344.31	<.0001	244.14	<.0001
A*B	2	2.34	0.0964	24.46	<.0001	22.81	<.0001
B*C	2	6.65	0.0013	15.85	<.0001	27.35	<.0001
A*C	1	39.52	<.0001	7.81	0.0052	1.60	0.2067
A*B*C	2	5.52	0.0041	24.58	<.0001	29.92	<.0001

Height growth variation between species

ANOVA showed evidence of an effect of species on height growth during the first growing season (F= 185.83, p<.0001), second growing season (F= 28.44, p<.0001), and overall (F= 14.32, p= 0.0002) (Table 4.13).

White oak seedlings had greater height growth, while water oak seedlings actually showed height loss during the first growing season (WHO= 4.2 cm, WAO= -9.2 cm) (Table 4.14). Height loss of water oak is due to a significant amount of dieback on the Reinike site. During the second growing season, white oak seedlings continued to add positive height growth, but not at as high of a rate as during the first growing season. Water oak seedlings were able to rebound (9.6 cm) during the second growing season and surpass the average initial height with a positive overall height growth (1.4 cm). Although white oak seedlings exhibited greater overall height growth (7.4 cm), water oak seedlings could surpass white oak if the same trend were to continue.

Table 4.14 Average height growth by species, growing season, and overall for both sites and all planting stocks

	Growing Season		
Species	2018	2019	Overall**
	-----------------------Centimeters---------------------------		
White oak	4.2a*	2.5b	7.4a
Water oak	-9.2b	9.6a	1.4b

*Values in a column followed by the same letter are not significantly different (α=0.05).
**Overall results may slightly differ from sum of both growing seasons due to additive mortality

Height growth variation among planting stocks

ANOVA did not reveal evidence of an effect of planting stock on height growth during the first growing season ($F = 0.91$, $p = 0.4030$), but significant differences were noted during the second growing season ($F = 17.93$, $p < .0001$), and overall ($F = 8.25$, $p = 0.0003$) (Table 4.13). MCP analysis was used to further determine significant interactions.

During the first growing season, seedlings of all planting stocks experienced a small amount of dieback when both species and sites were considered, but EKO seedlings (-1.7cm) exhibited the least dieback and conventional containerized seedlings (-3.5cm) experienced the most at the end of the first growing season (Table 4.15). During the second growing season, bareroot (9.8 cm) and conventional containerized (6.4 cm) seedlings exhibited significantly greater height growth than EKO seedlings (1.9 cm). From initial planting to the end of the second growing season, bareroot seedlings (8.0 cm) showed significantly greater height growth than EKO seedlings (1.9 cm). Conventional containerized seedling growth (3.2 cm) was not significantly greater than EKO seedlings or lower than bareroot seedlings (8.0 cm).

Table 4.15 Average height growth by planting stock per growing season, and overall for both sites and species

Planting Stock	Growing Season 2018	2019	Overall**
	------------------Centimeters----------------------		
Bareroot	-2.2a*	9.8a	8.0a
Conventional Containerized	-3.5a	6.4a	3.2ab
EKOgrown®	-1.7a	1.9b	1.9b

*Values in a column followed by the same letter are not significantly different (α=0.05).
**Overall results may slightly differ from sum of both growing seasons due to additive mortality

Height growth variation between sites

ANOVA did not reveal evidence of an effect of site on height growth during the first growing season (F= 0.68, p= 0.4108), but significant differences were detected during the second growing season (F= 344.31, p<.0001), and overall (F= 244.14, p<.0001) (Table 4.13).

When both species and all planting stocks were considered, seedlings on both sites experienced a small amount of dieback at the end of the first growing season, but the Baxter site (Reinike= -2.9 cm, Baxter= -2.1cm) had the least (Table 4.16). Seedlings on the Reinike site were able to rebound and accumulate significant height growth (18.5 cm) during the second growing season, with an overall height growth of 16.7 cm. Seedlings on the Baxter site continued to die back in the second growing season (-6.4 cm) with a significantly lower overall height growth (-7.9 cm) than the Reinike site.

Table 4.16 Average height growth by site per growing season, and overall for both species and all planting stocks.

Site	Growing Season 2018	2019	Overall**
	-------------------Centimeters-----------------------		
Reinike site	-2.9a*	18.5a	16.7a
Baxter site	-2.1a	-6.4b	-7.9b

*Values in a column followed by the same letter are not significantly different (α=0.05).
**Overall results may slightly differ from sum of both growing seasons due to additive mortality

Height growth variation by species and planting stock interaction

ANOVA did not reveal evidence of an effect of species and planting stock interaction on height growth during the first growing season ($F= 2.34$, $p= 0.0964$), but significant interactions were revealed during the second growing season ($F= 24.46$, $p<.0001$), and overall ($F= 22.81$, $p<.0001$) (Table 4.13).

White oak exhibited positive growth in all planting stocks while water oak displayed dieback in all planting stocks during the first growing season. White oak EKO seedlings (4.9cm) had the most height growth, and water oak conventional containerized seedlings (-11.5cm) produced the least amount of growth (Table 4.17). This could be attributed to heavy dieback of conventional containerized water oak seedlings on the Reinike site during the first growing season.

At the end of the second growing season, all species/stock combinations exhibited positive height growth (Table 4.17). Water oak bareroot (18.1 cm) exhibited significantly greater height growth than other species/stock combinations, which led to it also having the overall highest height growth (11.1 cm). Water oak conventional containerized seedlings (9.7 cm) also did well during the second growing season, along with white oak conventional containerized (3.1 cm) and EKO (2.8 cm) seedlings. White oak bareroot (1.5 cm) and water oak EKO (1.1 cm) seedlings exhibited the least amount of growth during the second growing season. Although all species/stock combinations exhibited positive second-year growth, water oak conventional containerized and EKO seedlings did not fully regrow growth lost in the first growing season and ended the second growing season with negative overall growth (WAO CC= -1.9 cm, WAO EKO= -5.0 cm). White oak conventional containerized (8.3 cm), white oak EKO (8.9 cm), and water oak bareroot (11.1 cm) seedlings exhibited the greatest overall growth. White oak bareroot seedlings were able to maintain positive height growth during the second growing season (1.5 cm), but only had a 4.9 cm overall height growth.

Table 4.17 Average height growth by species and planting stock per growing season, and overall for both sites.

	Growing Season		
Species/Planting Stock	2018	2019	Overall**
	--------------------Centimeters----------------		
White oak Bareroot	3.1a*	1.5c	4.9bc
White oak Conventional Containerized	4.4a	3.1bc	8.3abc
White oak EKOgrown®	4.9a	2.8bc	8.9ab
Water oak Bareroot	-7.6b	18.1a	11.1a
Water oak Conventional Containerized	-11.5b	9.7b	-1.9cd
Water oak EKOgrown®	-8.5b	1.1c	-5.0d

*Values in a column followed by the same letter are not significantly different (α=0.05).
**Overall results may slightly differ from sum of both growing seasons due to additive mortality

Height growth variation by planting stock and site interaction

ANOVA showed evidence of an effect of planting stock and site interaction on height growth during the first growing season (F= 6.65, p= 0.0013), second growing season ($F = 15.85$, $p < .0001$), and overall ($F = 27.35$, $p < .0001$) (Table 4.13). MCP analysis was used to further determine significant interactions.

All planting stock and site interactions experienced some level of dieback during the first growing season when both species are considered (Table 4.18). Bareroot seedlings on the Baxter site experienced the greatest dieback, while bareroot seedlings on the Reinike site experienced the least dieback at the end of the first growing season (Baxter= -4.5 cm, Reinike= -0.006 cm). Conventional containerized seedlings on both sites experienced a moderate amount of dieback with little difference between sites at the end of the first growing season (Baxter= -3.8 cm, Reinike= -3.2 cm). EKO seedlings had differing amounts of dieback between sites. They exhibited moderate dieback on the Reinike site while exhibiting very little dieback on the Baxter site at the end of the first growing season (Baxter= -0.4 cm, Reinike= -3.1 cm) (Table 4.18).

During the second growing season, all planting stocks on the Reinike site exhibited positive height growth, while all planting stocks on the Baxter site continued to exhibit dieback (Table 4.18). Bareroot seedlings on the Reinike site (second season= 26.7 cm, overall= 26.8 cm) exhibited significantly greater height growth than all other stock/site combinations. Conventional containerized (second season= 16.8 cm, overall= 13.8 cm) and EKO (second season= 12.0 cm, overall= 9.6 cm) seedlings on the Reinike site exhibited significantly greater height growth than all planting stocks on the Baxter site during the second growing season. Bareroot seedlings on the Baxter site exhibited the most amount of dieback overall (-10.8 cm).

Table 4.18 Average height growth by planting stock and site per growing season, and overall for both species

Planting Stock/Site	Growing Season 2018	2019	Overall**
	----------------Centimeters--------------		
Bareroot Reinike site	-0.006a*	26.7a	26.8a
Conventional Containerized Reinike site	-3.2ab	16.8b	13.8b
EKOgrown® Reinike site	-3.1ab	12.0b	9.6b
Bareroot Baxter site	-4.5b	-7.2c	-10.8c
Conventional Containerized Baxter site	-3.8ab	-3.9c	-7.4c
EKOgrown® Baxter site	-0.4a	-8.1c	-5.6c

*Values in a column followed by the same letter are not significantly different (α=0.05).
**Overall results may slightly differ from sum of both growing seasons due to additive mortality

Height growth variation by species and site interaction

ANOVA revealed evidence of an effect of species and site interaction on height growth during the first growing season ($F= 39.52$, $p <.0001$), and second growing season ($F= 7.81$, $p= 0.0052$), but not overall ($F= 1.60$, $p= 0.2067$) (Table 4.13). MCP analysis was used to further determine significant interactions. Failure to detect significant differences in overall growth is attributed to variation in the data.

When all planting stocks were considered, water oak seedlings exhibited negative height growth on both sites during the first growing season (Reinike= -11.9 cm, Baxter= -7.7 cm) (Table 4.19). Water oak seedlings on the Reinike site experienced the least growth at the end of the first growing season. White oak seedlings had positive height growth on both sites, with the greatest growth on the Reinike site at the end of the first growing season (Reinike= 7.7 cm, Baxter= 0.7 cm).

Neither species exhibited positive height growth on the Baxter site during the second growing season (WHO= -8.1 cm, WAO= -4.7 cm), or overall (WHO= -5.9 cm, WAO= -9.9 cm). Both species exhibited positive height growth on the Reinike site during the second growing season and overall. Water oak exhibited significantly greater growth during the second growing season (23.9 cm) than white oak (13.1 cm), but growth of white oak was significantly greater overall (WHO= 20.7, WAO= 12.7).

Table 4.19 Average height growth by species and site per growing season and overall for all planting stocks.

Species/Site	Growing Season 2018	2019	Overall**
	-----------------------Centimeters---------------------		
White oak Reinike site	7.7a*	13.1b	20.7a
White oak Baxter site	0.7b	-8.1c	-5.9c
Water oak Reinike site	-11.9d	23.9a	12.7b
Water oak Baxter site	-7.7c	-4.7c	-9.9c

*Values in a column followed by the same letter are not significantly different (α=0.05).
**Overall results may slightly differ from sum of both growing seasons due to additive mortality

Height growth variation by treatment and site interaction

ANOVA revealed evidence of an effect of treatment and site interaction on height growth during the first growing season (F= 5.52, p= 0.0041), second growing season (F= 24.58, p<.0001), and overall (F= 29.92, p<.0001) (Table 4.13). MCP analysis was used to further determine significant interactions.

