8-2019

Comparison of the Survival and Growth of West Gulf Coastal Plain Pine in East Texas

Jamie Hooker
Stephen F. Austin State University, jamiehooker83@yahoo.com

Comparison of the Survival and Growth of West Gulf Coastal Plain Pine in East Texas

By

Jamie Hooker, Bachelor of Science

Presented to the Faculty of the Graduate School of

Stephen F. Austin State University

In Partial Fulfillment

Of the Requirements

For the Degree of

Master of Science in Forestry

STEPHEN F. AUSTIN STATE UNIVERSITY

May 2019

ABSTRACT

West Gulf Coastal Plain provenance loblolly *(Pinus taeda* L.), longleaf (*Pinus palustris* Mill.), shortleaf (*Pinus echinata* Mill.), and slash pines (*Pinus elliottii* Engelm.) were planted in East Texas to compare initial growth and survival. Containerized seedlings were planted in December 2015 on three study sites in Shelby, Houston, and Cherokee counties using a randomized complete block design. Seedlings were measured in January-February 2016 and again January-February 2017, January 2018, and January 2019. Three years after planting, survival was best (76.4%) in Houston County and was lowest in Cherokee County (26.4). Damage by Texas leafcutter ants (*Atta texana*) caused significant mortality in Cherokee County, while feral hog (*Sus scrofa*) herbivory and uprooting greatly affected survival in Houston and Shelby counties. Tree heights were greater in loblolly and slash pine than in shortleaf and longleaf pine, while diameters were greater in loblolly than slash and shortleaf pine, which where greater than longleaf diameters. Height and survival rates were greater in Shelby County and were least in Cherokee County. Tree height was affected by soil moisture and texture, while plant moisture stress did not affect aboveground production.

ACKNOWLEDGMENTS

Funding and land allocation for this project was provided by ST Microelectronics and the Arthur Temple College of Forestry and Agriculture at Stephen F. Austin State University (SFASU). I am truly grateful for the opportunity and support that my advisor, Dr. Brian Oswald, has given me throughout my graduate career. Much appreciation also goes to my committee members: Dr. Jeremy Stovall, Dr. Yuhui Weng, and Dr. Hans Williams for their encouragement and guidance. Without the direction of my advisor and graduate committee this thesis would only have a title page.

A huge thank you to Jason Grogan for his assistance with the experimental design, site prep, and caretaking of my research plots. Thank you to Southern Power for providing financial assistance to me during my enrollment at SFASU. Thank you to Ron Ray for allowing me to work, learn, and build experience, while also providing me with the flexibility to continue my education. My research and completion of this degree would not have been possible without your generosity. Much appreciation to Stephen McInnis for all the advice, patience, and tough love given to me throughout the years. Also, thank you Stephen, for giving me the extra push I needed to make things happen and for always believing in my ability to accomplish anything. Thank you to Bill MacClain for teaching me the ins-and-outs of life and encouraging me to pursue this degree and the even greater adventures beyond it. And thank you to the rest of my Plant Nacogdoches family for fully supporting me in life, work, and school and for treating me with so much love and kindness. Thank you to the many technicians who assisted with field and lab work: Taylor Barton, K’Shel Bell, Jade Buckley, Kai Busch-Peterson, Thomas Dimmitt, Bobby Hearne, Logan Hope, Susanna Husbands, Ashley Johnson, Will Kruckeburg, Rachel Murray, Jordan Muegge, Nick Peckham, Bella Reyes, Ellart Vreugdenhil, Allie Williams, and Kaitlyn Yates. Without your hard work and dedication, I would still be in the field measuring trees and collecting soil samples. Many thanks to my fellow graduate students who supported me and kept me smiling during this entire process: Connor Adams, Hannah Angel, Ryan Assenheimer, Amy Brennan, Bryce Gerlach, Josue Gonzalez, Melissa Griffith, Ryan Jacques, Alix Matthews, Cassie Phillips, Ryan Svhela, Mike Tiller, and Tamara Wood. Finally, thank you to my parents, James and Debbie, and brother, Gary, for all the encouragement, support, and love you have shown to me throughout my life and especially throughout my pursuit of a master’s degree.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Pine plantation forests are an important economic resource in East Texas and account for 22% of all forested area within the region. Pines are grown for timber production across diverse landscapes and soil types by private landowners and large timberland management organizations. Because these plantations can take up to 35 years to maximize productivity, it is important for landowners to invest their money in the species that will best meet desired objectives. Each of the four major southern yellow pine species: loblolly pine (*Pinus taeda* L.), longleaf pine *(Pinus palustris* Mill.), shortleaf pine (*Pinus echinata* Mill.), and slash pine (*Pinus elliottii* Engelm.), require specific site conditions that allow them to produce valuable timber at higher growth rates. These differences in yield can provide the landowner with improved profit. Due to the economic value of timber in East Texas, there is an interest in finding the differences in growth rates of the four major southern pines on a variety of soil types. These comparisons may be able to provide landowners with a better understanding of which species will maximize wood production on their land in the early years of rotation.

There has also been an increased interest in the improved genetics of West Gulf Coastal Plain southern pines. The West Gulf Coastal Plain provenance pines are gaining more attention because of their resistance to fusiform rust (*Cronartium quercuum* f.sp, *fusiforme*) and high drought tolerance in this sub-region.

Choosing the appropriate species to use is the most important decision to be made prior to planting pine in the South. Species, soil type, and seedling source play a large role in the growth and survival of trees in pine plantations. Although thousands of acres supporting shortleaf and longleaf pine have been declining in East Texas, the ecosystems associated with these species still hold high ecologic value. In recent years, large efforts have been made in promoting planting longleaf and shortleaf over loblolly pine in an attempt to restore these ecosystems in their native range. For landowners who have objectives that are not solely timber production, planting shortleaf and longleaf may be a viable choice for ecologic importance, as well as economic return if they are planted on suitable sites. Landowners can increase profits and maximize yields if species requirements and site characteristics are considered carefully.

OBJECTIVES

The goal of this study was to compare the survival and growth of single West Gulf Coastal Plain provenances of loblolly pine, longleaf pine, shortleaf pine, and slash pine in East Texas with the following objectives:

1. Assess seedling survival and growth rates each year.
2. Use soil texture, drainage classifications, and moisture to determine the effects of these characteristics on seedling growth and survival response.
3. Utilize leaf water potential of each species at each site to test seedling response to stress and moisture availability and its effects on survival and growth.
4. Correlate needle and soil nutrients with mean height and diameters to determine the uptake of nutrients by trees for species and site.

LITERATURE REVIEW

Silvics

Climate is one of the driving factors of tree growth and local adaptation (Schmidtling 2001) to drought-avoidance, biomass allocations, and water use efficiency (Eckert et al. 2010). Loblolly, longleaf, slash, and shortleaf pines require humid, hot summers with mild winters. Mean annual temperature and rainfall shape the distributions of the southern pines (Morgenstern 1996), where areas with temperatures ranging from 13° to 24° C are preferred and average precipitation ranges from 102 cm to 152 cm (Baker and Langdon 1990).

Loblolly Pine

Loblolly pine grows from central Florida, northward to Delaware, and westward as far as East Texas. It is the major timber species in the southeastern United States where it is over 50% of standing pine volume (Shultz 1999) and dominates 11.7 million hectares (Baker and Balmer 1983). Loblolly pine is often chosen to reforest sites that have been previously impacted by human activities because it is highly adaptable (Shultz 1999). Although it can establish itself on a wide variety of soil types, loblolly pine grows faster than any other southern pines on well-drained, productive sites (Shiver et al. 2000). Best growth can be obtained on slightly acidic soils with a moderate surface drainage, and a thick, silt loam texture, while the poorest performance occurs on shallow soils, or very wet, waterlogged sites (Baker and Langdon 1990). It is also an important component of moist sites that are not subject to frequent burning (Schultz 1999). The best seedling height growth occurs when day and night temperatures differ by 12 to 13 °C during the growing season (Boyer 1970; Griffing and Elam 1971). Soil moisture is a critical factor in loblolly pine seedling establishment (Baker and Langdon 1990); however, seedlings cannot tolerate prolonged periods of flooding, with significant mortality occurring within two weeks of complete inundation (Baker and Balmer 1983). Height and diameter growth are greatly reduced by spring droughts (Fowells 1965; Stransky and Wilson 1964; Zahner 1968).

Longleaf Pine

Longleaf pine once occupied 37 million hectares across the southeastern U.S. from Virginia to Texas (Frost 2006). Due to fire suppression and land conversion to agriculture and urban development, longleaf pine monocultures have declined to approximately 1 million hectares (Scott and Burger 2014). While longleaf pine is relatively drought tolerant and competes well on xeric, sandy soils, it is also native to wet bottomlands where frequent fire reduces loblolly pine encroachment (Scott and Burger 2014). Longleaf pine can tolerate heavy fluctuations between dry periods during the spring and summer months and heavy rains in the winter months (Ware et al. 1993). The most productive longleaf pine sites have been on upland sites with high nutrient content in both North Carolina and Texas (Outcalt 2000). Along with its ability to grow on variable soils, longleaf pine is also the most insect, disease, windthrow, and fire-resistant pine in the southern United States (Franklin 2008). It also helps to maintain diverse early successional conditions in the understory with its narrow crown that allows sunlight to penetrate the forest floor and because it can be safely burned at shorter intervals than other southern pines. (Franklin 2008). During the first few years after germination, longleaf pine seedlings remain in a grass stage where its long needles form a protective barrier around the cambium and terminal bud, shielding them from fire damage. During the grass stage, the majority of seedling growth occurs in the root system and once sufficient root growth has been made, longleaf pine seedlings can put on as much as 2 m in stem growth within a couple of years (Outcalt 2000). Longleaf pine seedlings can remain in the grass stage for several years, but once they emerge from the grass stage they are as productive in growth as the other southern pine species (Landers et al. 1995). In order to be successful, longleaf pine requires herbaceous and woody plant control during the first few years after establishment. It is a very intolerant species and cannot easily compete with other pines and hardwoods without fire or chemical control (Landers et al. 1995). Its deep taproot gives longleaf an advantage over other southern pine species on well-drained sandy soils (Little 1980).

Shortleaf Pine

Shortleaf pine has the most widespread native range of the southern pines (Hallgren and Tauer 1989). It has been recorded in 22 states and is the most common species to be regenerated in the northern and western portions of its range (Lawson 1990). Shortleaf communities are usually associated with soils that are low in organic matter; the best growth rate from the species as a community occurs west of the Mississippi River (Guldin 1986). Preferred soils are those that are well-drained and have a fine sandy loam or silty loam texture. Despite its wide range and adaptability to different sites, shortleaf pine is less preferred as a timber species due to its comparative slow growth rate, difficulty of regeneration, and its susceptibility to pathogens (Guldin 1986). Shortleaf pine seedlings develop a j-shaped crook at their base in the first or second growing season (Little and Somes 1956). This crook is the most important adaptation for shortleaf pine seedlings (Mattoon 1915) because it provides seedlings with protection from low intensity fires (Schwilk and Ackerly 2001). Dormant buds are protected by the litter in the forest floor at the base of the crook, which gives them a higher chance of survival than buds above the ground (Shelton and Cain 2000). Shortleaf pine growth decreases the importance of the j-shaped crook as the seedling bark thickens and provides protection for the cambium (Lilly et al. 2012). After several years, shortleaf pine saplings have no visible trace of the j-shaped crook (Little and Mergen 1966).