All water oak seedling treatments on both sites exhibited negative height growth during the first growing season (Table 4.20). EKO seedlings on the Baxter site had the least height loss of all water oak treatments, while EKO seedlings on the Reinike site had the most height loss all treatments (Reinike = -15.0 cm, Baxter = -1.2 cm). All white oak treatments across both sites, except bareroot seedlings on the Baxter site (-1.6 cm), exhibited positive height growth during the first growing season. All white oak treatments on the Reinike site exhibited greater height growth than on the Baxter site during the first growing season. White oak bareroot and EKO seedlings on the Reinike site exhibited the greatest height growth of all treatments on both sites (BRT= 7.8cm, EKO= 8.9cm), while water oak containerized seedlings on both sites and EKO water oaks on the Reinike site exhibited the greatest height loss of all treatments (CC Reinike= -12.7 cm, CC Baxter= -10.2 cm, EKO Reinike= -15.0 cm) (Table 4.20).

Bareroot water oak seedlings on the Reinike site were able to regain growth lost from the first growing season during the second growing season (41.3 cm). These seedlings had significantly greater height growth than any other treatment on either site, leading to the greatest average overall height growth (33.5 cm), as well. Conventional containerized water oak seedlings on the Reinike site also exhibited good height growth during the second growing season (22.4 cm), but dieback from the first growing season resulted in only 10.1 cm of overall height growth. EKO water oak seedlings exhibited positive height growth on the Reinike site during the second growing season (8.2 cm), but it was not enough to offset dieback from the first growing season resulting in an overall height loss of -5.4 cm. White oak bareroot, conventional containerized, and EKO seedlings on the Reinike site exhibited positive height growth again during the second growing season (BRT= 12.2 cm, CC= 11.1 cm, EKO= 15.8 cm). These treatment also exhibited some of the better average overall height growth of the treatments on either site (BRT= 20.1 cm, CC= 17.5 cm, EKO= 24.6 cm). All treatments on the Baxter site exhibited dieback during the second growing season. Bareroot and EKO seedlings of both species had the most dieback during the second growing season (WHO BRT= -9.2 cm, WHO EKO= -10.2 cm, WAO BRT= -5.1 cm, WAO EKO= -6.1 cm). All treatments on the Baxter site exhibited negative average overall height growth. Bareroot seedlings of both species (WHO= -10.2 cm, WAO= -11.3 cm) and water oak conventional containerized seedlings (-13.9 cm) exhibited the most overall dieback.

Table 4.20 Average height growth by treatment and site per growing season for both species

Species	Planting Stock/Site	2018	2019	Overall**
		Growing Season		
		--------------Centimeters--------------		
White oak	Bareroot Reinike site	7.8a*	12.2bc	20.1b
White oak	Bareroot Baxter site	-1.6bcd	-9.2d	-10.2e
White oak	Conventional Containerized Reinike site	6.3ab	11.1bc	17.5b
White oak	Conventional Containerized Baxter site	2.6abc	-4.9d	-0.9cde
White oak	EKOgrown® Reinike site	8.9a	15.8bc	24.6ab
White oak	EKOgrown® Baxter site	1.1bc	-10.2d	-6.7de
Water oak	Bareroot Reinike site	-7.8ef	41.3a	33.5a
Water oak	Bareroot Baxter site	-7.4def	-5.1d	-11.3de
Water oak	Conventional Containerized Reinike site	-12.7fg	22.4b	10.1bc
Water oak	Conventional Containerized Baxter site	-10.2fg	-2.9d	-13.9de
Water oak	EKOgrown® Reinike site	-15.0g	8.2c	-5.4cde
Water oak	EKOgrown® Baxter site	-1.2cde	-6.1d	-4.6cde

*Values in a column followed by the same letter are not significantly different (α=0.05).
**Overall results may slightly differ from sum of both growing seasons due to additive mortality

Height growth comparison discussion

All planting stocks of water oak expressed height loss on both sites during the first growing season. During the second growing season, all treatments on the Reinike site experienced positive height growth. Bareroot water oak seedlings on the Reinike site had the highest overall height growth after experiencing 7.8 cm of dieback during the first growing season (Table 4.20). The same trend was expressed in a study by Dowdy (2015), where only the conventional containerized seedlings experienced positive growth for water oak during the first growing season. After the second growing season in his study except EKO, all planting stocks of water oak experienced an overall positive height growth. This indicates that water oak seedlings are more likely to experience dieback during the first growing season, likely allocating resources to the root system so it can better support height growth in the future. Even though water oak seedlings experienced more first-year dieback than white oak in this study, bareroot and conventional containerized water oak seedlings on the Reinike site exhibited significantly greater height growth than white oak seedlings of the same planting stock during the second growing season. All white oak planting stocks on the Reinike site experienced positive height growth during the first growing season, second growing season, and overall. Except bareroot, all white oak planting stocks on the Baxter site experienced positive height growth during the first growing season, but all white oak treatments experienced dieback on the Baxter site during the second growing season, and overall. White oak treatments on the Reinike site, surpassed only by bareroot water oak on the Reinike site (41.3 cm), had the greatest growth at the end of the second growing season. In this study, white oak seedlings had a steady slow growth throughout the two growing seasons, whereas water oaks experienced dieback during the first growing season, and exhibited rapid growth during the second growing season.

There were no significant differences in height growth between sites when considering both species during the first growing season (Reinike= -2.9 cm, Baxter= -2.1

cm) (Table 4.16). A clear difference was evident in the second growing season (Reinike= 18.5 cm, Baxter= -6.4 cm) and overall (Reinike= 16.7 cm, Baxter= -7.9 cm), as seedlings on the Reinike site had significantly greater height growth than seedlings on the Baxter site. This difference is believed to be due to the nutritional and drainage differences between sites. The frequent wet conditions of the Baxter site prevented the application of herbaceous weed control to a greater portion of the site, leading to a highly competitive environment for seedlings on the nutrient-poor site. The wet conditions of the Baxter site are also not ideal for water oak or white oak, as they prefer better drained soils (Rogers 1990). This combination of poor site conditions led to poor performance of all seedlings on the Baxter site, as all treatments experienced dieback throughout the study.

There were no significant differences in height growth among planting stocks when considering both species during the first growing season. Alkire (2011), Conrad (2013), Dowdy (2015), Hall (2017), Durbin (2018), and Miles (2019) all reported that conventional containerized or EKO seedlings had significantly greater height growth than bareroot seedlings during the first growing season, but that trend was not evident in this study. During the second growing season, bareroot and conventional containerized seedlings exhibited significantly greater height growth than EKO seedlings. Bareroot seedlings had the highest average growth during the second growing season and overall. Conrad (2013), Dowdy (2015), and Miles (2019) had a similar trend where bareroot seedlings outperformed EKO seedlings during the second growing season and overall. This trend is opposite to that found by Williams and Craft (1998), Hollis (2011), Reeves (2016), and Durbin (2018), where bareroot seedlings had significantly less growth than conventional containerized or EKO seedlings.

Overall, white oak seedlings experienced significantly greater height growth than water oak during the first growing season and overall. Water oak seedlings experienced negative height growth during the first growing season, but had significantly greater height growth than white oak during the second growing season (WHO= 2.5 cm, WAO= 9.6 cm) (Table 4.14). Water oak seedlings only had an average overall height growth of 1.4 cm compared to 7.4 cm for white oaks. The dieback of water oaks during the first growing season could possibly be attributed to a combination of stress and allocation of resources towards the roots before stem growth. The improved root system would be able to support more height growth as shown in water oak seedlings during the second growing season. White oak seedlings may be dividing resources more evenly to both the root system and stem, as they had positive height growth throughout both growing seasons. If the same trend in growth rates continues, water oak seedlings could surpass white oak seedlings in future growing seasons.

GLD growth comparison

Analysis of variance

ANOVA was used to determine if there was any statistical significance for GLD growth (Table 4.21) from the effects of site, species, and planting stock. ANOVA is limited to reporting significance among groups, therefore a Tukey-Kramer multiple comparisons procedure (MCP) was performed to determine significance within groups. The ANOVA and MCP analyses results for each variable are explained subsequently in the proper section for site, species, planting stock, and their interactions.

Table 4.21 ANOVA results for average groundline diameter growth by year and overall

		Growing Season					
		2018		2019		Overall	
Source	DF	F	P>F	F	P>F	F	P>F
(A) Species	1	0.54	0.4610	14.96	0.0001	20.90	<.0001
(B) Stock	2	9.01	0.0001	9.31	<.0001	31.73	<.0001
(C) Site	1	17.97	<.0001	346.58	<.0001	450.31	<.0001
A*B	2	5.18	0.0057	13.64	<.0001	33.21	<.0001
B*C	2	58.18	<.0001	9.45	<.0001	21.61	<.0001
A*C	1	1.64	0.2002	0.32	0.5703	0.58	0.4450
A*B*C	2	0.76	0.4698	0.96	0.3839	3.87	0.0211

GLD growth variation between species

ANOVA did not reveal evidence of an effect of species on GLD growth during the first growing season ($F= 0.54$, $p= 0.4610$) (Table 4.21). Significant differences were detected during the second growing season ($F= 14.96$, $p= 0.0001$) and overall ($F= 20.90$, $p<.0001$).

There was no significant difference in GLD growth between species during the first growing season (WHO= 0.9 mm, WAO= 1.0 mm) (Table 4.22). However, water oak seedlings exhibited significantly greater GLD growth during the second growing season (WHO= 1.5 mm, WAO= 2.2 mm) and overall (WHO= 2.4 mm, WAO= 3.3 mm).

Table 4.22 Average groundline diameter growth by species, growing season, and overall for both sites and all planting stocks

Species	Growing Season 2018	2019	Overall**
	-----------------------Millimeters-------------------------		
White oak	0.9a*	1.5b	2.4b
Water oak	1.0a	2.2a	3.3a

*Values in a column followed by the same letter are not significantly different (α=0.05).
**Overall results may slightly differ from sum of both growing seasons due to additive mortality

GLD growth variation among planting stocks

ANOVA revealed evidence of an effect of planting stock on GLD growth during the first growing season (F= 9.01, p= 0.0001), second growing season (F= 9.31, p<.0001), and overall (F= 31.73, p<.0001) (Table 4.21). MCP analysis was used to further determine significant interactions.

All planting stocks exhibited positive GLD growth during both years. EKO seedlings had significantly higher growth than bareroot or containerized seedlings during the first growing season (BRT= 0.7 mm, CC= 0.8 mm, EKO= 1.3 mm), second growing season (BRT= 1.5 mm, CC= 1.7 mm, EKO= 2.3 mm), and overall (BRT= 2.3 mm, CC= 2.5 mm, EKO= 3.7 mm) (Table 4.23).

Table 4.23 Average groundline diameter growth by planting stock per growing season, and overall for both sites and species

Planting Stock	Growing Season 2018	2019	Overall**
	--------------------Millimeters--------------------		
Bareroot	0.7b*	1.5b	2.3b
Conventional Containerized	0.8b	1.7b	2.5b
EKOgrown®	1.3a	2.3a	3.7a

*Values in a column followed by the same letter are not significantly different (α=0.05).
**Overall results may slightly differ from sum of both growing seasons due to additive mortality

GLD growth variation between sites

ANOVA revealed evidence of an effect of site on GLD growth during the first growing season ($F= 17.97$, $p<.0001$), second growing season ($F= 346.58$, $p<.0001$), and overall ($F= 450.31$, $p<.0001$) (Table 4.21).

GLD growth of seedlings was significantly higher on the Reinike site than on the Baxter site during the first growing season (Reinike= 1.2 mm, Baxter= 0.6 mm), second growing season (Reinike= 3.7 mm, Baxter= 0.02 mm), and overall (Reinike= 4.9 mm, Baxter= 0.8 mm) (Table 4.24).

Table 4.24 Average groundline diameter growth by site per growing season, and overall for both species and all planting stocks.

Site	Growing Season 2018	2019	Overall**
	----------------------Millimeters----------------------		
Reinike site	1.2a*	3.7a	4.9a
Baxter site	0.6b	0.02b	0.8b

*Values in a column followed by the same letter are not significantly different (α=0.05).
**Overall results may slightly differ from sum of both growing seasons due to additive mortality

GLD growth variation by species and planting stock

ANOVA revealed evidence of an effect of species and planting stock interaction on GLD growth during the first growing season (F= 5.18, p= 0.0057), second growing season (F= 13.64, p<.0001), and overall (F= 33.21, p<.0001) (Table 4.21). MCP analysis was used to further determine significant interactions.

All species/planting stock combinations experienced some GLD growth (Table 4.25). Water oak conventional containerized seedlings exhibited the lowest growth (0.6 mm) of all species/planting stock combinations, while water oak EKO seedlings exhibited the greatest growth (1.6 mm) during the first growing season. During the second growing season and overall, water oak EKO seedlings exhibited significantly greater GLD growth than all other species/stock combinations (3.4 mm) and overall (5.2 mm). The other species/stock combinations did not differ significantly during the second growing season (1.2-1.9 mm). White oak bareroot (1.9 mm), EKO (2.3 mm) and water oak conventional containerized (2.0 mm) seedlings exhibited the least GLD growth overall.

Table 4.25 Average groundline diameter growth by species and planting stock per growing season, and overall for both sites.

Species/Planting Stock	Growing Season 2018	2019	Overall**
	---------------Millimeters--------------		
White oak Bareroot	0.7b*	1.2b	1.9c
White oak Conventional Containerized	1.0ab	1.9b	3.0b
White oak EKOgrown®	0.9b	1.3b	2.3bc
Water oak Bareroot	0.7b	1.9b	2.7b
Water oak Conventional Containerized	0.6b	1.4b	2.0bc
Water oak EKOgrown®	1.6a	3.4a	5.2a

*Values in a column followed by the same letter are not significantly different (α=0.05).
**Overall results may slightly differ from sum of both growing seasons due to additive mortality

GLD growth variation by planting stock and site

ANOVA revealed evidence of an effect of site on GLD growth during the first growing season (F= 58.18, p<.0001), second growing season (F= 9.45, p<.0001), and overall (F= 21.61, p<.0001) (Table 4.21). MCP analysis was used to further determine significant interactions.

Bareroot and conventional containerized seedlings on the Baxter site exhibited negative GLD growth during the first growing season. Bareroot and conventional containerized seedlings on the Reinike, site along with EKO seedlings on the Baxter site, exhibited significantly greater GLD growth during the first growing season when all planting stock/site combinations were considered (1.5 mm, 1.6 mm, and 1.9mm, respectively) (Table 4.26).

Bareroot seedlings on the Baxter site continued to express negative GLD growth during the second growing season (-0.4 mm) (Table 4.26). GLD growth of all planting stocks on the Baxter site was significantly lower than on the Reinike site during the second growing season. EKO seedlings on the Reinike site expressed the highest GLD growth (4.7 mm) during the second growing season, followed by bareroot (3.5 mm) and conventional containerized seedlings (2.8 mm). All planting stocks on the Reinike site expressed significantly greater GLD growth overall (BRT= 5.0 mm, CC= 4.4 mm, EKO= 5.2 mm) than on the Baxter site. EKO seedlings expressed significantly greater GLD growth than other planting stocks on the Baxter site overall (BRT= -0.4 mm, CC= 0.7 mm, EKO= 2.2 mm).

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

Planting Stock/Site	Growing Season 2018	2019	Overall**
	--------------Millimeters--------------		
Bareroot Reinike site	1.5a*	3.5b	5.0a
Conventional Containerized Reinike site	1.6a	2.8b	4.4a
EKOgrown® Reinike site	0.6b	4.7a	5.2a
Bareroot Baxter site	-0.1c	-0.4c	-0.4d
Conventional Containerized Baxter site	-0.02bc	0.4c	0.7c
EKOgrown® Baxter site	1.9a	0.02c	2.2b

*Values in a column followed by the same letter are not significantly different (α=0.05).
**Overall results may slightly differ from sum of both growing seasons due to additive mortality

GLD growth variation by species and site

ANOVA did not reveal evidence of an effect of species and site interaction on GLD growth during the first growing season (F= 1.64, p= 0.2002), second growing season (F= 0.32, p= 0.5703), or overall (F= 0.96, p= 0.4450) (Table 4.21). This is due to variation within the data sets.

Seedlings of both species on the Reinike site exhibited the best GLD growth during the first growing season (WHO=1.3 mm, WAO=1.2 mm) (Table 4.27). Both species on the Reinike site exhibited significantly greater GLD growth than on the Baxter site during the second growing season and overall. Water oak seedlings on the Reinike site (4.1 mm) exhibited the best GLD growth during the second growing season, followed by white oak seedlings on the Reinike site (3.2 mm). White oak seedlings on the Baxter site exhibited negative GLD growth during the second growing season (-0.3 mm). Water oak seedlings on the Reinike site (5.2 mm) exhibited the best overall GLD growth, followed by white oaks on the Reinike site (4.5 mm). White oak seedlings on the Baxter site exhibited very little overall GLD growth (0.3 mm).

Table 4.27 Average groundline diameter growth by species and site per growing season and overall for all planting stocks.

	Growing Season		
Species/Site	2018	2019	Overall**
	-----------------------Millimeters---------------------		
White oak Reinike site	1.3a*	3.2b	4.5b
White oak Baxter site	0.5c	-0.3c	0.3d
Water oak Reinike site	1.2ab	4.1a	5.2a
Water oak Baxter site	0.8bc	0.3c	1.3c

*Values in a column followed by the same letter are not significantly different (α=0.05).
**Overall results may slightly differ from sum of both growing seasons due to additive mortality

GLD growth variation by treatment and site

ANOVA did not reveal evidence of an effect of treatment and site interaction on GLD growth during the first growing season (F= 0.76, p= 0.4698), or second growing season (F= 0.96, p= 0.3839). However, significant interactions were detected in overall growth (F= 3.87, p= 0.0211) (Table 4.21). MCP analysis was used to further determine significant interactions.

White oak conventional containerized seedlings on the Reinike site exhibited the greatest GLD growth during the first growing season (1.8 mm), while the same treatment on the Baxter site exhibited very little growth by comparison (0.2 mm) (Table 4.28). EKO white oak was the only treatment to exhibit GLD growth of more than 1.0 mm on the Baxter site during the first growing season (1.4 mm), while all other treatments at that site expressed either low or negative growth (-0.2 – 0.2 mm). All water oak treatments on the Baxter site exhibited the least GLD growth of all treatments during the first growing season.

White oak conventional containerized, water oak conventional containerized, and water oak EKO seedlings were the only treatments on the Baxter site to exhibit positive GLD growth during the second growing season (Table 4.28). Seedlings on the Reinike site grew at least twice as much compared to seedlings in the same treatment on the Baxter site. Water oak EKO seedlings on the Reinike site (5.6 mm) exhibited significantly greater GLD growth than any other treatment on either site during the second growing season. Bareroot seedlings of both species (WHO= -0.7 mm, WAO= -0.1 mm) and white oak EKO (-1.1 mm) on the Baxter site had the greatest GLD reduction during the second growing season. All treatments on the Reinike site, except water oak EKO, had similar GLD growth during the second growing season (2.8-3.9 mm).

Water oak EKO seedlings on the Reinike site exhibited the greatest amount of GLD growth overall (6.3 mm) (Table 4.28). Water oak bareroot (5.4 mm) and white oak conventional containerized seedlings (4.7 mm) on the Reinike site exhibited overall GLD growth exceeded only by EKO water oaks at the Reinike site. White oak bareroot (-0.8 mm), water oak bareroot (-0.04 mm), and water oak conventional containerized (-0.08 mm) seedlings on the Baxter site all exhibited negative overall GLD growth.

Table 4.28 Average groundline diameter growth by treatment and site per growing season for both species.

Species	Planting Stock/Site	Growing Season 2018	2019	Overall**
		--------------Millimeters-------------		
White oak	Bareroot Reinike site	1.5b*	3.1b	4.6bc
	Bareroot Baxter site	-0.1d	-0.7fg	-0.8e
	Conventional Containerized Reinike site	1.8ab	2.9bc	4.7abc
	Conventional Containerized Baxter site	0.2d	0.9cdef	1.4d
	EKOgrown® Reinike site	0.5cd	3.8b	4.2c
	EKOgrown® Baxter site	1.4bc	-1.1g	0.4de
Water oak	Bareroot Reinike site	1.4b	3.9b	5.4ab
	Bareroot Baxter site	-0.02d	-0.1efg	-0.04de
	Conventional Containerized Reinike site	1.3abcd	2.8bcd	4.1bc
	Conventional Containerized Baxter site	-0.2d	0.002efg	-0.08de
	EKOgrown® Reinike site	0.8bcd	5.6a	6.3a
	EKOgrown® Baxter site	-0.1d	1.2de	4.1c

*Values in a column followed by the same letter are not significantly different (α=0.05).
**Overall results may slightly differ from sum of both growing seasons due to additive mortality

GLD growth comparison discussion

Oak seedlings tend to prioritize root growth over shoot growth in their early years after establishment (Gardiner et al. 2010, Canham et al. 1996). Conventional containerized and EKO seedlings should have an advantage over bareroot seedlings because their root systems are not disturbed during planting and should not need to allocate as many resources to further root development before improving shoot growth.

Jacobs et al. (2005) stated that taller seedlings, such as EKO seedlings, have an advantage over smaller seedlings because they are able to compete better against surrounding vegetation for light and should have greater first year GLD growth. A study by Dey et al. (2004) showed that large potted seedlings planted in a Missouri floodplain exhibited significantly greater GLD and height growth than bareroot seedlings. Similar studies by Hollis (2011), Alkire (2011), Reeves (2016), and Miles (2019) also support this statement as the large potted seedlings in their studies exhibited significantly greater GLD growth than other planting stocks. This trend was observed in this study as the EKO planting stock exhibited significantly greater GLD growth than bareroot and conventional containerized seedlings in the first growing season, second growing season, and overall. Some other similar studies reported differing results, as stated by Durbin (2018), where bareroot seedlings exhibited significantly greater GLD growth than large potted or conventional containerized seedlings throughout the entire two-year study. Bareroot seedlings in Hall (2018) had greater GLD growth than EKO seedlings in the second growing season, but not overall. Although EKO seedlings in this study exhibited greatest GLD growth, survival was significantly lower than bareroot planting stock (BRT= 71.8%, EKO= 66.9%) (Table 4.7), and height growth was the least of all planting stocks (BRT= 8.0 cm, CC= 3.2 cm, EKO= 1.9 cm) (Table 4.15).

Although not a significant difference, water oak seedlings exhibited greater average GLD growth compared to white oak during the first growing season. Water oak seedlings exhibited significantly greater GLD growth compared to white oak seedlings during the second growing season and overall (WHO= 2.4 mm, WAO= 3.3 mm) (Table 4.22). This trend is similar to Dowdy's (2015) study where water oak seedlings exhibited greater GLD growth compared to swamp chestnut oak (*Quercus michauxii*) in the first and second growing seasons. In contrast, Shumard oak (*Quercus shumardii*) seedlings in Durbin's (2018) study exhibited less GLD growth than swamp chestnut oak seedlings. The greater GLD growth in this study could contribute to the rapid second year height growth of water oak, as it could have grown a more developed root system.