Slash Pine

Slash pine has the smallest native range of the southern pine species in the United States and naturally occurs on the nutrient deficient soils of the lower Gulf Coastal Plain and into the hills of southern Georgia (Dicus and Dean 2008). Although it is not native to western Louisiana or East Texas, it has been planted commercially and is now naturalized. Typical slash pine excels in height growth as a seedling, while the south Florida provenance seedlings may develop a grass-like stage similar to longleaf pine for 2 to 6 years (Little Jr. and Dorman 1954). Minimum temperature is an important factor in the limited range of slash pine (Fowells 1965). Slash pine grows best on sites with sufficient amounts of available soil moisture and on soils that are well aerated (Shoulders 1976, Shoulders and Parham 1983), but due to fire exclusion it has spread into drier, less typical sites (Abrahamson and Hartnett 1990, Hebb et al. 1976). Because slash pine has lower nutrient requirements than the other southern pine species (Fisher 1983), it often outcompetes them on nutrient deficient soils (Haines et al. 1981). Exposing mineral soil via prescribed fire greatly increases seed germination and seedling survival (McMinn 1981, Osborne and Harper 1937). Fire resistance also plays a large role in slash pine's ability to dominate sites where frequent fires occur. Slash pine bark is thick and overlapping, which protects the cambium from fire damage (de Ronde 1982). If crown scorch damage mature slash pine trees, scorched foliage is replaced with new shoots, also giving slash pine the advantage over other southern pines that do not tolerate scorching as well (Wade 1983). Soils that do not support good slash pine growth and establishment are those that are deep, well drained sands or very poorly drained soils with high water tables. The most influential factors that affect growth and productivity of slash pine seedlings are the amount of water and space available to roots (Lohrey and Kussuth 1990).

Growth Comparisons Between Species

Growth rates of southern pines has been studied throughout the southeastern United States, including the West Gulf Coastal Plain. These studies are often on comparable site conditions to observe the response of the trees to different silvicultural practices. Growth comparisons should provide land managers with better decision-making skills regarding stand management (Gibson et al. 1986).

Branan and Porterfield (1971) compared growth and survival of six southern pines in the Piedmont of South Carolina 13 years after planting, and found loblolly and slash pines were the most successful species in both growth and survival. Mean heights of loblolly and slash were 25cm and 33cm taller than shortleaf pine and longleaf pine, respectively. Kramer (1943) also found that loblolly pine produced the most growth of six coniferous species planted in northern North Carolina, while shortleaf and slash pine seedlings made only two-thirds of the growth of loblolly pine after 4 growing seasons. He also measured length of growing season for each species and concluded that while loblolly pine had longer growing seasons (by 4 days on average) than shortleaf and slash pines, it was not long enough to explain the large differences in amount of growth between the three southern pine species.

Early growth responses of slash pine and loblolly pine were examined by Jokela et al. (2000) after fertilizer and herbaceous weed control were applied in the lower coastal plains of the southeastern United States. They found that loblolly pine growth responses to the silvicultural treatments were higher than slash pine growth at 5 years old. On sites where herbaceous weed control was the only treatment, mean loblolly pine heights and diameters were nearly double that of slash pine. However, Swindell et al. (1988) recorded that slash pine outcompeted loblolly pine in the flatwoods of central Florida when herbaceous weed control was applied. Haywood et al. (1990) found that 10 year old loblolly pine grew better than slash pine on well drained soils, while slash pine produced significantly more growth on the poorly drained soils of the West Gulf Coastal Plain. Faust et al. (1999) applied intense silviculture management practices to young stands of loblolly and slash pine in the Peidmont of Georgia and Coastal Plain of Florida, respectively. They found that the mean annual increment (MAI) of the 14 year old loblolly stands where 68-100% higher than the 17 year old slash pine stands. Loblolly and slash pine second rotation growth response was observed on poorly drained soils of the Gulf Coastal Plain in Louisiana after being burned, disked, and bedded (Haywood and Tiarks 2002). Loblolly pine growth was negative when planted on old beds, while slash pine remained unaffected. Second rotation slash pine trees also had significantly greater height, diameter, and volume per tree than the loblolly stands. Although the loblolly stands had higher densities than the slash pine stands, slash pine produced more yield on a per acre basis.

Scott and Burger (2014) compared the response of longleaf and loblolly pine seedlings to soil compaction and soil water content in potted soils comparable to the soils of the West Gulf Coastal Plain. Longleaf pine growth was severely stunted (70%

less) compared to loblolly seedlings in compacted soils with extremes in both high and low soil water content.

Creighton et al. (1987) compared longleaf, slash, and loblolly pine seedling growth after different herbicide treatments in the Gulf Coastal Plain from Louisiana to North Carolina. They reported that longleaf pine seedlings were significantly smaller in height and diameter than slash and loblolly pine seedlings. Loblolly pines had the highest response to herbaceous weed control and were the tallest of the three species. Longleaf, loblolly, and slash pine plantations were measured for response and recovery after a severe ice storm in the Georgia Piedmont (Mckellar 1942). Significantly less loblolly pine trees were badly bent compared to longleaf and slash pine trees. Loblolly pine also received less net losses in ice damage via broken stems, uprooted stems, and broken limbs than the other two species. However, longleaf pine and slash pine trees made nearly as much recovery to damage as loblolly pine trees, suggesting that longleaf and slash pines may be more susceptible to ice damage, but are just as capable of damage recovery as loblolly pine trees. Smith et al. (1992) used data collected from loblolly, shortleaf, and longleaf pine stands in the southeastern United States to develop predictive growth and yield models for the species by recording crown widths, diameters, and radial growth of open grown trees. They found that loblolly pine had the highest growth rate followed by, shortleaf pine then longleaf pine.

Schmidtling (1973) studied the effects of cultivation and fertilizer on the growth of slash, loblolly, and longleaf pines in Mississippi. Cultivated longleaf pines were significantly shorter than slash and loblolly pine trees. Fertilizer applications increased longleaf, slash, and loblolly pine tree height by 9ft, 7ft, and 12ft, respectively. Longleaf pine had the lowest volume of the three species, while slash and loblolly pine had comparable volumes. In an earlier study, Smith and Schmidtling (1970) found that early height growth at 5 years old was greater in slash and loblolly pine by more than 1ft compared to longleaf growth. Loblolly pine grew at an average of 5.5ft per year, making it the tallest and fastest growing of the three species on fertilized plots.

Gibson et al. (1986) reported the specific gravities, moisture content, heights, and diameters of the four major southern pine species on three sites and of the same age in northern Louisiana. All four species were planted on wet, dry, and intermediate sites in the same year, and data were collected at ages 25, 26, and 27. Diameter differences among species was only seen on the wet site, where slash and loblolly pine were larger than shortleaf pine. Shortleaf and longleaf pine heights were significantly shorter than the other two species on wet sites, but the shortest loblolly and slash pine trees were recorded on the dry site.

West Gulf Coastal Plain Pines

Transferring provenances across regions where they have not been tested leaves the landowner at risk of loss of wood volume, production, and profit (Schmidtling 2001). Studies have shown that it is better to move provenances east, rather than west because of the risk of drought in western regions (Wakeley 1963). A good example may be seen in loblolly pine, where eastern provenances have greater mortality when planted in the West Gulf Coastal Plain due to drought intolerance and fusiform rust susceptibility

(Long 1980), while western varieties of loblolly pine are better adapted to drought than eastern varieties (Grissom and Schmidtling 1997). Long (1980) confirmed that choosing a drought resistant seed source is critical for regions with high possibilities of drought, such as East Texas. Longleaf pines (Schmidtling 1999) and shortleaf pines (Schmidtling 2007) have no differences in adaptive traits among sources east and west of the Mississippi River. However, when comparing longleaf pine provenances from Virginia to East Texas, Wells and Wakeley (1970) saw that the longleaf seed sources from East Texas were the most susceptible to brown spot disease and in a slash pine provenance test by Snyder et al. (1976), western seed sources from Louisiana survived better than eastern variety slash pines planted in the Gulf Coast states. When choosing slash pine seed sources for west of the species' natural range, Mississippi or Louisiana provenances are preferred and sources from central Florida should be completely avoided (Lantz and Kraus 1987).

Conversely, moving western varieties east will increase survival due to disease resistance, although growth rates may be slower (Wells 1983). Powers and Matthews (1987) recorded that Texas and Arkansas seed source loblolly pine were the tallest and the most resistant to fusiform rust when planted in North Carolina. Wells (1983) compared the survivability and growth of eight seed sources of loblolly pine planted in Mississippi, Alabama, and Georgia at age 27. He found that the seed sources collected west of the Mississippi River were on average 7ft shorter than the more eastern sources.

The most important factor that influences growth and survival of southern pine seedlings is minimum temperature (Schmidtling 1997). Seedlings will survive and grow well if they come from an area having a minimum temperature within -15°C of the planting site's minimum temperature (Schmidtling 2001). Transporting provenances outside of this range could lead to ice damage, decreased growth, and mortality. Although it is highly suggested to use local seed sources when planting, if provenances from other regions have been tested and proven to have high productivity in the new desired area, the landowner may gain wood volume. Additional reasons to use nonlocal seed sources include increased fusiform rust resistance, increased growth rate, increased survival, and lack of local seed source (Lambeth et al. 2005).

Tree Physiology

Leaf Water Potential

Leaf water potential is used to determine the stress level of plants as a result of environmental factors. The stress levels of plants can influence their ability to produce new roots (Nambiar et al. 1979), regulate photosynthesis (Teskey et al. 1987), and produce leaves (Bongarten et al. 1985). Plant moisture stress can vary widely throughout the year, during different times of day, and within individual plants (Hellkvist et al. 1974) and can negatively affect processes that promote growth (Lopushinsky 1969; Kaufmann 1968, Ramos and Kaufman 1979; Rutter and Sands 1958).

Several studies analyzed the changes in the plant moisture stress of coniferous species throughout the day and the effects these changes have on plant production. Brissette and Chambers (1992) studied leaf water potential values and how they affected the root systems of shortleaf pine seedlings transplanted from a nursey into a growth chamber. They found that seedlings that were able to return to their predawn water potential values the fastest after being exposed to light for several hours provided a longer period of time where conditions were favorable for cell division and elongation. Consequently, these seedlings were able to produce more extensive root systems than those seedlings who took longer to recover from being exposed to prolonged periods of light.

Hellkvist et al. (1974) studied water potential of Sitka spruce (*Picea sitchensis*) throughout the height of tree. They found that on cloudy, wet days leaf water potentials were higher than warm, sunny days. They also noted that changes in moisture stress from pre-dawn to mid-day was less significant on overcast days than on clear days. They concluded that low water potentials were a result of high water loss into the atmosphere via needles and an increased distance for water flow from the soil to the leaves.

Foliar Nutrients

Foliar nutrient analysis can provide an important indication of the amount of nutrients taken up by the tree from the soil. It is also a good indicator of tree health and vigor during different life stages and changing environmental and ecological conditions throughout the life of a tree (Turner et al. 1978). When foliar nutrient concentrations are at or below the critical thresholds (1.0 % and 1.2% nitrogen for slash and loblolly pines, respectively, and 0.09% and 0.12% phosphorus for slash and loblolly pines, respectively (Wells et al. 1973; Pritchett and Comerford 1982; Allen 1987, plants respond with visible physical responses such as yellowing/thinning foliage, needle twisting, shoot die back, and branch deformities (Stone 1968). At optimum foliar nutrient levels, however, increases leaf area index (Albaugh et al. 1998) and increased photosynthetic rate (Runion et al. 1999) have been observed.

Soils

Soil quality is the most important factor in forest management and influences which species will grow best. Physical soil factors have been found to be most critical in the prediction of height growth in southern pine plantations (Nemeth and Davey 1974). The most influential factors that impact soil productivity are topsoil depth, soil texture, limiting layers, and fertility. Topsoil depth is said to be the most critical factor affecting pine seedling growth and is where maximum root penetration and growth is most important. Typically, deep topsoils provide the most nutrients, water, and aeration and therefore, produce the highest yields (Hamilton 2003).

Soil Texture

Soil texture is the most crucial factor causing changes in species composition and ecosystem dynamics (Knox et al. 1995). Sandy soils often have lower nutrient levels and generally only support species such as longleaf pine that are able to perform well on nutrient deficient sites. Clay textured soils tend to have higher water holding capacity and contain adequate nutrients; however, soils with larger ratios of clay have less water available to plants because water and clay soil particles are tightly bound, making it more difficult for plant roots to take up water.