Seedlings on the Reinike site displayed significantly greater GLD growth during the first growing season, second growing season, and overall. Water oak EKO seedlings on the Reinike site exhibited greater overall GLD growth (6.3 mm), but not significantly greater than water oak bareroot (5.4 mm) or white oak conventional containerized seedlings (4.7 mm) on the Reinike site. All water oak and white oak bareroot seedlings experienced negative GLD growth on the Baxter site during the first growing season. White oak bareroot (-0.7 mm) and EKO (-1.1 mm), and water oak bareroot (-0.1 mm) seedlings continued to show decreasing GLD on the Baxter site during the second growing season. Water oak EKO seedlings on the Baxter site were able to regain first-year growth loss and had an overall GLD growth of 4.1 mm. One possible explanation for this reduction could be that sediment deposition on the site possibly created a difference in the exact point of measurement between initial measurements and at the end of the first growing season. All treatments with GLD reduction also exhibited height loss. This height loss could be partially attributed to the possible sedimentation creating a higher ground-level than before, but dieback was present in the crowns of the seedlings on the Baxter site. This may also indicate that seedling diameter actually shrank due to internal resource allocation resulting from poor site conditions. Both species prefer better drained soils than those on the Baxter site. The Baxter site was inundated throughout most of the study and has a soil pH of 4.5. This is on the low end of white oak's pH tolerance and is actually outside the tolerance range of water oak (WHO= 4.5-6.8, WAO= 4.8-6.8). Rogers (1990) mentions that mineral nutrition is a limiting factor for white oak growth in sandy soils. The Baxter site is nutrient limited compared to the Reinike site (Table 4.4). Conventional containerized and EKO seedlings are supplied with essential nutrients in the potting mixture to assist with seedling transplant. This could explain why bareroot seedlings were the only white oak planting stock on the Baxter site to experience negative GLD growth during the first growing season. Bareroot seedlings on the Baxter site continued to experience GLD reduction during the second growing season. White oak EKO seedlings had shown GLD growth during the first growing season, but decreased by 1.1 mm during the second growing season. This was the only treatment to exhibit shrinkage during the second growing season after having positive growth during the first growing season. This treatment also exhibited height dieback (-10.2 mm) during the second growing season, so it is not likely that it shifted resource allocation from the roots to the stem. It is likely that failure to consider species/site relations is causing seedlings to respond to a lack of resources necessary to survive in that environment.

Physiological Measurements Comparison

V_{cmax}, J_{max}, and TPU

ANOVA was used to determine if there was any statistical significance from the effects of site, species, planting stock, and month for maximum Rubisco carboxylation rate (V_{cmax}), maximum electron transport rate (J_{max}), and triose phosphate utilization rate (TPU). ANOVA is limited to reporting significance among groups, therefore a Tukey-

Kramer multiple comparisons procedure (MCP) was performed to determine significance within groups, if necessary. The ANOVA and MCP analyses results only found significant differences among the monthly measurements for these tested variables.

V_{cmax}

ANOVA revealed evidence that months differed significantly in terms of maximum Rubisco carboxylation rate (V_{cmax}) during the first growing season ($F= 3.601$, $p=0.0356$). MCP analysis was used to further determine significance between specific months. V_{cmax} was highest during the month of July (95.0 μmol m^{-2} s^{-1}) (Figure 4.1). V_{cmax} was significantly greater in July than September (81.3 μmol m^{-2} s^{-1}), but not June (82.1 μmol m^{-2} s^{-1}). V_{cmax} in June was not significantly different from July or September.

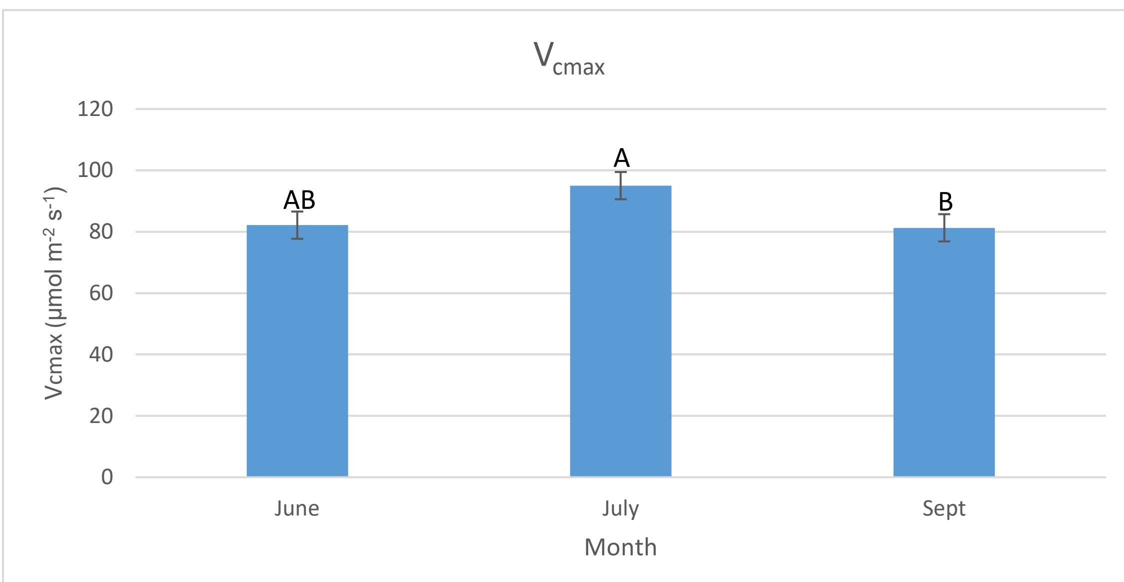

Figure 4.1 Average maximum Rubisco carboxylation rate (V_{cmax}) of all measured seedlings separated by month during the first growing season

J_{max}

ANOVA revealed evidence that months differed significantly in terms of maximum electron transport rate (J_{max}) during the first growing season ($F= 4.866$, $p= 0.0123$). MCP analysis was used to further determine significance among specific months.

J_{max} was highest in the month of July (164.9 μmol m^{-2} s^{-1}) (Figure4.2). J_{max} in July was significantly greater than in June (137.3 μmol m^{-2} s^{-1}), but not September (157.2 μmol m^{-2} s^{-1}). J_{max} in September was not significantly different from J_{max} in June or July.

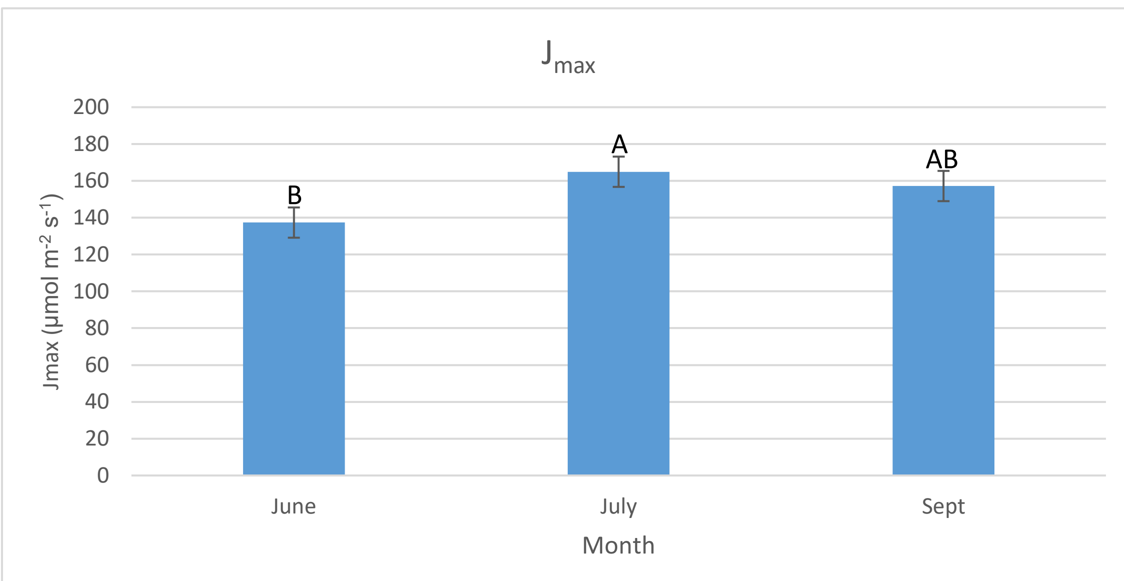

Figure 4.2 Average maximum electron transport rate (J_{max}) of all measured seedlings separated by month in the first growing season

TPU

ANOVA revealed evidence that months differed significantly in terms of triose phosphate utilization rate (TPU) during the first growing season (F= 6.740, p= 0.0028). MCP analysis was used to further determine significance among specific months.

TPU was highest in the month of July (11.9 µmol m^{-2} s^{-1}) (Figure 4.3). TPU in the July and September (11.6 µmol m^{-2} s^{-1}) were significantly greater than in June (9.8 µmol m^{-2} s^{-1}), but not significantly different from each other.

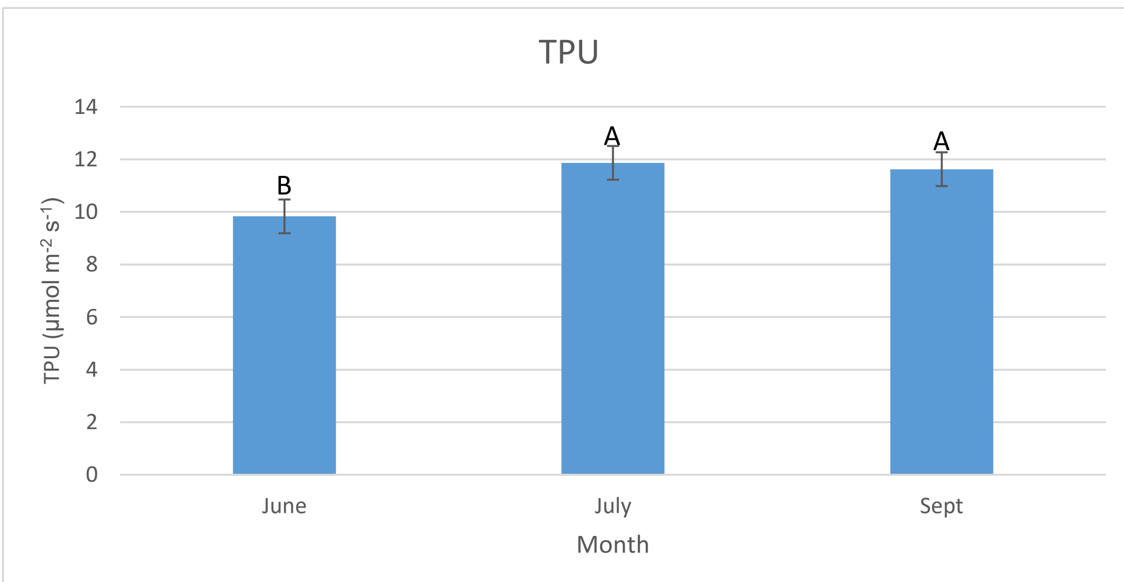

Figure 4.3 Average triose phosphate utilization rate (TPU) of all measured seedlings separated by month during the first growing season

Photosynthesis rates

Analysis of variance (ANOVA) was used to determine if there was any statistical significance for photosynthesis rates from the effects of site, species, planting stock, and month that the data were collected. ANOVA is limited to reporting significance among groups, therefore a Tukey-Kramer multiple comparisons procedure (MCP) was performed to determine significance within groups, if necessary. The ANOVA and MCP analyses results for each variable are explained subsequently in the proper section for site, species, planting stock, month, and their interactions.

Photosynthesis rates between sites

ANOVA revealed evidence that sites differed significantly in terms of photosynthesis rates during the first growing season ($F= 4.677$, $p= 0.0412$).

Reinike site had significantly higher photosynthetic rates across the growing season than the Baxter site (Reinike= 3.4 μmol m^{-2} s^{-1}, Baxter= 1.9 μmol m^{-2} s^{-1}) (Figure 4.4).