Drainage Class

Drainage class also greatly affects nutrient and water absorption of plants. The relationship between soil drainage and tree diameter and height growth exists because the productivity of southern pines is influenced by the volume of soil available for root exploitation (Lorio et al. 1972). On better drained sites, establishment and early growth is rapid because seedlings have adequate rooting volume where excessive soil moisture is not limiting (Dicken et al. 1988). However, early growth is slower on poorly drained sites because of high water tables (Mckee and Willhite 1986).

Bulk Density

Bulk density is the ratio of dry soil solids to the total volume of soil and is often used as an indication of soil strength and porosity. Bulk density values can vary greatly between soils in the same stand and even within the same soil series. The utilization of harvesting/site prep machinery often determines an increase or decrease of soil compaction and bulk density. High soil bulk density values due to soil compaction typically produce soil conditions that have reduced root penetration, aeration, and percolation and high volumetric water content and soil strength (Greacen and Sands 1980). High soil bulk densities can restrict a plant's ability to extract water and nutrients from the soil, leading to a reduction in growth and, at a stand level, negatively impact establishment (Daddow and Warrington 1983). Bulk density values become restricting for plant growth when they reach their growth-limiting bulk density, generally determined by soil texture (Veihmeyer and Hendrickson 1948; Schuurman 1965; O'Connell 1975) because of its impact on pore size and resistance to soil compaction. At growth-limiting bulk density, soils have been compacted to the point where pore space is so limiting that roots can no longer penetrate the soil and growth is almost completely stopped (Wiersum 1957; Aubertin and Kardos 1965; O'Connell 1975). Typically, coarser textured soils will have higher growth limiting bulk densities because of their larger pore spaces, while fine textured soils have lower growth limiting bulk densities (Daddow and Warrington 1983).

Soil Nutrients

Forest productivity and tree vigor is reliant on the amount of resources in the soil that are readily available for uptake by the plant. Increases of nutrients via fertilization have been shown to increase photosynthetic rates of plants (Zhang 1993; Murthy et al. 1996; Runion et al. 1999) and increase maintenance respiration rates (Maier et al. 1998). Soils that are deficient in important macronutrients can result in low leaf area production, yellowing foliage, and stem deformities (Fisher and Binkley 2000).

Nitrogen is required by plants at more abundant rates than other macronutrients, and is often the most limiting nutrient in the soil of temperate forests (Flanagan and Van Cleve 1983; Pastor et al. 1984). Jose et al. (2003) found that increases in soil nitrogen availability could potentially increase net photosynthesis of longleaf pine, as long as soil water availability was not limiting. Albaugh et al. (1998) found that loblolly pine subjected to varying amounts of soil nutrients and water showed a strong positive response to the optimum nitrogen and phosphorus availability treatments. Fertilization provided an increased growth of leaf area and stem volume growth.

Phosphorous availability is also a major limiting factor affecting the growth of southern pine stands (Fisher and Garbett 1980; Comerford et al. 1983; Gent et al. 1986; Allen 1987). Although phosphorous is typically applied at lower rates than nitrogen, when they are applied together growth increases of 25% have been obtained (Fox et al. 2007). Pritchett et al. (1961) and Laird (1972) saw large increases (5 to 15ft) in site index after applying applications of phosphorus to slash pine on poorly drained clay soils in Florida.

Planting

Conditions

Timing and weather conditions play a large role in the establishment and survival when planting southern pine seedlings. Winter months are considered the best time to plant because competing species are dormant, allowing seedlings to root and establish. Dormancy of pine seedlings during winter also makes handling easier for nurseries and planters while also reducing the likelihood of seedling damage during transport and planting. Studies have shown, however, that a planting season including late fall and early spring months ranging from mid-October to mid-March may be sufficient. Several studies show that planting earlier in the fall can improve tree survival and growth because roots are given a longer time period to grow and acclimate before summer (Taylor et al. 2006; Larson 2002; Brissette et al. 1991; Mexal et al. 1979). Planting should take place in cool temperatures ranging from 1.6°C to 15.5°C with a relative humidity greater than 40% (Lantz et al. 1996). In order to prevent seedling roots from drying, wind speeds should remain below 16 kph and soil moisture above 50%. Although these weather conditions are preferred, special care of the seedlings must be considered to prevent damage. If the soil is extremely dry, planting should be delayed until adequate moisture is reached. Planting during below freezing weather can also decrease seedling survival (Barry 2013).

Seedlings

Bare-root seedlings are more often used over containerized seedlings in the West Gulf Coastal Plain because they are easily produced but require more care than containerized seedlings and are more prone to drying out on sunny or windy days (Taylor et al. 2006). Containerized seedlings have several other advantages over bare-root seedlings that increase survival and establishment rates: lower cost of survival on a per seedling basis, ease of planting, storage of seedlings is less complicated, and they are more widely available in most areas (Franklin 2008). Probably the greatest advantage of planting containerized seedlings is the extended planting season on excessively dry or wet sites (Schultz 1999). These types of seedlings produce well on a wide variety of sites but especially outperform bare-root seedlings on sites that are flooded at the time of planting or sites that have seasonal droughts (Larson 2002).

Depth

In general, planting at greater depths has been shown to increase seedling survival. Greater survival of deeply planted seedlings is related to less exposed foliage, and roots retaining moisture for longer periods (South et al. 2012). Deep planting is a technique that has been shown to increase the survival of loblolly, shortleaf, and slash pines in the south (Lantz et al. 1996). On the other hand, longleaf seedling survival is negatively affected by deep planting and the terminal bud remaining covered after planting (Hainds 2004). For longleaf pine, the root collar must be above the soil surface in order for the seedling to establish and acquire nutrients. Incorrect planting depth is the primary cause of longleaf establishment failure (Hainds et al. 2005).

METHODS

Site Locations and Description

This study occurred on three study sites in Houston, Cherokee, and Shelby Counties within the East Texas Upper West Gulf Coastal Plain. All study sites were in recently clearcut areas adjacent to loblolly pine plantations, but varied greatly in dominant soil type and drainage classifications. All research plots were blocked based on differences in soil series (Table 1).

The Swink property was located 9.6 km west of Rusk, Texas in Cherokee County (31°46'32.3"N 95°13'46.2"W), on Bowie, Lilbert, and Darco soil series (Appendix A). The Bowie soil series is a fine-loamy, siliceous thermic Plinthic Paleudult that is well drained with 1 to 8 percent slopes (websoilsurvey.nrcs.usda.gov). The Lilbert soil series is a loamy Arenic Plinthic Paleudult with 5 to 8 percent slopes and a well-drained drainage class. The Darco series is a loamy, siliceous Grossarenic Paleudult that is somewhat excessively drained and has slopes that range from 1 to 25 percent. Study plots were located on a small ridge where commercial plantings of loblolly pine had recently failed. The ridge was mowed with a tractor and bush hog as a site prep operation prior to planting.

The Arbor Grove study site was located 11.3 km East of Crocket, Texas in Houston County (31°18'45.7"N 95°18'05.1"). Study plots were predominantly on Fuller, Lovelady, and Pophers soil series (Appendix B). The Fuller soil series is a fine-loamy, siliceous, thermic Albic Glossic Natraqualf that is somewhat poorly drained with slopes ranging from 0 to 5 percent. The Lovelady series is a loamy, mixed, thermic Arenic Glossudalf that is classified as well drained with moderate slopes from 1 to 8 percent, while the Pophers soil series is a fine silty loam, acidic Fluvaquentic Endoaquepts that is also somewhat poorly drained with a maximum of 1 percent slopes. All study plots were located in a relatively flat area with a slopes that ranged from 1 to 5 percent. A mixture of herbicides including 1.4 L of Chopper, 3.7 L of Accord, and 0.1 L of Oust were applied at 30 L per hectare by ground application in Fall 2015.

The Hilliard Creek property was located 6.4 km southeast of Tenaha, Texas in Shelby County (31°54'48.8"N 94°12'43.9"W). The Eastwood, Latex, and Metcalf-Sawtown soil series made up the area where study plots were placed (Appendix C). The soil textures represented by these series are very fine sandy loam, fine sandy loam, and a complex of very fine sandy loam, loam, and clay, respectively. The Eastwood series is a fine, smetitic, thermic Chromic Vertic Hapludalf and contains slopes ranging from 5 to 15 percent and has a drainage class rated as well drained. The Latex series is a fine-loamy, siliceous, thermic Glossic Paleudalf and has a maximum slope of 3 percent and are moderately well drained. The Metcalf-Sawtown series is fine-loamy, siliceous, active thermin Typic Glossudalf that is relatively flat with slopes less than 2 percent and has a somewhat poorly drained drainage class rating. Study plots were laid out on the property edge on either side of the logging road that splits the tract. A mixture of herbicides including 1.4 L of Chopper, 3.7 L of Accord, and 0.1 L of Oust were also applied at 30 L per hectare by ground application in Fall 2015

Table 1. Soil series characteristics found in Cherokee, Houston, and Shelby counties in East Texas. Data from websoilsurvey.nrcs.usda.gov, August 29, 2016.

Site/Soil Series	Soil Texture	Drainage Class	Slope (%)
Cherokee			
Bowie	fine sandy loam	well drained	3-8
Darco	loamy fine sand	somewhat excessively drained	1-3
Lilbert	loamy fine sand	well drained	3-8
Houston			
Fuller	fine sandy loam	somewhat poorly drained	1-3
Lovelady	loamy sand	well drained	1-5
Pophers	silt loam	somewhat poorly drained	0-1
Shelby			
Eastwood	very fine sandy loam	well drained	5-15
Latex	fine sandy loam	moderately well drained	1-3
Metcalf-Sawtown	complex	somewhat poorly drained	0-2

Experimental Design

Plots were arranged in a randomized complete block design (RCBD) with 3 replicates per site for each of the four species. Soil texture and drainage class were attempted to be used as the blocking variables so that each block had all four species on the same soil type. Each species were planted in a 36.5 m by 36.5 m plot that had 9 to 11 rows, with trees planted at a 2.4 m by 2.7 m spacing (1,500 trees per hectare). In Houston and Shelby counties, all blocks were directly adjacent to the others, but plots were more dispersed in Cherokee County based on available space within the existing14 year old loblolly pine plantation

Planting

Planting took place during December 2015. Loblolly, slash, and shortleaf pines were machine planted as containerized seedlings, while longleaf pine containerized seedlings were hand planted to reduce the potential of a machine planting the root collar too deep, increasing the probability of seedling mortality. All seedlings were planted in furrows created by the machine planter. The furrows broke up compacted soil, promoting root growth and establishment while also reducing the likelihood of j-rooting seedlings. Seedlings were provided by International Forest Company (IFCO) and all were of West Gulf Coastal Plain Coast provenance (Table 2).

Table 2. Genetic information and origin of pines planted in Houston County, Shelby County, and Cherokee County, December 2015.

Species	**Genetics**	**Origin**
Loblolly	Improved, second generation, superior growth and form	Cherokee Co., TX
Longleaf	Natural stand mix	Newton Co., TX
Shortleaf	Improved, orchard mix	Southern AR
Slash	Improved, second generation, superior growth, form, and rust resistance	Northern LA

Data Collection

Growth and Survival

To ensure observational units were not affected by adjacent plots or edge effects, the outer rows of each plot were reserved as unmeasured buffer rows. Measurement plots consisted of 7 to 10 rows with 14 to 16 seedlings per row (98 to 160 trees per plot). Ground-line diameter (GLD) was measured on each seedling, taken where the main stem of the seedling intercepted the soil and recorded to the nearest millimeter. Seedling height was defined as the distance (to the nearest half centimeter) from the intercept of the main stem and the soil to the top of the terminal bud. Initial establishment and survival surveys were conducted in April 2016. All measurement plots were tallied and seedlings were recorded as live or dead. GLD, height, and survival data were recorded each January-February from 2016-2019.