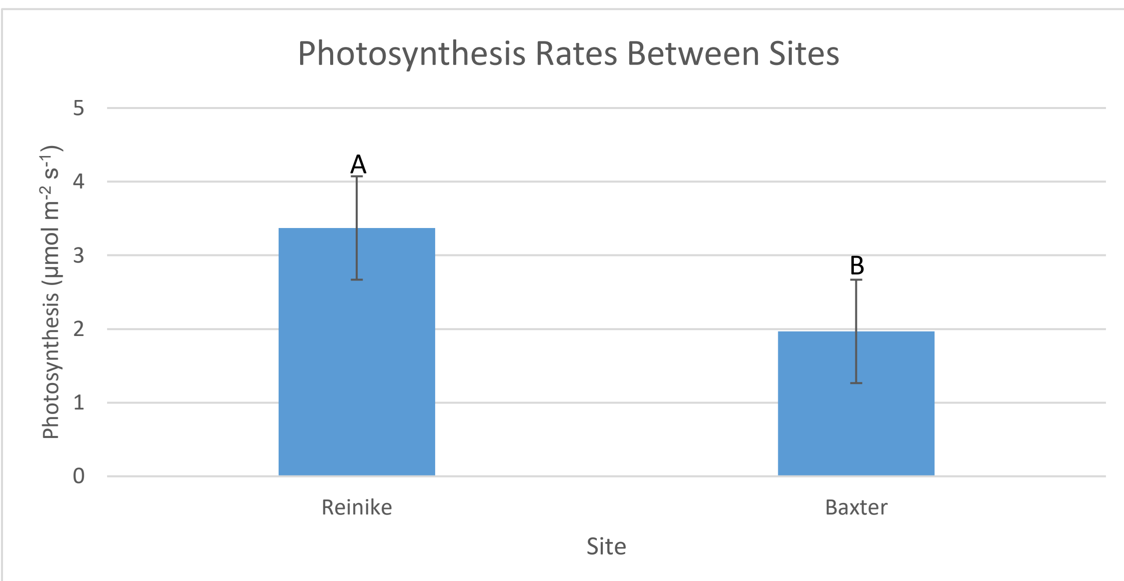

Figure 4.4 Average photosynthesis rates of all measured seedlings on each site during the first growing season.

Photosynthesis rates among months

ANOVA revealed evidence that months differed significantly in terms of photosynthesis rates during the first growing season ($F= 4.184$, $p= 0.0282$). MCP analysis was used to further determine significant differences among months.

Photosynthesis rates were highest in the month of July (3.6 μmol $m^{-2}s^{-1}$) (Figure 4.5). Photosynthesis rates in July were not significantly greater than in June (2.3 μmol $m^{-2}s^{-1}$), but were significantly greater than in September (1.9 μmol $m^{-2}s^{-1}$).

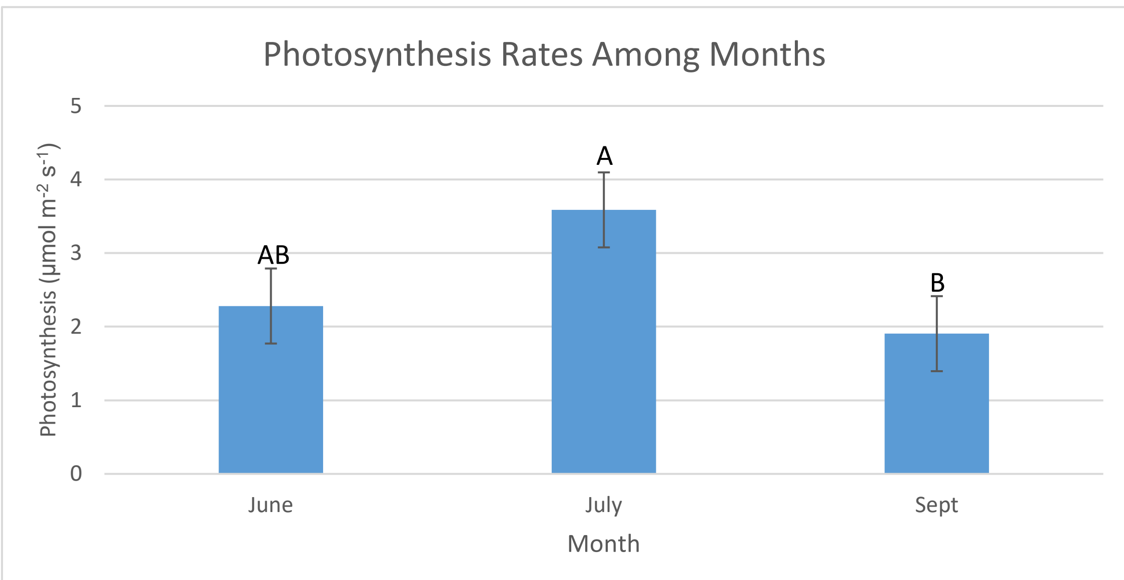

Figure 4.5 Average monthly photosynthesis rates of all measured seedlings during the first growing season.

Photosynthesis rates between species among months

ANOVA revealed evidence of a significant species by month interaction on photosynthesis rates during the first growing season ($F= 3.743$, $p= 0.0392$). MCP analysis was used to further determine significance between groups.

Photosynthesis rates were greatest in white oak seedlings during the month of July than any other species during any other month (4.5 µmol $m^{-2}s^{-1}$) (Figure 4.6). Rates were significantly lower in white oak seedlings during the month of June (1.3 µmol $m^{-2}s^{-1}$) than white oaks in July. White oak rates were higher in September than white oaks in June, but not significantly. White oaks exhibited an overall bell-shaped curve throughout the first growing season. Water oak seedlings exhibited photosynthetic rates that were not significantly different from each other, but exhibited a steady decline throughout the first growing season (June= 3.5 µmol $m^{-2}s^{-1}$, July= 2.7 µmol $m^{-2}s^{-1}$, September= 1.9 µmol $m^{-2}s^{-1}$). Photosynthetic rates in water oaks in June and July were higher than white oaks in June and September. Photosynthetic rates were lowest in either species in any month for white oaks during the month of June (June= 1.3 µmol $m^{-2}s^{-1}$).

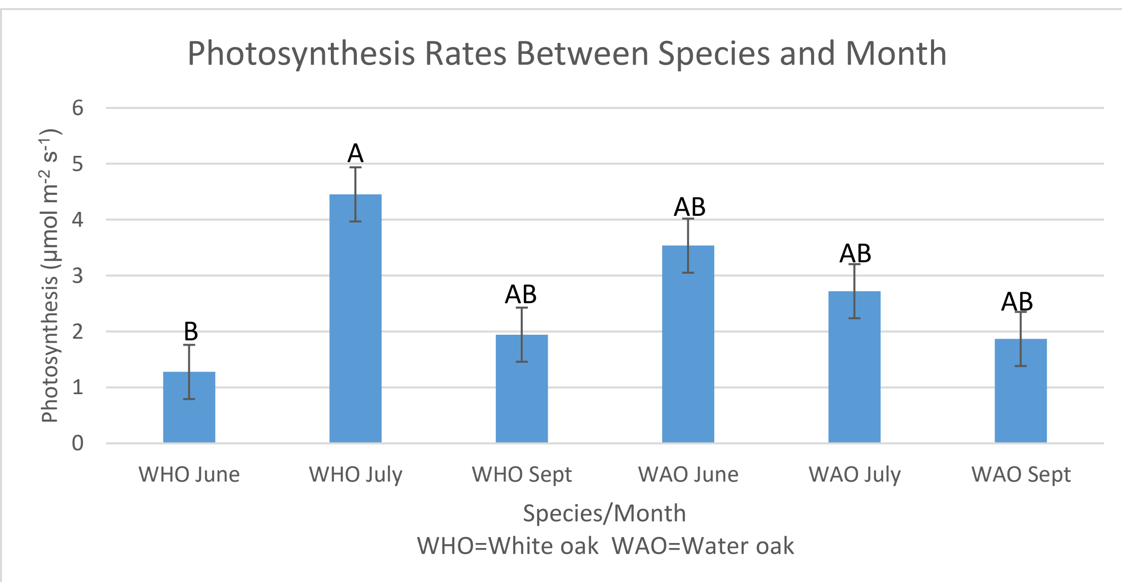

Figure 4.6 Average monthly photosynthetic rates between species during the first growing season.

Transpiration

Analysis of variance (ANOVA) was used to determine if there was any statistical significance for transpiration rates from the effects of site, species, planting stock, and month that the data were collected. ANOVA is limited to reporting significance among groups, therefore a Tukey-Kramer multiple comparisons procedure (MCP) was performed to determine significance within groups, if necessary. The ANOVA and MCP analyses results for each variable are explained subsequently in the proper section for site.

Transpiration rates between sites

ANOVA revealed evidence that sites differed significantly in terms of transpiration rates during the first growing season ($F = 6.079$, $p = 0.0198$).

Transpiration rates were significantly higher from seedlings measured on the Baxter site (3.8 mmol $m^{-2}s^{-1}$) than the Reinike site (2.7 mmol $m^{-2}s^{-1}$) (Figure 4.7).

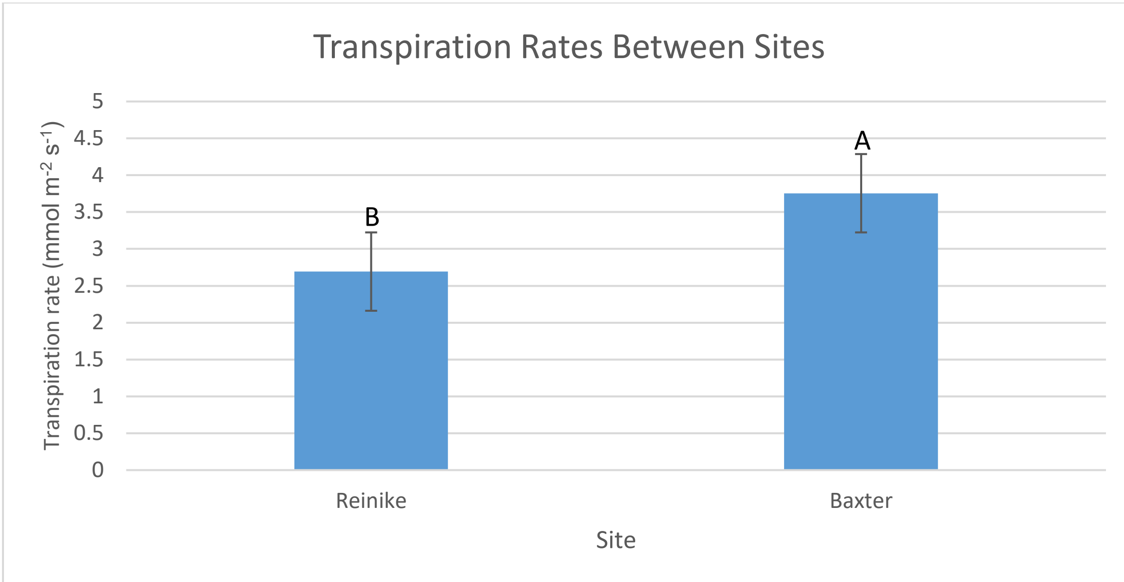

Figure 4.7 Average transpiration rates of all measured seedlings between sites during the first growing season.

Water use efficiency (WUE)

Analysis of variance (ANOVA) was used to determine if there was any statistical significance for water use efficiency (WUE) rates from the effects of site, species, planting stock, and month that the data were collected. ANOVA is limited to reporting significance among groups, therefore a Tukey-Kramer multiple comparisons procedure (MCP) was performed to determine significance within groups, if necessary. The ANOVA and MCP analyses results for each variable are explained subsequently in the proper section for site and month.

WUE between sites

ANOVA revealed evidence that sites differed significantly in terms of water use efficiency (WUE) during the first growing season ($F= 12.780$, $p= 0.00216$).

WUE rates were significantly greater on the Reinike site (1.5 µmol $mmol^{-1}$) than the Baxter site (0.7 µmol $mmol^{-1}$) (Figure 4.8).