Soil Parameters

Soil samples were collected and sent to the SFASU Soil, Plant, and Water Analysis Laboratory in order to obtain nutrient and pH data. Soil data was collected during summer 2018 at each plot corner and plot center to a depth of 15cm. Corner and center samples were compiled and mixed together to form a composite sample for each plot.

Soil profile descriptions were conducted during winter 2019. The web soil survey was used to determine the predominant soil series of each study site in order to compare those soil attributes with characteristics from soils found in each plot. Due to extremely wet conditions, profile descriptions could not be obtained in the field. An auger hole was made at the four corners and in the center of each measurement plot. Individual horizons from each sample hole were bagged and taken back to the SFASU campus lab to dry. Once the samples were adequately dried, the color, field texture, consistency, pH, structure, and rooting and mottling amounts were observed in the A, E, and B horizons in order to determine which soil series was represented within each research plot.

Soil samples were also taken between pre-dawn and mid-day leaf water potential measurements (see page 28) to determine soil moisture. An auger or soil probe was used to take soil samples at rooting depth at the base of the tree used for moisture stress analysis. Rooting depth was previously determined by augering into the soil next to a border tree that represented the average height of each species at each site, until no roots were visible within the sample. Field weights of soil moisture samples were taken immediately upon returning to the lab. Samples were dried at 41°C for 96 hours and weighed again before calculating gravimetric water content.

Bulk density was measured using standard Soil Science Society of America methods. Samples were taken at the center of each research plot with a slide hammer. Field weights of soil and rings were recorded immediately upon returning to the lab. Bulk density rings were dried with the soil intact at 41°C for 96 hours. Once soil dry weight was taken, the soil was removed from the rings and each ring weight was recorded with its respective soil sample. Bulk density was calculated by using the formula:

$$\text{bulk density (g/cm}^3\text{)} = \text{dry soil weight(g) / soil volume (cm}^3\text{)} \qquad [1]$$

Soil bulk density was also used to calculate the volumetric water content of samples from each research plot.

Tree Physiology Parameters

Leaf water potential data was collected pre-dawn and mid-day from March 2018 through December 2018. Each study site was visited monthly during dormant season months (October-December), and bimonthly during the growing season (May-August). No leaf water potential data was collected during September 2018 due to extended rainy weather conditions. Needle fascicles from three randomly selected trees per plot were collected and placed in the pressure chamber. Pressure inside the chamber was steadily increased until a film of water began seeping from the top of the fascicle. Bar values were recorded at this pressure and later used to compare leaf water potential between species across all soil types and all three sites.

Five needles were collected from each of the three randomly selected trees used for leaf water potential measurements in order to obtain needle moisture content. From March 2018-June 2018, needles collected were from the first growth flush of the year and from July 2018-December 2018 needles collected were from the second growth flush. Field weights of needles were recorded to the nearest 0.01g prior to drying. Needles were placed in a 41°C oven for 48 hours and then weighed again to obtain dry weight. Needle moisture was determined by the gravimetric moisture formula:

$$\text{Moisture content (\%)} = 100-((\text{dry weight (g)}/\text{wet weight (g)})*100). \qquad [2]$$

Foliar samples were also collected during summer 2018 and sent to the Stephen F. Austin Soil, Plant, and Water Analysis Laboratory in order to obtain nutrient values. Composite samples were made from needles removed from five individual seedlings located at each of the four corners and at plot center on all research plots. Foliar nutrient samples were labeled to correlate with the soil samples collected within the same plot prior to being sent to the lab.

Data Analysis

A mixed model analysis was used to determine the effects of individual seedling responses of height and ground-line diameter based on soil type and tree species. Analysis of variance (ANOVA) was used to test the effects of site and species on seedling height and diameter. Assumptions of normality were met by plotting residual values of heights and diameters by species for all three measurement years. Data was analyzed using the following model:

$$Y_{ijkl}=\mu + Site_i + Species_j + Block_{k(i)} + Site_i{*}Species_j + \varepsilon_{ijkl} \qquad [3]$$

Where Y is the tree height or diameter of the lth tree of the jth species growing at the kth block at the ith site.

Survival data, expressed as 0/1, was analyzed using a logistics model to calculate the odds ratio estimates and probability of survival for each species at each research site. The effect of site and species on survivability were analyzed using the model:

$$Y_{ijkl}= \mu + Site_i + Species_j + Block_{k(j)}+ Site_i{*}Species_j + \varepsilon_{ijk} \qquad [4]$$

Where Y is the survival of the l^{th} tree of the j^{th} species growing at the k^{th} block at the i^{th} site.

Volumetric water content was analyzed using an ANOVA mixed model. The effects of soil volumetric water content, species, and site on tree leaf water potential was analyzed using the model:

$$Y_{ijkl} = Site_i + Species_j + Volumetric\ Water\ Content_k + Block(site)_l + Site_i * Species_j + \varepsilon \qquad [5]$$

Where Y is the moisture stress of the ith tree of the jth species on the soil with the kth volumetric water content growing at the lth block of the ith site.

Soil and foliar nutrient data were analyzed using a mixed model ANOVA. The effect of site and species on soil nutrient values was analyzed using the model:

$$Y_{ii}=\mu + Site_i + Species_j + Block_{k(i)} + Site_i * Species_j + \varepsilon_{ij} \qquad [6]$$

Where Y is the soil nutrient concentrations of the l^{th} plot of the j^{th} species growing at the k^{th} block at the i^{th} site or where Y is the foliar nutrient concentrations of the l^{th} tree of the j^{th} species growing at the k^{th} block at the i^{th} site.

A Pearson correlation between foliar and soil nutrient content was used to determine the uptake of nutrients from the soil in the plant for each individual species and among all species at each site. A correlation between foliar and soil nutrients was used to assess the effects of nutrient availability on tree height and diameter. A Pearson correlation was also used to determine the effects of predawn and midday leaf water potential values on mean tree height and diameter.

RESULTS

Soil

Soil profile descriptions confirmed that the soil series provided by Web Soil Survey were present at the respective study sites; however, soil series was not used as a blocking variable because of the inconsistent location of soil series within each block. Because soil texture, drainage class, and slope were similar within each site, but different between the sites, soil type was only used as an effect on growth and survival at the site level.

Growth and Survival

Establishment

Initial Height, Basal Diameter, and Survival

One month after planting, mean initial heights of loblolly and slash pine were significantly greater ($p<0.0001$) than shortleaf, which was also greater than longleaf pine (Figure 1). Mean basal diameters were determined to be significantly different at the species ($p<0.0001$) and site ($p=0.0090$) level, with Cherokee County diameters greater than Shelby and Houston County and longleaf diameters greater than loblolly and slash pine; slash were greater than shortleaf (Figure 2). Four months after planting, survival did not significantly differ among species ($p=0.9688$), site ($p=0.0720$), or at the site*species interaction level ($p=0.8254$).

Figure 1. Mean initial height (centimeters) of loblolly, longleaf, shortleaf, and slash pines across all study sites. Data collected January-February 2016. Tukey analysis conducted the species level, where a change in letters represents a significant difference p<0.0001) by species.

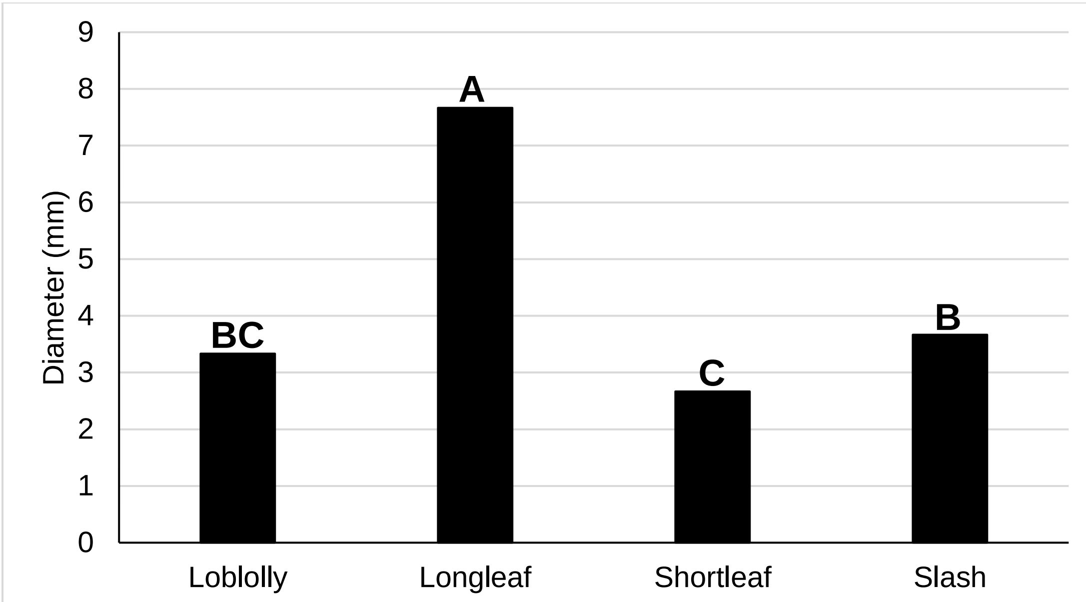


Figure 2. Mean initial basal diameter (millimeters) of loblolly, longleaf, shortleaf, and slash pines across all study sites. Data collected January-February 2016. Tukey analysis conducted at the species level, where a change in letters represents a significant difference ($p<0.0001$) at the species level.

<u>Year 1</u>

Height, Diameter, and Survival

Mean height were significantly different ($p<0.0001$) across the four species after the first year of growth. Loblolly heights were significantly greater than slash pine heights, while slash pine and shortleaf pine were greater than longleaf pine. Mean heights were also significantly ($p=0.0463$) different at the site interaction level. Shelby and Houston Counties mean tree heights for all pine species were the greatest, where Shelby County heights were significantly larger than Cherokee County, but Houston

County heights were not greater than Cherokee County. Mean heights were also significantly different at the site*species level (p=0.0298). Loblolly pine mean heights in Shelby County were not greater than at Houston County, but Shelby County was were greater than at Cherokee County (Figure 3). Longleaf, shortleaf, and slash pine mean heights were not significantly different.

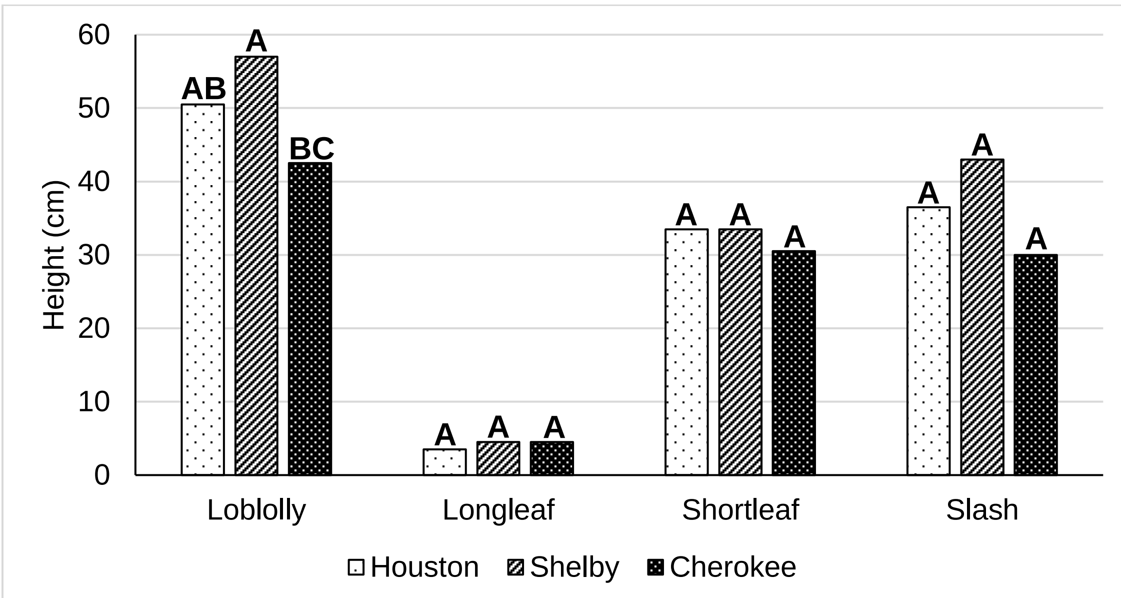


Figure 3. Mean height (centimeters) one year after planting of loblolly, longleaf, shortleaf, and slash pines at all study sites. Tukey analysis conducted within species, where a change in letters represent a significant difference (p=0.0298) in height. Data collected January-February 2017.

Mean diameters were significantly different at the site (p=0.0143) and species levels (p<0.0001). Longleaf diameters were significantly greater than loblolly and slash pine; all were greater than shortleaf diameters (Figure 4).

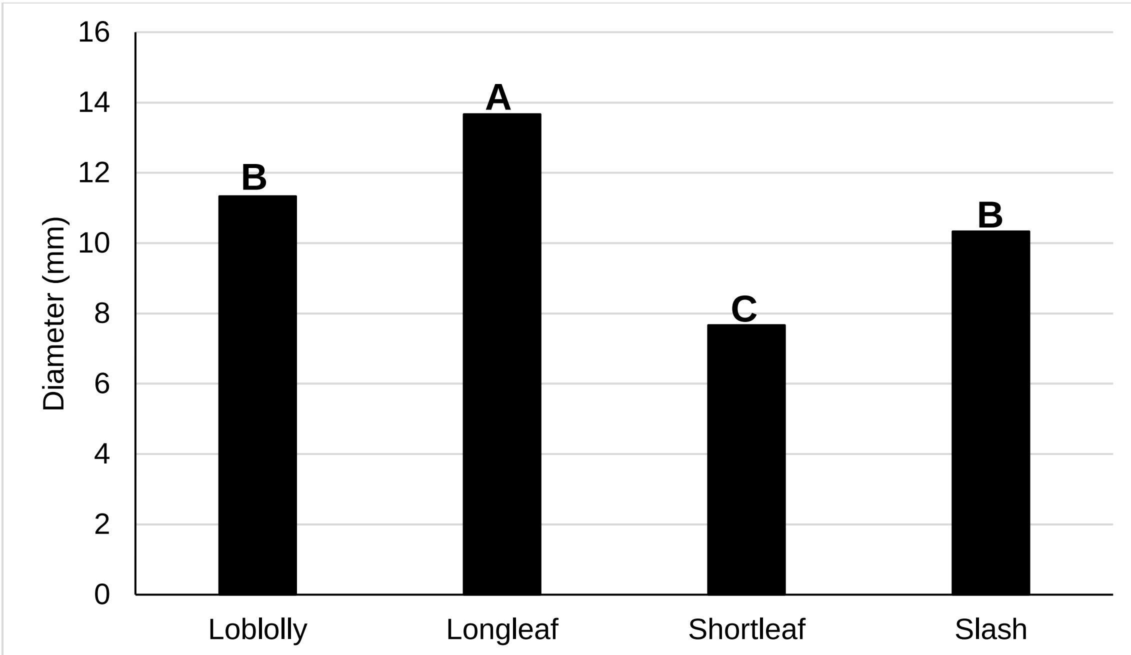


Figure 4. Mean diameter (millimeters), one year after planting, of loblolly, longleaf, shortleaf, and slash pines across all study sites. Tukey analysis conducted at the species level, where a change in letters represent a significant difference ($p<0.0001$) in diameter. Data collected January-February 2017.

One year after planting, Houston and Shelby County survivals were greater than in Cherokee County ($p=0.0010$) for all species (Figure 5), and loblolly, shortleaf, and slash pine survival rates across all sites were greater than longleaf pine ($p=0.0015$).

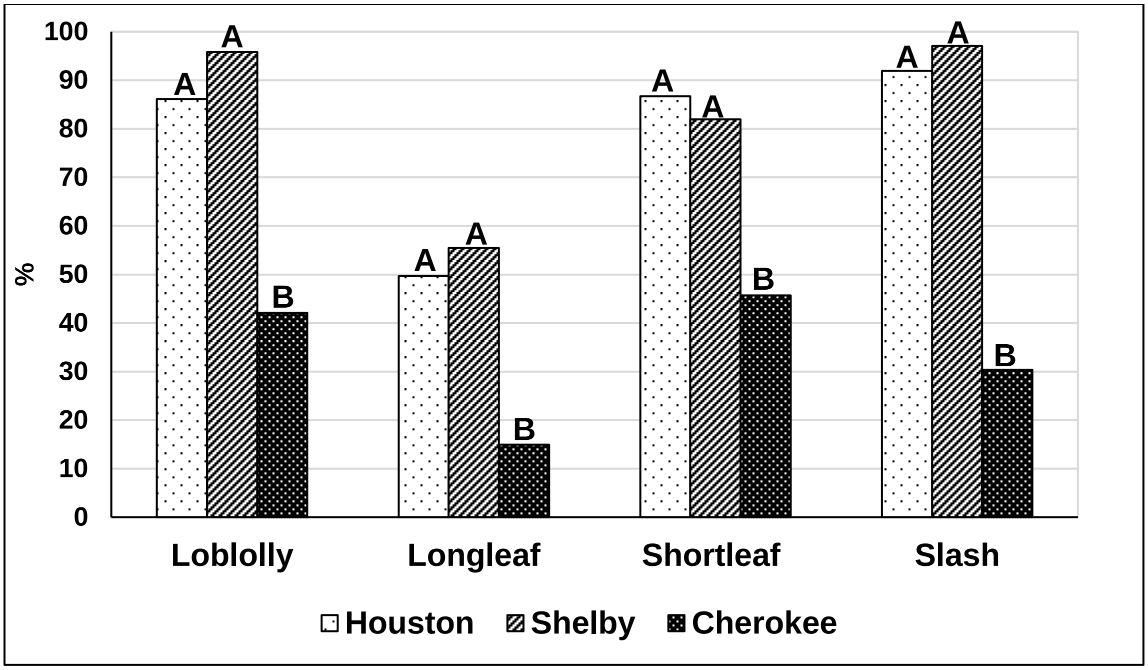


Figure 5. Percent survival of loblolly, longleaf, shortleaf, and slash pines in each county one year after planting. Tukey analysis conducted within species, where a change in letters represent a significant difference (p=0.0015) in survival by site.

<u>Year 2</u>

Height, Diameter, and Survival

Mean heights were significant (p<0.0001) by species two years after planting. Loblolly pine heights were greater than shortleaf and slash, which were greater than longleaf. Mean heights were also significant across the three study sites (p=0.0158), with both Shelby and Houston County heights not significantly different. Shelby County mean heights were greater than Cherokee County heights; Houston and Cherokee County heights were not different. Mean heights two years after planting were significantly different at the site*species level (p=0.0022). Loblolly pine in Houston and Shelby counties were both greater than in Cherokee County (Figure 6); longleaf and shortleaf heights did not significantly differ across study sites. Cherokee County slash pine were significantly taller than slash pine in both Shelby and Houston counties, but Houston and Shelby County slash did not differ from each other.

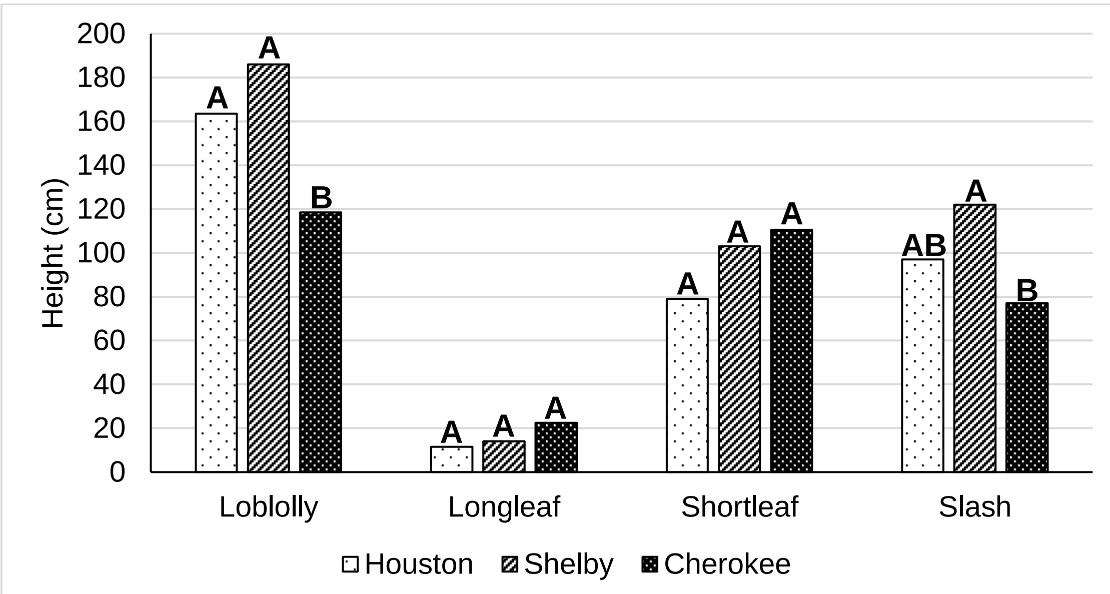


Figure 6. Mean height (centimeters) two years after planting of loblolly, longleaf, shortleaf, and slash pines at each study site. Tukey analysis conducted within species, where a change in letters represent a significant difference (p=0.0022) in height by site. Data collected January-February 2018.

Mean diameters were also significantly different (p<0.0001) by species. Loblolly pine diameters were greater than shortleaf and slash, and slash pine was greater than longleaf pine. Mean diameters were also different at the site as level Shelby and

Houston County mean diameters were significantly greater (p=0.0075) than Cherokee County. Diameters were also significant at the site*species level (p=0.0004) with loblolly diameters in Shelby and Houston counties greater than in Cherokee County (Figure 7); longleaf, shortleaf pine, and slash pine mean diameters did not significantly differ between study sites.

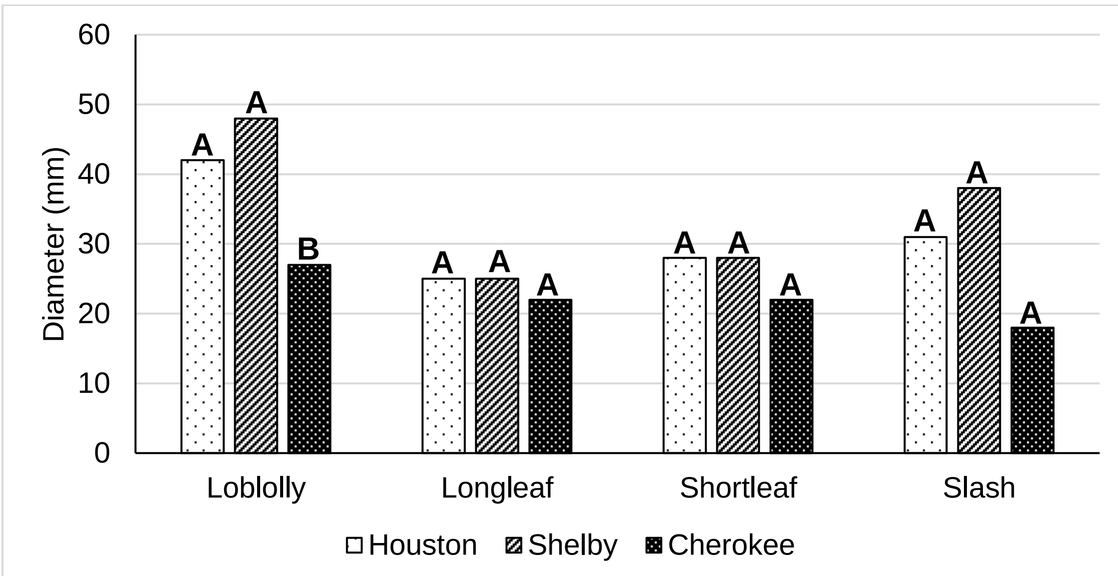


Figure 7. Mean diameter (millimeters) two years after planting of loblolly, longleaf, shortleaf, and slash pines at each study site. Tukey analysis conducted within species where a change in letters represent a significant difference (p=0.0004) in diameters by site. Data collected January-February 2018

Two years after planting, survival rates were significant at the site (p=0.0015) and species (p=0.0002) levels. Houston and Shelby County survivals were greater than in

Cherokee County, and loblolly, shortleaf and slash pine survival rates were greater than longleaf survival (Figure 8).