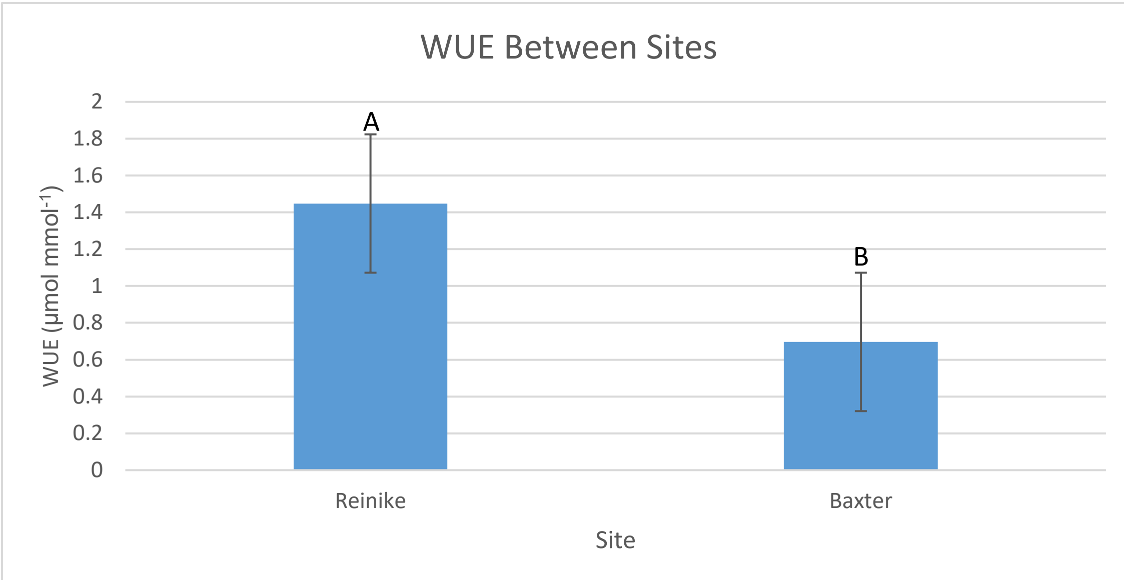

Figure 4.8 Average water use efficiency (WUE) rates of all measured seedlings between sites during the first growing season.

Monthly differences in WUE

ANOVA revealed evidence that months differed significantly in terms of water use efficiency (WUE) during the first growing season (F= 7.856, p= 0.00353). MCP analysis was used to further determine significance among months.

WUE declined throughout the first growing season. It was highest in June and lowest in September. WUE in June and July (1.9 µmol $mmol^{-1}$ and 1.3 µmol $mmol^{-1}$, respectively) were not significantly different from each other, but both were significantly greater than in September (0.6 µmol $mmol^{-1}$) (Figure 4.9).

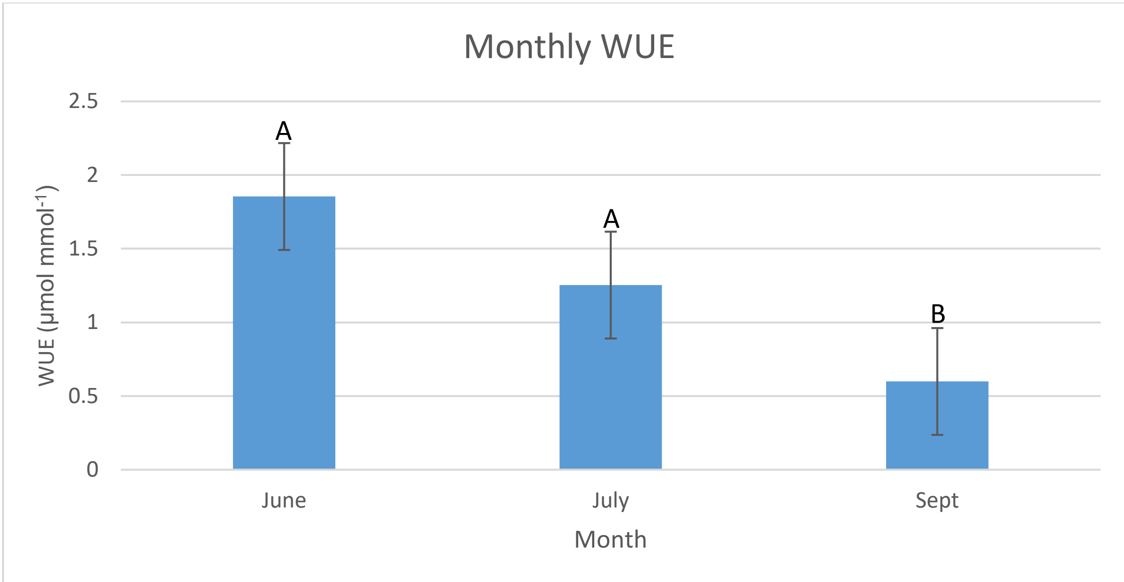

Figure 4.9 Average monthly water use efficiency (WUE) of all measured seedlings during the first growing season.

Leaf Mass per Area (LMA)

Analysis of variance (ANOVA) was used to determine if there was any statistical significance for leaf mass per area (LMA) from the effects of site, species, planting stock, and month that the data were collected. ANOVA is limited to reporting significance among groups, therefore a Tukey-Kramer multiple comparisons procedure (MCP) was performed to determine significance within groups. The ANOVA and MCP analyses results for each variable are explained subsequently in the proper section for site, species, planting stock, month, and their interactions.

LMA between species

ANOVA revealed evidence that species differed significantly in terms of leaf mass per area (LMA) during the first growing season (F= 7.419, p= 0.0105).

Water oak seedlings (110.6 g m^{-2}) exhibited a significantly higher LMA than white oak seedlings (99.6 g m^{-2}) (Figure 4.10).

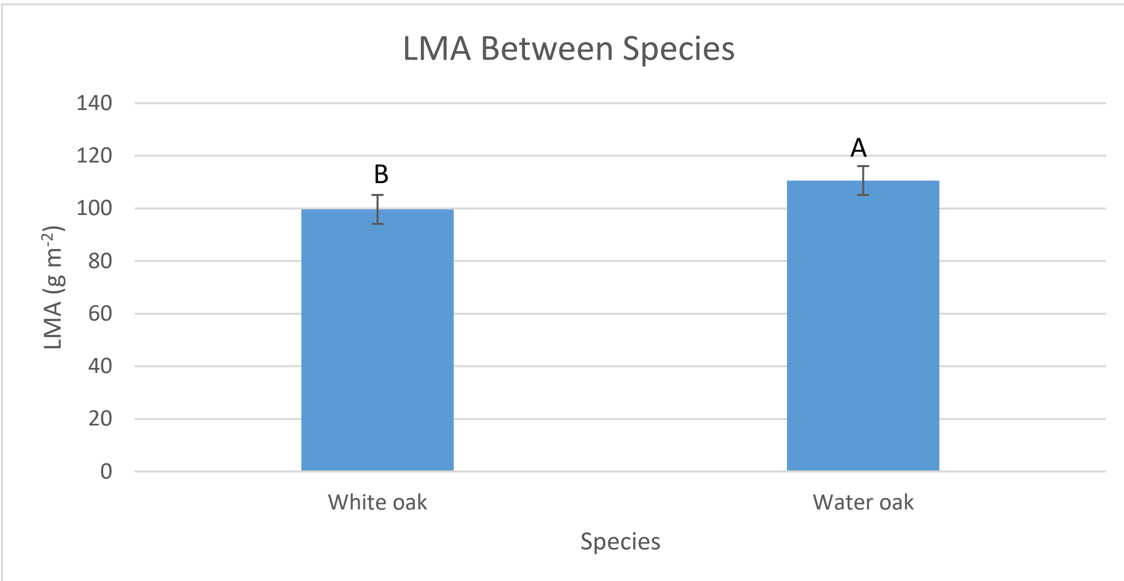

Figure 4.10 Average leaf mass per area (LMA) of all measured seedlings between species during the first growing season.

LMA between sites

ANOVA revealed evidence that sites differed significantly in terms of leaf mass per area (LMA) during the first growing season (F= 5.086, p= 0.0313).

The Baxter site (110.4 g m^{-2}) exhibited a significantly greater LMA than the Reinike site (101.1 g m^{-2}) (Figure 4.11).

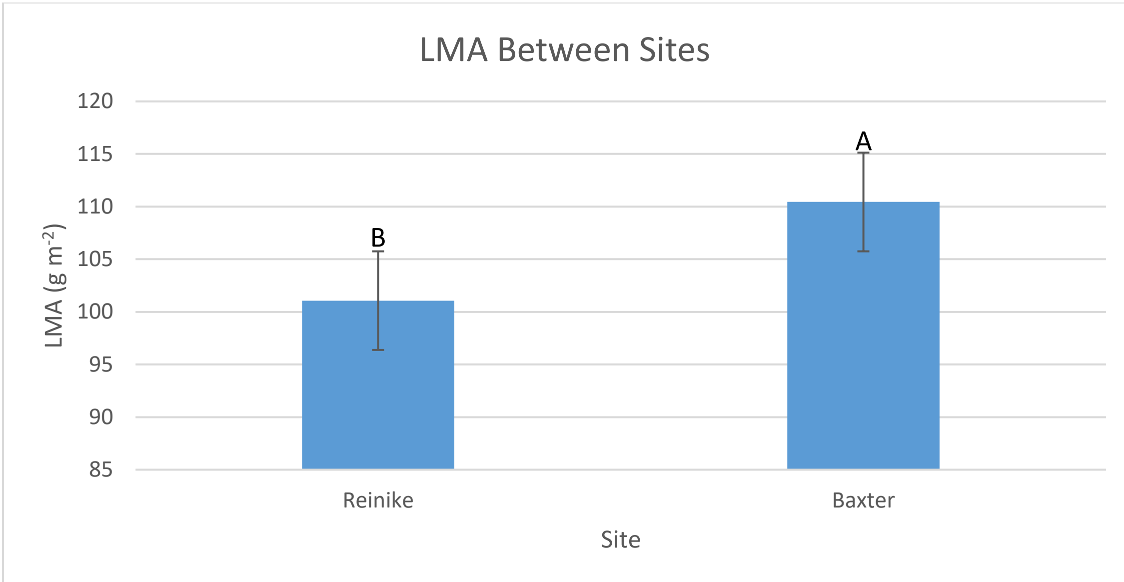

Figure 4.11 Average leaf mass per area (LMA) of all measured seedlings between sites during the first growing season.

LMA among planting stocks

ANOVA revealed evidence that planting stocks differed significantly in terms of planting stock on leaf mass per area (LMA) during the first growing season ($F= 14.934$, $p<0.0001$). MCP analysis was used to further determine significant interactions.

EKO seedlings (119.6 g m^{-2}) had a significantly greater LMA than bareroot (101.7 g m^{-2}) and conventional containerized seedlings (93.7 g m^{-2}) (Figure 4.12). Bareroot seedlings had a greater, though not significant, LMA than conventional containerized seedlings.