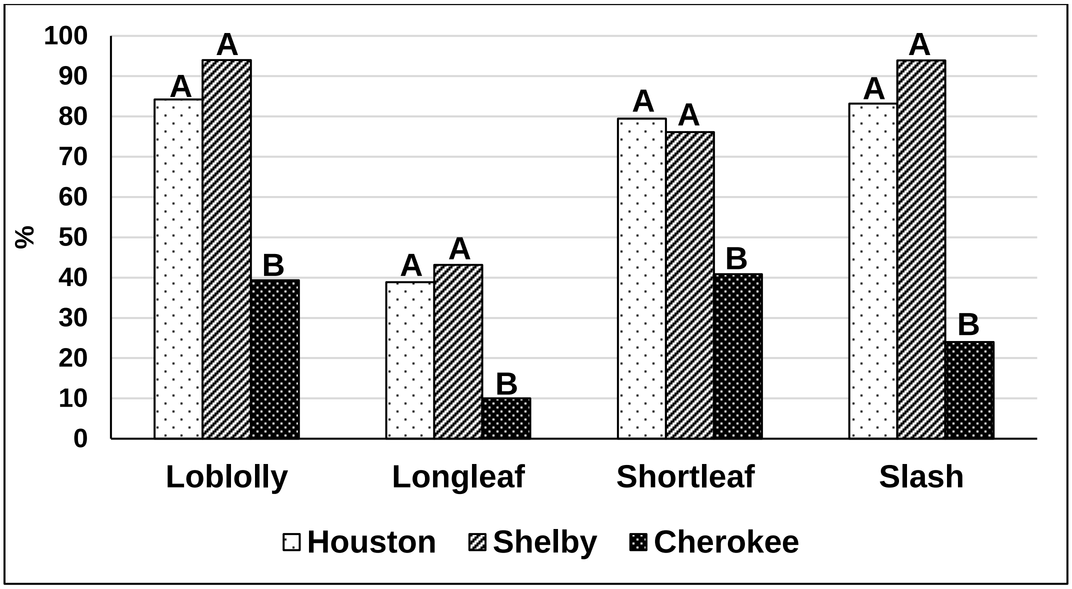


Figure 8. Percent survival of loblolly, longleaf, shortleaf, and slash pines at each study site two years after planting. Tukey analysis conducted within species where a change in letters represent a significant difference (p=0.0002) in survival by site.

Year 3

Height, Diameter, and Survival

At the end of the third year, loblolly pine mean heights were significantly greater (p<0.0001) than slash and shortleaf pines, which were greater than longleaf pine. The site level interaction was also significant (p=0.0143). Shelby and Houston County mean heights were not significantly different; however, Shelby County heights were larger than

Cherokee County, but Houston County heights were not. Site*species interaction was also significantly different (p=0.0028). Loblolly pine in Houston and Shelby counties were greater than in Cherokee County (Figure 9). Longleaf and shortleaf pine mean heights were not different across study sites. Slash pine in Shelby and Houston counties did not significantly differ in height, and Shelby and Cherokee County slash pine also did not differ in mean height, but Houston County slash pine were significantly taller than Cherokee County slash pines.

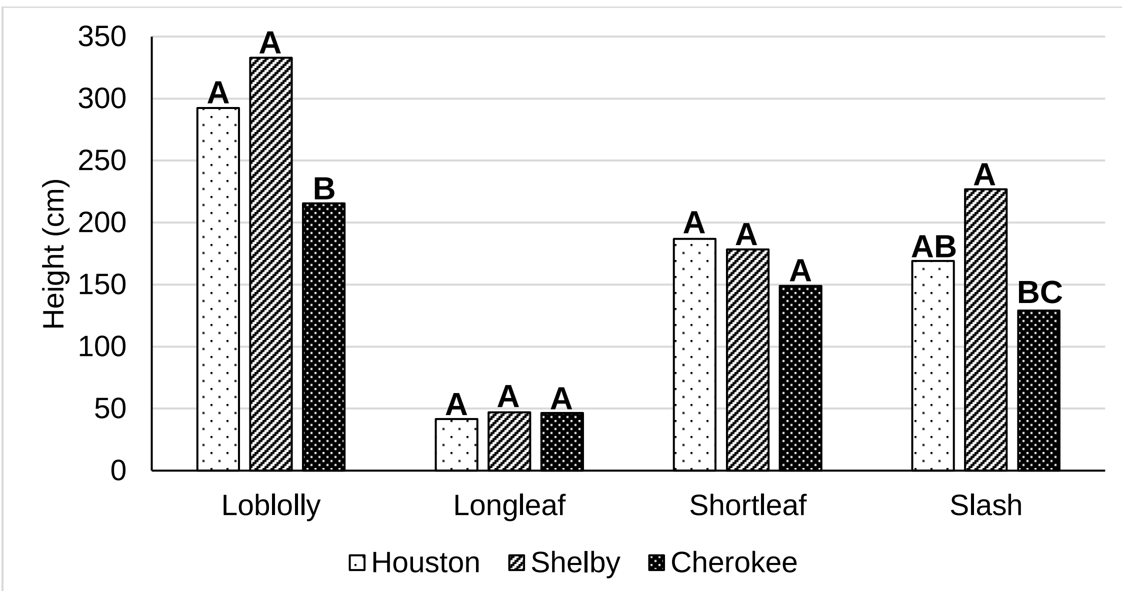


Figure 9. Mean height (centimeters) three years after planting of loblolly, longleaf, shortleaf, and slash pines at each study site. Tukey analysis conducted within species where a change in letters represent a significant difference (p=0.0028) in height by site. Data collected January 2019.

Mean diameters of loblolly pine were significantly greater than slash and shortleaf diameters, which were greater than mean diameters of longleaf pine ($p<0.0001$). Diameters also differed significantly at the site level ($p=0.0033$). Houston and Shelby County mean diameters were greater than those in Cherokee County. Mean diameters were also significant at the site*species level ($p=0.0005$). Loblolly pine in Houston and Shelby counties obtained higher mean diameters than in Cherokee County (Figure 10). Although longleaf and shortleaf pine mean diameters did not differ between sites, Houston and Shelby County slash pine mean diameters were greater than Cherokee County slash.

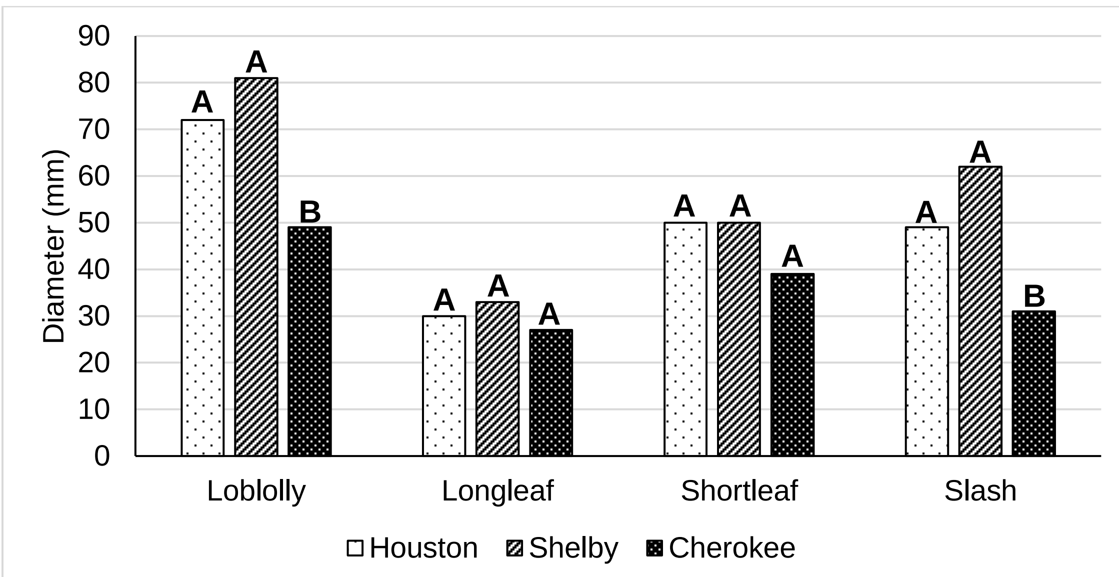


Figure 10. Mean diameter (millimeters) three years after planting of loblolly, longleaf, shortleaf, and slash pines at each study site. Tukey analysis conducted within species where a change in letters represent a significant difference ($p=0.0005$) in diameter by site. Data collected January-February 2019.

Survival rates were significantly different at the site (p=0.0014) and species (p<0.0001) levels three years after planting, where Houston and Shelby counties were greater than Cherokee County (Figure 11). Loblolly, shortleaf, and slash pine survivals were greater than longleaf pine across all study sites.

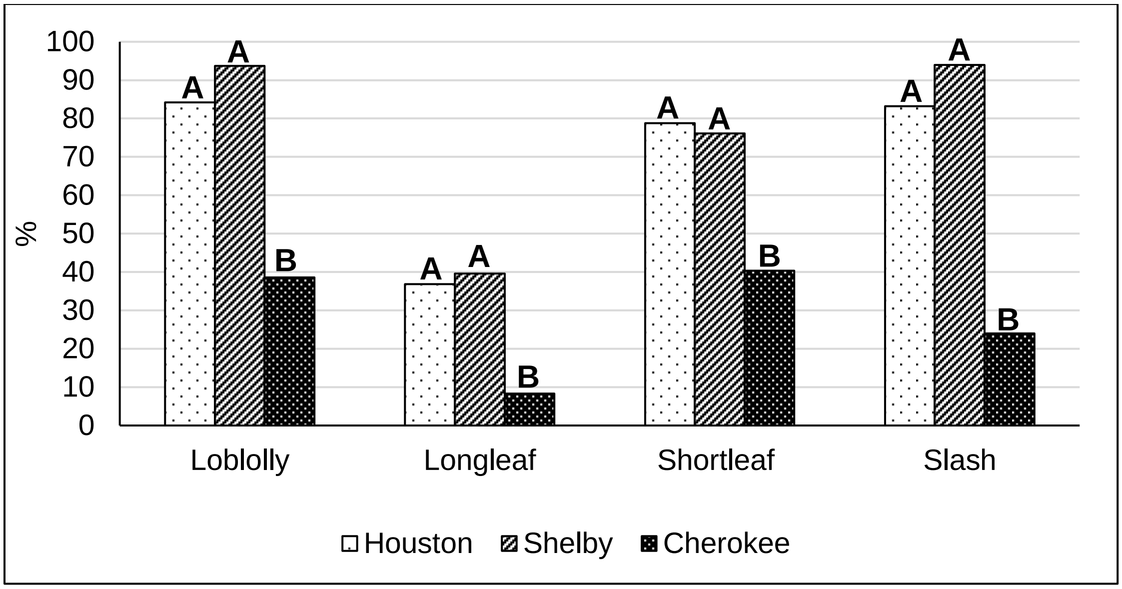


Figure 11. Percent survival of loblolly, longleaf, shortleaf, and slash pines at each study site three years after planting. Tukey analysis conducted within species where a change in letters represents a significant difference (p=0.0014) in survival by site.

Seedling Physiology

Leaf Water Potential

Pre-dawn moisture stress levels were more negative in shortleaf pines than the other species (p=0.0016) (Figure 12). Tree heights of all species in Houston County were significantly (p= 0.0143) and negatively correlated (r= -0.2037) with predawn moisture stress values.

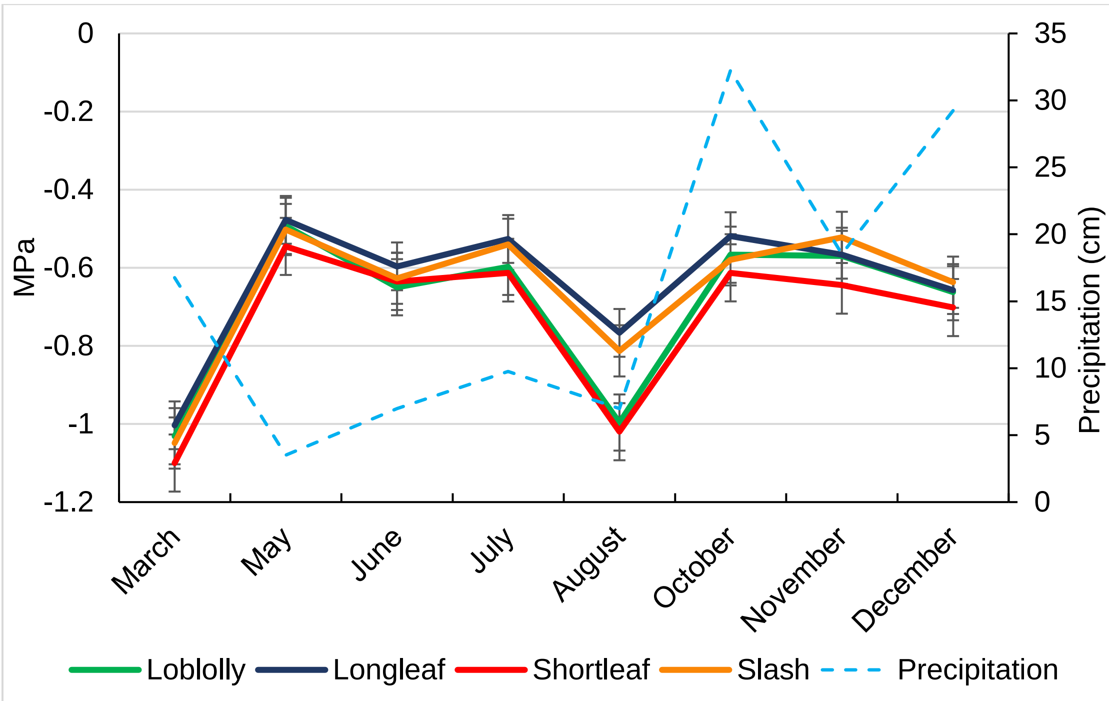


Figure 12. Mean pre-dawn leaf water potentials, in megapascals (MPa), of loblolly, longleaf, shortleaf, and slash pines, and mean monthly precipitation (centimeters) across all study sites from March 2019-December 2019.

Midday water potential levels were significant at the site (p=0.0449) and species (p<0.0001) levels. Cherokee County water moisture stress values were more negative than Houston County, which were more negative than Shelby County. Water potentials were most negative in shortleaf and loblolly pines; loblolly and longleaf pine values were more negative than slash pine leaf water potentials (Figure 13). Leaf water potential values were also significant (p=0.0073) and had a negative correlation (r= -0.2317) on tree height for all species.

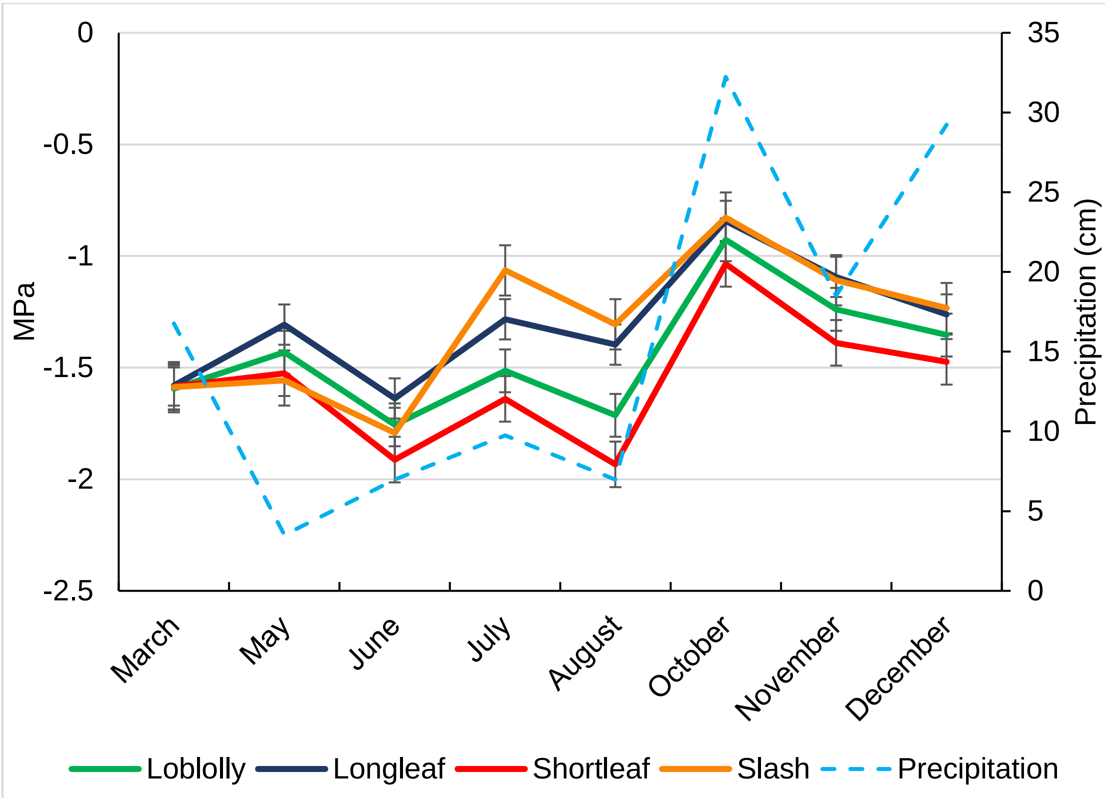


Figure 13. Mean midday leaf water potentials, in megapascals (MPa), of loblolly, longleaf, shortleaf, and slash pines, and mean monthly precipitation (centimeters) across all study sites from March 2019-December 2019.

Soil Moisture

Soil moisture significantly affected leaf water potential values for both pre-dawn and mid-day measurements (p<0.0001). Volumetric water content was significantly greater at Shelby County than in Houston County, with an average moisture content of

0.16g/g (Figure 14). Houston County soil moisture average was 0.12g/g with lows of 0.04g/g during summer months. Cherokee County soils held the least amount of moisture throughout the year, averaging 0.099g/g from May-December 2019.

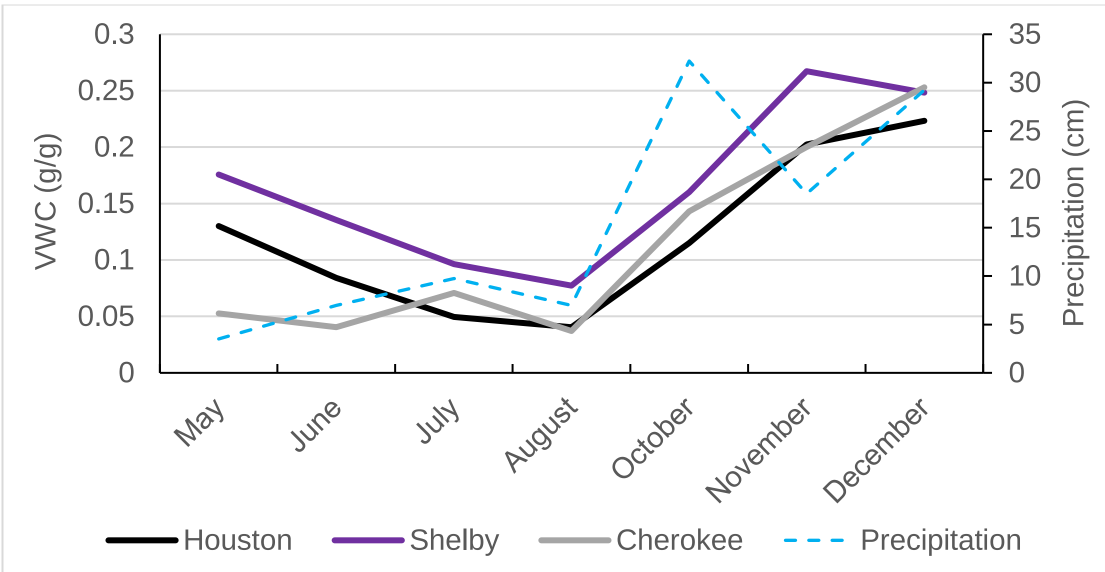


Figure 14. Mean volumetric water content (VWC) of soil by site and mean monthly precipitation (centimeters) across all study sites May 2019-December 2019. Soil moisture data collected on same day as leaf water potential measurements. No data was collected for Cherokee County in November.

<u>Soil Nutrients</u>

Macronutrients

Phosphorus values were significantly greatest ($p<0.0001$) Shelby County than in Houston and Cherokee counties (Table 3), with the same relationships for soil potassium ($p=0.0052$). Potassium soil levels in the soil were also significantly correlated with the mean height ($p=0.0415$) and mean diameter ($p=0.0347$) of loblolly pine, with positive correlations of 0.6855 and 0.70292, respectively. Slash pine mean heights were also significantly ($p=0.0372$) and positively correlated ($r=0.69619$) with potassium availability. Calcium availability in the soil significantly varied by site ($p<0.0001$), as Houston County had higher levels than Shelby County, which had higher levels than Cherokee County. Magnesium levels were significantly higher ($p=0.0006$) in Houston and Shelby counties than in Cherokee County. Sulfur levels were higher in Shelby County than in Houston and Cherokee counties ($p=0.0002$). Sulfur availability in the soil was also significantly and positively correlated with mean height ($p=0.0135$) and diameter ($p=0.0192$) of slash pine across all sites with a correlation of 0.7784 and 0.75276, respectively.

Soil Quality

Soil pH was not significantly different at any interaction level. Nitrate values were significant ($p=0.0008$) at the site level only, with Shelby County greater than Houston and Cherokee counties. Soil salinity was also significant ($p=0.0003$) at the site level and were greater in Shelby County than in Houston and Cherokee counties.

Table 3. Mean values of soil components, Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulfur (S), pH, nitrates, and salinity, at study sites. Data analyzed at the Stephen F. Austin State University Soil, Plant, and Water Analysis Lab December 2018. A change in Tukey letters represents a significant difference (p<.05) at the site level.

	P	**K**	**Ca**	**Mg**	**S**	**Nitrates**	**Salinity**	**pH**
	ppm							
Site								
Houston	19.50^{B}	50.56^{B}	676.36^{A}	45.42^{A}	5.58^{B}	1.45^{B}	43.46^{B}	5.91^{A}
Shelby	111.65^{A}	64.17^{A}	474.60^{B}	41.52^{A}	12.32^{A}	3.62^{A}	83.92^{A}	5.18^{A}
Cherokee	45.24^{B}	41.51^{B}	335.80^{C}	27.24^{B}	4.94^{B}	2.97^{B}	40.35^{B}	5.54^{A}

Foliar Nutrients

Macronutrients

Foliar phosphorus values were significantly different at the site (p=0.0038) and species (p=0.0003) levels. Shelby County phosphorus values were greater than Houston and Cherokee counties (Table 4). At the species level, phosphorus was higher in loblolly and shortleaf pine than in longleaf and slash pines. Potassium values were significantly different (p=0.0032) at the site level only as, Cherokee and Shelby County K values were greater than Houston County. Foliar magnesium values were only significantly different (p=0.0028) at the species level, with longleaf and shortleaf having the highest concentrations of Mg; longleaf pine was greater than slash pine, and longleaf and shortleaf were greater than loblolly pine. Foliar magnesium levels were significantly and positively correlated with mean height of longleaf pine (p=0.0274) and had a correlation of 0.72403. Sulfur values were significant at the site (p=0.0020) level. Foliar sulfur was greater in Shelby and Cherokee counties than in Houston County. Foliar sulfur was also significant at the species level (p=0.0012). Sulfur concentrations were higher in shortleaf and loblolly pines, where shortleaf values were greater than longleaf and slash pines. Calcium foliar concentrations were not significant at any interaction level; however, calcium availability was strongly correlated (0.80071) with mean height of longleaf pine across all sites (p=0.0095).