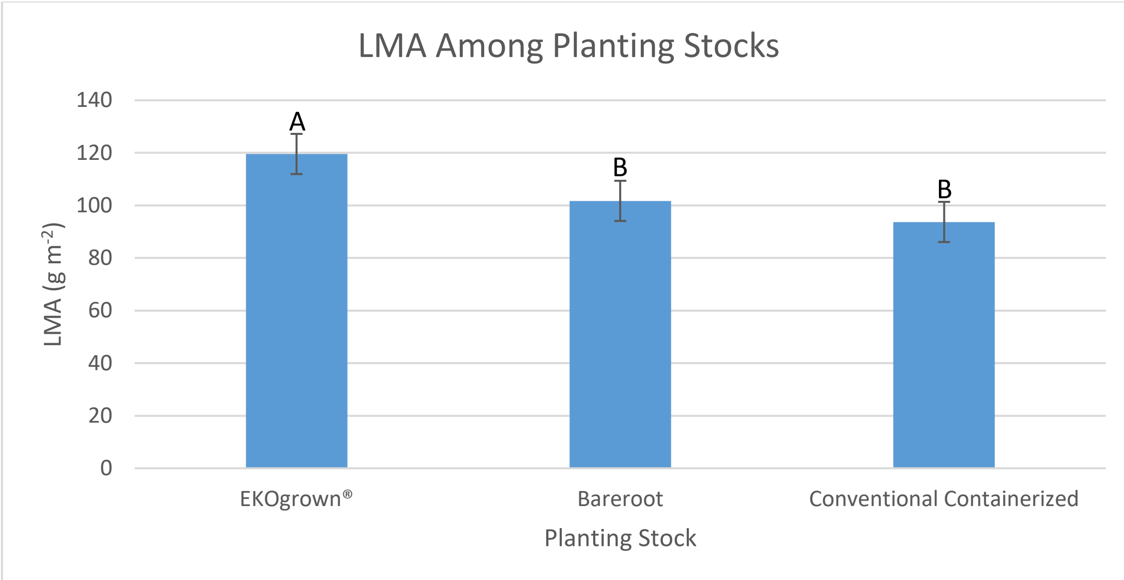

Figure 4.12 Average leaf mass per area (LMA) of all measured seedlings among planting stocks during the first growing season.

LMA among treatments

ANOVA revealed evidence that treatments differed significantly in terms of leaf mass per area (LMA) during the first growing season (F= 3.576, p= 0.0401). MCP analysis was used to further determine significant interactions.

White oak EKO (120.9 g m^{-2}) seedlings exhibited the greatest LMA of all treatments (Figure 4.13), but was not significantly greater than any of the water oak treatments. White oak bareroot (91.2 g m^{-2}) and white oak conventional containerized seedlings (85.4 g m^{-2}) were significantly lower than all other treatments except for water oak conventional containerized seedlings (101.2 g m^{-2}). Conventional containerized seedlings of both species had lower LMA than the bareroot planting stock of the corresponding species. Both species of the EKO planting stock exhibited the highest LMA of all treatments.

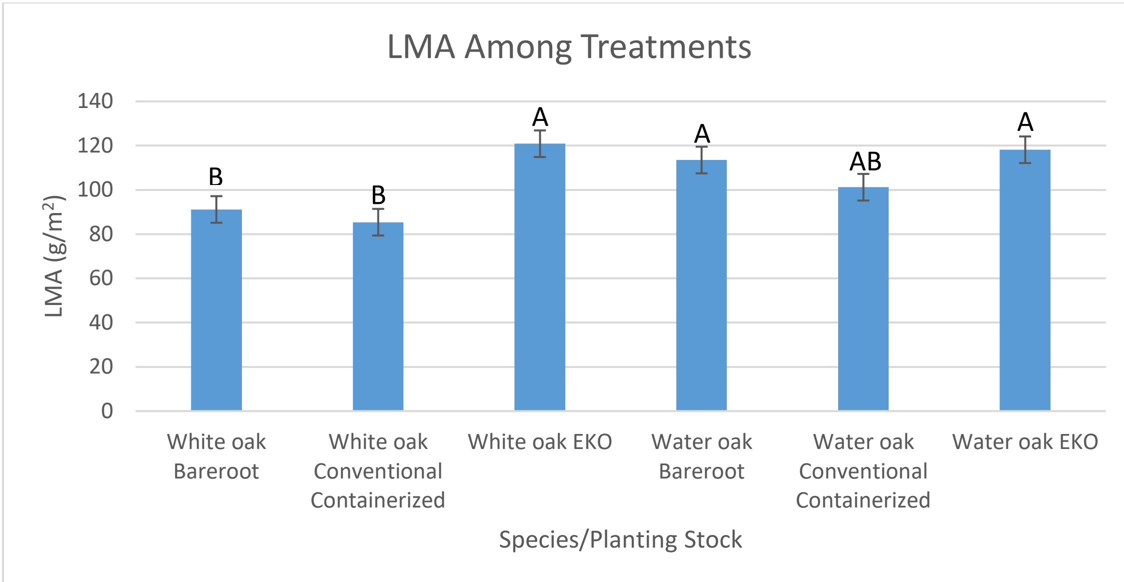

Figure 4.13 Average leaf mass per area (LMA) of all measured seedlings among treatments during the first growing season.

Physiological measurements discussion

The photosynthetic parameters of V_{cmax}, J_{max}, and TPU all exhibited significant relationships only at the monthly level. All three parameters started with lower levels in June, building up in July, and then falling again in September (Figure 4.1). The increase from June to July may have occurred because seedlings had limited competition due to the effects of HWC and the roots were exploiting the surrounding area. Late July and early August was when competition was beginning to encroach upon the seedlings, likely causing the decrease between July and September. The same trend was also exhibited by the photosynthesis rates. Miles (2018) also saw the same trend in photosynthesis rates with cherrybark oak and willow oak, where rates reached a peak in August and fell as the end of the growing season approached.

Photosynthetic rates in this study also differed between sites. The Reinike site exhibited much greater photosynthetic rates than the Baxter site (Figure 4.4). This could be attributed to the difference in soil conditions between the two sites. The Reinike site had higher nutritional value for the seedlings (Table 4.4). Nutrition affects how well the seedlings can perform photosynthesis, and seedlings on the Reinike site had more nutrients available to them, thus increasing photosynthetic rates (Longstreth and Nobel 1980). Longstreth and Nobel (1980) found that lower concentrations of nitrogen, phosphorus, and potassium reduced the net uptake of CO_2 in leaves. Reduced CO_2 uptake leads to reduced CO_2 conductance which leads to reduced photosynthesis. Seedlings on the Baxter site exhibited higher transpiration rates than the Reinike site (Figure 4.9). The Baxter site had more abundant water available, therefore, seedlings on the Baxter site did not need to be efficient with how much water transpired through their leaves, thus decreasing their water use efficiency. Vaitkus and McLeod (1995) found that oaks with lower water availability exhibited higher water use efficiency and higher net photosynthesis.

Photosynthesis rates differed between white oak and water oak seedlings. White oak seedlings exhibited peak rates in July and declined in September (Figure 4.6). Water oak seedlings exhibited the highest photosynthesis rates in June, and steadily declined through the growing season. Miles (2018) also had a similar trend in a similar study. These declining rates could be due to the increasing herbaceous competition and increasing temperatures throughout the growing season. The herbaceous competition reduces photosynthesis of the seedlings by decreasing sunlight, nutrients, and water availability to the seedlings. As the growing season progressed, daily high temperatures increased. As temperatures increased, stomatal conductance increased to the point of the stomata closing during the day, decreasing photosynthesis. The trend of the white oak seedlings in this study resembled that of the overall monthly photosynthesis rates of this study and the overall monthly rates of Miles (2018). The monthly trend of the water oak seedlings of this study exhibited the same declining pattern of the willow oaks in Miles (2018). White oak is a more xeric oak than water oak. The increase in photosynthesis for white oak could be because it is better adapted for drier conditions than water oak, but then the conditions reached the point to where even the white oak could not perform very well. The water oak, being a more mesic oak, was not able to handle the drier conditions as well as the white oak and exhibited a steady decline in photosynthesis throughout the growing season.

Monthly WUE exhibited a declining pattern throughout the growing season in this study. This is another similar pattern to that of Miles (2018) (Figure 4.8). This trend was also shown in a study by Renninger et al (2018) where water use efficiency of planted oaks had a steady decline throughout the growing season. The decreased WUE is due to the higher temperatures of the area. As the temperature increased throughout the growing season, stomatal conductance increased leading to decreasing WUEs in all seedling types.

Leaf mass per unit area (LMA) was significantly higher for water oak seedlings than white oak (Figure 4.10). This could be due to water oaks having smaller leaves in comparison to white oak leaves, but an increased thickness would allow them to perform photosynthesis as well as white oak. LMA was significantly greater on the Baxter site, which exhibited lower photosynthesis rates and lower WUE. Normally, larger LMAs mean that there are more cells conducting photosynthesis in a leaf, but the Baxter site had lower photosynthesis rates. Since the Baxter site was a less suitable site, it could mean that LMA was higher there because the leaves were producing more cellulose for structural support for protection, rather than for photosynthesis. EKO seedlings had significantly greater LMA than bareroot and conventional containerized seedlings. This can be attributed to EKO seedlings' more developed root system and potentially more carbon allowing these seedlings to have greater mass per unit leaf area than the other planting stocks.

First-year physiological measurements could not be related to growth patterns of seedlings in this study. This could be due to overriding factors, such as the poor conditions of the Baxter site and nursery damage of the conventional containerized seedlings and small sample size.

CHAPTER V

CONCLUSIONS

The importance of matching a species to onsite soils and site conditions was obvious in this study. Poor drainage and lower nutrient levels present on the Baxter site created conditions that were not ideal for any planting stock of either species. This led to poor growth and survival of seedlings on that site, regardless of species or planting stock.

Nursery conditions can negatively influence seedling performance of any species or planting stock. Mortality of conventional containerized seedlings in this study began early in the first growing season, indicating damage from the nursery. Freeze damage was observed on seedling, likely resulting from improper care in the nursery. Survival after two growing seasons was very poor. Seedling quality thus remains one of the most important factors in regeneration efforts.

Herbaceous weed control (HWC) is essential to ensure successful regeneration of oak species (Ezell and Hodges 2002, Dey et al. 2007, Jacobs et al. 2005). EKO seedlings are advertised as not requiring HWC applications due to being above competition. EKO seedlings in this study suffered from competing vegetation, especially from climbing vines on the Reinike site. Seedlings that received proper HWC surpassed EKOs in survival and height growth. Lack of HWC on the Baxter site due to wet conditions is another factor leading to inferior seedling performance at that site.

The two species exhibited different growth patterns in this study. This project did not analyze causal factors, but there was a definite difference between first and second year growth of the two species. Water oak seedlings exhibited substantial dieback during the first growing season and rebounded with significant height growth during the second growing season. White oak seedlings exhibited a slower, steady growth pattern. If the observed trend continues, water oak is expected to outperform white oak seedlings in the future.

First year physiological measurements in this study could not be related to growth patterns in this study. Similar conclusions were found by Durbin (2018) and Miles (2019). Although economic analysis was were not used in this study, bareroot seedlings cost considerably less than EKO seedlings ($0.25 vs $15/tree), exhibited better growth and survival, and are therefore considered to be the most cost-effective option for artificial regeneration of bottomland oaks.

REFERENCES

Alkire, D.K. 2011. Artificial regeneration of bottomland hardwoods in southern Mississippi on lands damaged by Hurricane Katrina. M.S. Thesis. Department of Forestry. Mississippi State University. Starkville, MS. 54 pp.

Canham, C.D., A.R. Berkowitz, V.R. Kelly, G.M. Lovett, S.V. Ollinger, and J. Schnurr. 1996. Biomass allocation and multiple resource limitation in tree seedlings. Canadian Journal of Forest Research 26: 1521-1530.

Conrad, J.A. 2013. Early survival and growth performance of two oak species and three planting stocks on Hurricane Katrina disturbed lands. M.S. Thesis. Department of Forestry. Mississippi State University. Starkville, MS. 76 pp.

Dey, D.C., and W.C. Parker. 1997. Morphological indicators of stock quality and field performance of red oak (*Quercus rubra L.*) seedlings underplanted in a central Ontario shelterwood. New Forests 14: 145-156.

Dey, D.C., W. Lovelace, J.M. Kabrick, and M.A. Gold. 2004. Production and early field performance of RPM™® seedlings in Missouri floodplains. In: Michler, C.H., P.M. Pijut, J.W. Van Sambeek, M.V. Coggeshall, J. Seifert, K. Woeste, R. Overton, an F. Ponder. Ed). Proceedings of the sixth walnut council research symposium. USDA Forest Service North Central Research Station. General Technical Report. NC-243. St. Paul, MN. p. 188

Dey, D.C., J.M. Kabrick, and M.A. Gold. 2006. The role of large container seedlings in afforesting oaks in bottomlands. P.218-223. In: Proceedings of the 13th Biennial Southern Silvicultural Research Conference, U.S. Department of Agriculture, Forest Service: Gen. Tech. Rep. SRS-92

Dey, D.C., D. Jacobs, K. McNabb, G. Miller, V. Baldwin, and G. Foster. 2007. Artificial regeneration of major oak (*Quercus*) species in Eastern United States – A review of the literature. Forest Science 54(1): 77-106.

Dowdy. A.D. 2015. Survival and growth performance of two oak species and three planting stocks on lands disturbed by Hurricane Katrina. M.S. Thesis. Department of Forestry. Mississippi State University. Starkville, MS. p. 1-69

Dubois, M.R., A.H. Chappelka, E. Robbins, G. Somers, and K. Baker. 2000. Tree shelters and weed control: effects on protection, survival, and growth of cherrybark oak seedlings planted on a cutover site. New Forests 20(2): 105-118.

Durbin, T. 2018. Early growth and survival of two oak species and three planting stocks on lands disturbed by Hurricane Katrina. M.S. Thesis. Department of Forestry. Mississippi State University. Starkville, MS. 71 pp.

Ezell, A.W., and A.L. Catchot, Jr.. 1998. Competition control for hardwood plantation establishment. In Proceedings of the 9th Biennial Southern Silvicultural Research Conference. US For. Serv. Gen. Tech. Rep. SRS–20. P. 42-43

Ezell, A.W., and J.D. Hodges. 2002. Herbaceous weed control improves survival of planted shumard oak seedlings. In Proceedings of the 11th Biennial Southern Silvicultural Research Conference. US For. Serv. Gen. Tech. Rep. SRS–48. P. 273-275

Ezell, A.W., J. Lowery, B. Leopold, and P.J. Minogue. 1999. Use of imazapyr injection to promote oak regeneration and wildlife stand improvement in bottomland hardwood stands. In Proceedings of the 10th Biennial Southern Silvicultural Research Conference. US For. Serv. Gen. Tech. Rep. SRS-30. P. 151-153

Ezell, A.W., and L. Nelson. 2001. Weed control and crop tolerance after preemergent and postemergent applications of sulfometuron in oak (*Quercus spp*.) plantations. Weed Technology 15(3): 585-589

Ezell, A.W., J.L. Yeiser, and L.R. Nelson. 2007. Survival of planted oak seedlings is improved by herbaceous weed control. Weed Technology 21(1): 175-178

Gardiner, E.S., D.C. Dey, J.A. Stanturf, and B.R. Lockhart. 2010. Approaches to restoration of oak forests on farmed lowlands of the Mississippi River and its tributaries. Columbia Forestal 13(2): 223-236.

Grebner, D.L., A.W. Ezell, D.A. Gaddis, and S.H. Bullard. 2003. Impacts of southern oak seedling survival on investment returns in Mississippi. Journal of Sustainable Forestry 17(3): 1-19

Grossnickle, S.C., and Y.A. El-Kassaby. 2016. Bareroot versus container stocktypes: a performance comparison. New Forests 47(1): 1-51

Guan, B.T., and Y. Cheng. 2003. Ground level diameter as an indicator of sapling structural root characteristics for *Chamaecyparis obtuse* var. *formosana* in northeastern Taiwan. Forest Ecology and Management 173: 227-234.

Hall, A.T. 2017. Assessing two year growth and survival of two oak species and three planting stocks on Hurricane Katrina damaged land. M.S. Thesis. Department of Forestry. Mississippi State University. Starkville, MS. 83 pp.

Hodges, J.D. and G. Switzer. 1997. Development and ecology of bottomland forests. Forest Ecology and Management. 90(2-3): 117-125

Hodges, J.D., D.L. Evans, and L.W. Garnett. 2004. Mississippi trees. Mississippi Forestry Commission. Jackson, MS. p. 77-78, 119-120

Hollis, D.B., A.W. Ezell, E.B. Schultz, J.D. Hodges, A.B. Self, and D.K. Alkire. 2012. Evaluating different planting stocks for oak regeneration on Hurricane Katrina disturbed lands. In: Proceedings of the 16th Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-156. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. p. 151-156.

Humphrey, M.. 1993. Container oak seedlings for bottomland hardwood (BLH) restoration. WRP Technical Note: 1-4.

Jacobs, D.F., K.F. Salifu, and J.R. Seifert. 2005. Relative contribution of initial root and shoot morphology in predicting field performance of hardwood seedlings. New Forests 30: 235-251.

Johnson, P.S. 1984. Responses of planted northern red oak to three overstory treatments. Canadian Journal of Forest Research. 14(4): 536-542.

Johnson, R.L. 1984. Direct-seeded cherrybark and shumard oaks battle natural regeneration through 10 years. Southern Journal of Applied Forestry 8: 226-230.

Kennedy Jr., H., 1992. Artificial regeneration of bottomland oaks. Oak regeneration: Serious problems, practical recommendations. USDA For. Serv., Gen. Tech. Rep. SE-84, Southeastern Forest Experiment Station, Asheville, NC. p. 241-249.

King, S. L., and B. D. Keeland. 1999. Evaluation of reforestation in the Lower Mississippi River Alluvial Valley. Restoration Ecology 7(4): 348-359.

Lockhart, B.R., B. Keeland, J. McCoy, and T.J. Dean. 2003. Comparing regeneration techniques for afforesting previously farmed bottomland hardwood sites in the Lower Mississippi Alluvial Valley, USA. Forestry 76(2): 169-179.

Longstreth, D.J., and P.S. Nobel. 1980. Nutrient influences on leaf photosynthesis: effects of nitrogen, phosphorus, and potassium for *Gossypium hirsutum L.*. Plant Physiology 65(3): 541-543.

Lorimer, Craig G. 1993. Causes of the oak regeneration problem. Oak regeneration: Serious problems, practical recommendations. USDA For. Serv., Gen. Tech. Rep. SE-84, Southeastern Forest Experiment Station, Asheville, NC. p. 14-40.

Manter, D.K., and J. Kerrigan. 2004. A/C_i curve analysis across a range of woody plant species: influence of regression analysis parameters and mesophyll conductance. Journal of Experimental Botany 55(408): 2581-2588

Mattson, A. 1996. Predicting field performance using seedling quality assessment. New Forests 13: 223-248.

McLeod, K.W. 2000. Species selection trials and silvicultural techniques for the restoration of bottomland hardwood forests. Ecological Engineering 15: S35-S46.

Michael, J.L.. 1985. Growth of loblolly pine treated with hexazinone, sulfometuron methyl, and metsulfuron methyl for herbaceous weed control. Southern Journal of Applied Forestry 9(1): 20-26.

Miles, C. H. 2019. Assessing the early growth performance and survival of two oak species and three planting stocks on Hurricane Katrina damaged land. M.S. Thesis. Department of Forestry. Mississippi State University. Starkville, MS. 95 pp.

Miller, J.H.. 1993. Oak plantation establishment using mechanical, burning, and herbicide treatments. Proceedings of Symposium on Oak Regeneration: Serious Problems, Practical Recommendations. USDA Forest Service, General Technical Report SE-84. Southeastern Forest Experiment Station, Knoxville, TN. P. 264-289.

NOAA. 2019. Climate Data Online. Data Tools: 1981-2010 Normals. Available Online at https://www.ncdc.noaa.gov/cdo-web/datatools/normals; last accessed May 21, 2019.

Oswalt, S. N., C. Oswalt, and J. Turner. 2008. Hurricane Katrina impacts on Mississippi forests. Southern Journal of Applied Forestry 32(3): 139-141.

Ouchley, K., R.B. Hamilton, W.C. Barrow, Jr., and K. Ouchley. 2000. Historic and present-day forest conditions: implications for bottomland hardwood forest restoration. Ecological Restoration 18(1): 21.

Peairs, S. E., A. W. Ezell, K. L. Belli, and J. D. Hodges. 2004. A comparison of oak regeneration conditions following Midstory injection and partial overstory removal in a Tombigbee River terrace. Proceedings of the 12th Biennial Southern Silvicultural Research Conference. USDA Forest Service, General Technical Report SRS–71, Southeastern Forest Experiment Station, Asheville, NC. p. 499-501.

Reeves, J. 2016. Early growth and survival of Shumard oak and Nutall oak planting stocks. M.S. Thesis. Department of Forestry. Mississippi State University. Starkville, MS. 69 pp.

Rogers, R.. 1990. *Quercus alba L*. white oak. Silvics of North America 2: 605-613.

Schoenholtz, S.H., J.P. James, R.M. Kaminski, B.D. Leopold, and A.W. Ezell. 2001. Afforestation of bottomland hardwoods in the Lower Mississippi Alluvial Valley: status and trends. Wetlands 21(4): 602-613.

Schummer, M.L., H.M. Hagy, K.S. Fleming, J.C. Cheshier, and J.T. Callicutt. 2011. A guide to moist-soil wetland plants of the Mississippi Alluvial Valley. Jackson, MS: University Press of Mississippi. p. 207.

Self, A.B., A.W. Ezell, A.J. Londo, and J.D. Hodges. 2010. Evaluation of Nuttall oak and cherrybark oak survival by planting stock and site preparation treatment type in a WRP planting on a retired agricultural site. In: Proceedings of the 14th Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. P. 159-163.

Sharkey, T.D., C.J. Bernacchi, G.D. Farquhar, and E.L. Singaas. 2007. Fitting photosynthetic carbon dioxide response curves for C_3 leaves. Plant, Cell and Environment 30(9): 1035-1040.

Stanturf, J. A., C. J. Schweitzer, and E. S. Gardiner. 1998. Afforestation of marginal agricultural land in the Lower Mississippi River Alluvial Valley, U.S.A. Silva Fennica 32(2): 281-297.

Stanturf, J. A., W.H. Conner, E.S. Gardiner, C.J. Schweitzer, and A.W. Ezell. 2004. Overcoming difficult site conditions for afforestation of bottomland hardwoods. Ecological Restoration 22(3): 183-193.

Taylor, J. R., M. A. Cardamone, W. J. Mitsch. 1990. Bottomland Hardwood Forests: Their functions and values. Ecological Processes and Cumulative Impacts: Illustrated by Bottomland Hardwood Wetland Ecosystems. 13-73.

Thompson, J.R., and R.C. Schultz. 1995. Root system morphology of *Quercus rubra L*. plantings stock and 3-year field performance in Iowa. New Forests. 9(3): 225-236.

U.S. Climate Data. 2019. Available Online at. https://www.usclimatedata.com/climate/hattiesburg/mississippi/united-states/usms0152/2019/; last accessed May 21, 2019.

USDA Web Soil Survey. 2019. Available online at https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx; last accessed May 21, 2019.

Vaitkus, M.R., and K.W. McLeod. 1995. Photosynthesis and water-use efficiency of two sandhill oaks following additions of water and nutrients. Bulletin of the Torrey Botanical Club 122(1): 30-39.

Vozzo, J.A.. 1990. *Quercus nigra L*., water oak. Silvics of North America 2: 701-703.

Wang, F., and Y.J. Xu. 2009. Hurricane Katrina-induced forest damage in relation to ecological factors at landscape scale. Environmental Monitoring and Assessment. 156: 491-507.

Williams, H.M., and M.N. Craft. 1998. First-year survival and growth of bareroot, container, and direct-seeded Nuttall oak planted on flood-prone agricultural fields. In: Proceedings of the Ninth Biennial Southern Silvicultural Research Conference. USDA Forest Service, General Technical Report SRS–20, Southeastern Forest Experiment Station, Asheville, NC. p. 300-303.

Yadav, N., R.E. McDevitt, S. Benard, and S.C. Falco. 1986. Single amino acid substitutions in the enzyme acetolactate synthase confer resistance to the herbicide sulfometuron methyl. Proceedings of the National Academy of Sciences of the United States of America. 83: 4418-4422.