Table 4. Mean foliar nutrient values of macronutrients, Phosphorus (P), Potassium (K), Magnesium (Mg), Sulfur (S), and Calcium (Ca) by species at each site. Data analyzed at the Stephen F. Austin State University Soil, Plant, and Water Analysis Lab December 2018. A change in Tukey letters represents a significant difference (p<.05) at the site or species level.

Species/Site	**P**	**K**	**Mg**	**S**	**Ca**
	--------------------------------------ppm-----------------------------------				
Loblolly					
Houston	1121.71^{B}	4284.48^{B}	888.97^{A}	858.62^{B}	2676.84^{A}
Shelby	1648.62^{A}	6828.05^{A}	929.93^{A}	1085.89^{A}	3706.89^{A}
Cherokee	1426.72^{AB}	7050.76^{A}	896.26^{A}	930.73^{B}	2460.96^{A}
Longleaf					
Houston	1049.05^{A}	5835.07^{A}	1249.56^{A}	781.32^{A}	2528.46^{A}
Shelby	1214.71^{A}	7543.96^{A}	1021.85^{A}	866.16^{A}	1954.15^{A}
Cherokee	1237.93^{A}	7066.50^{A}	1272.01^{A}	977.91^{A}	2988.89^{A}
Shortleaf					
Houston	1267.91^{A}	6639.71^{A}	1013.01^{A}	1017.37^{A}	2916.77^{A}
Shelby	1397.91^{A}	7020.97^{A}	1192.13^{A}	1045.27^{A}	3250.34^{A}
Cherokee	1445.47^{A}	8039.50^{A}	1102.56^{A}	1068.82^{A}	3245.77^{A}
Slash					
Houston	969.76^{A}	5085.11^{A}	1015.05^{A}	776.39^{A}	3218.15^{A}
Shelby	1199.21^{A}	6392.04^{A}	887.18^{A}	857.21^{A}	3676.09^{A}
Cherokee	1048.49^{A}	7852.27^{A}	974.37^{A}	938.17^{A}	2646.01^{A}

Micronutrients

Foliar amounts of manganese were significantly higher in Shelby and Cherokee counties than in Houston County (p=0.0227) (Table 5). Needle amounts of zinc were significantly (p<0.0001) higher in Shelby County than in Cherokee and Houston counties. Copper levels in needles were also significantly (p=0.0070) at higher in Shelby

County than in Cherokee and Houston counties. Molybdenum needle concentrations were greater (p=0.0006) in Shelby and Houston counties than in Cherokee County. Boron values were significantly different at the site ($p<0.0001$) and species (p=0.0344) levels. Needle content of boron was greater in Shelby and Houston counties than in Cherokee County. Boron values by species were greatest in longleaf, slash, and shortleaf, and longleaf was greater than loblolly. Nickel content was significant (p=0.0079) at the site level only, with higher values Shelby County than in Houston and Cherokee counties. Boron concentrations that were determined as negative were due to analyzation errors made within the lab. Needle sodium values were significant at the site (p=0.0128) level and the site*species interaction level (p=0.0070). Na values were greater in Shelby and Houston counties, and Shelby County values were higher than Cherokee County needle Na amounts. Loblolly pine Na concentrations were greater in Shelby and Houston counties than in Cherokee County loblolly pine. Sodium amounts in longleaf, shortleaf, and slash pine were not significant across sites. Foliar content of aluminum was significant (p=0.0149) at the species level. Aluminum values were higher in loblolly, longleaf, and shortleaf pines, and shortleaf pine values were greater than slash.

Table 5. Mean needle nutrient values of micronutrients, Sodium (Na) Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Aluminum (Al), Boron (B), and Nickel (Ni), by species at each site. Data analyzed at the Stephen F. Austin State University Soil, Plant, and Water Analysis Lab December 2018. A change in Tukey letters represents a significant difference (p<.05)

Species/Site	**Na**	**Fe**	**Mn**	**Zn**	**Cu**	**Al**	**B**	**Ni**
Loblolly								
Houston	48.48^{AB}	93.23^{A}	237.55^{A}	26.94^{A}	3.86^{B}	171.59^{A}	6.02^{A}	1.47^{A}
Shelby	187.33^{A}	750.01^{A}	478.21^{A}	60.67^{A}	10.61^{A}	987.10^{A}	7.75^{A}	3.96^{A}
Cherokee	18.02^{B}	126.78^{A}	273.08^{A}	30.19^{A}	5.05^{AB}	367.43^{A}	-5.59^{A}	1.64^{A}
Longleaf								
Houston	20.90^{A}	101.69^{A}	190.05^{A}	46.26^{A}	4.81^{A}	142.92^{A}	13.28^{A}	1.65^{A}
Shelby	50.98^{A}	921.57^{A}	311.41^{A}	63.67^{A}	8.37^{A}	784.53^{A}	13.71^{A}	3.21^{A}
Cherokee	36.25^{A}	215.03^{A}	336.91^{A}	39.60^{A}	6.23^{A}	397.97^{A}	0.51^{A}	4.14^{A}
Shortleaf								
Houston	60.60^{A}	116.01^{A}	194.09^{A}	46.05^{AB}	4.31^{A}	289.93^{A}	6.53^{AB}	0.72^{A}
Shelby	78.13^{A}	663.94^{A}	482.02^{A}	82.59^{A}	8.41^{A}	861.55^{A}	10.62^{A}	3.91^{A}
Cherokee	19.42^{A}	129.73^{A}	483.16^{A}	36.97^{B}	4.77^{A}	744.79^{A}	-6.96^{B}	2.46^{A}
Slash								
Houston	190.74^{A}	73.42^{A}	251.22^{A}	35.92^{A}	3.26^{A}	107.28^{A}	8.04^{A}	1.02^{A}
Shelby	77.30^{A}	258.03^{A}	560.28^{A}	74.50^{A}	4.54^{A}	473.72^{A}	9.82^{A}	3.50^{A}
Cherokee	19.05^{A}	83.02^{A}	349.10^{A}	40.09^{A}	3.83^{A}	264.19^{A}	5.20^{A}	2.83^{A}

Nutrient Uptake

Seedling potassium uptake from the soil was significant (p=0.0091) for all species in Shelby County, with a positive correlation of 0.7143. Availability of sulfur in needles in Shelby County was also significant (p=0.0021) and had a positive correlation of uptake from the soil of 0.7937. At the species level, phosphorus needle uptake was significant for loblolly ($p=0.0246$) and slash ($p=0.0444$) pine and had positive correlations of 0.73303 and 0.67874, respectively. Loblolly pine sulfur uptake was also significantly ($p=0.0039$) and positively correlated (0.8482) with needle-soil sulfur availability.

DISCUSSION

Growth

Greater loblolly pine mean heights and diameters could be due to their improved genetics compared to the longleaf, shortleaf, and slash pine used in this study (McCrady and Jokela 1996), the closeness of the origin of planted seedlings to the study sites, and the overall observed faster growth rates of loblolly pine (Smith and Schmidtling 1970, Gibson et al. 1986). Loblolly pine also outperform other southern pines on loamy textured, moist soils (Baker and Langdon 1990) that are considered to have adequate drainage conditions (Haywood et al. 1990, McKee and Shoulders 1970, Shoulders 1976, Tiarks and Shoulders 1982), similar to those present in Houston and Shelby counties. Loblolly pine has produced a much higher yield than the other southern pines on soils with adequate nutrient and moisture availability (Kramer 1943, Haines et al. 1981, Haywood et al. 1990, Faust et al. 1999, Jokela et al. 2000).

Slash pine were genetically superior to shortleaf pine in terms of growth, form, and rust resistance (based on genetic information provided by IFCO); however, East Texas is west of the native range of slash pine and receives less average annual rainfall, which could potentially stunt its growth. Slash pine typically outperforms shortleaf and loblolly pines when planted in poorly drained soils (Shoulders 1976, Shoulders and Parham 1983), which made up a small area of the Houston County site but were not present in Shelby or Cherokee County sites. Slash pine typically outcompetes the other southern pines in growth and volume production on sites that are nutrient deficient (Fisher 1983), but do not put on substantial growth on soils with nutrient availability that satisfies its growth demands (Jokela et al. 2000). The shortleaf seedling genetics and transferring them into a warmer, drier climate than their region of origin most likely affected seedling growth and establishment. A naturally slower growth rate (Guldin 1986, Lawson 1990) than loblolly and slash pine also resulted in the lower growth rates of shortleaf pine.

The majority of longleaf seedlings remained in the grass stage, producing almost no aboveground stem biomass three years after planting. The length of the grass stage in longleaf pine was likely due to the lack of herbaceous plant control after the initial herbicide applications (Barnett 1989, Boyer 1993, Brockway and Outcalt 1998, Nelson et al. 1985, Scott and Burger 2014, Ramsey et al. 2003). Those few longleaf that grew out of the grass stage have put on substantial amounts of growth and potentially could meet the productivity of the other pine species in the future (Croker 1990, Landers et al. 1995).

Survival

Loblolly, shortleaf, and slash pine survival most likely remained high because East Texas received above average rainfall between 2016 and 2019 (2016=1440mm, 2017=1235mm, 2018=1490mm, historic mean rainfall in East Texas=1185mm). The greatest causes of mortality among loblolly, shortleaf, and slash pine were damage to seedlings by feral hog activity in Houston and Shelby counties. Similar to Pessin 1939, feral hogs uprooting pine seedlings leaves root systems without soil contact and exposed to high temperatures and sunlight, which leads to mortality. Another factor affecting seedling mortality post-planting was the inundated conditions of several field plots for several weeks after establishment.

Much of the longleaf mortality in the first year could have been due to non-optimum planting conditions. Planting temperatures (26°C) were higher than recommended for planting (Lantz et al. 1996), and several plots in Houston and Shelby counties were inundated by frequent, heavy rains. Terminal buds and root collars of the longleaf pine seedlings remained underwater for weeks prior to planting, preventing them from receiving sunlight and oxygen for root allocation and causing several containerized seedlings to float out of the planting bar hole. Even after waters had subsided, sediment moved over the terminal buds and buried the root collars of longleaf pine, resulting in high mortality within the first four months (Hainds 2004; Larson 2002).

Feral hog damage to seedlings was the main cause of mortality in Shelby and Houston counties. Cherokee County soils were well drained to excessively well-drained, hindering the amount of water available to seedlings during summer months with low precipitation. The highest cause of mortality in Cherokee County was defoliation of seedlings by Texas leafcutter ant (*Atta texana*). Leafcutter ants began defoliating all species as early as one month after planting and continued through the third year. Cherokee County longleaf pine plots were also subject to feral hog damage and deer herbivory. Herbivory mortality caused the removal of the terminal bud and root collar and the exposure of root systems in the summer (Pessin 1939).

Leaf Water Potential

Because longleaf pine seedlings in the grass stage do not allocate much energy to aboveground biomass and the distance water must travel from the root system to the needles is much shorter than the other species, longleaf pine is able to conserve more energy, thus leading to lower moisture stress levels. Longleaf pine also have a higher needle moisture content as an adaptation to fire. Nutrient and water demands of slash pine were adequately met, allowing the seedlings to perform growth throughout the year without experiencing long periods of moisture stress. Loblolly pine predawn water potentials were comparable to other studies from April-June and September-December and less negative during late summer months (Dalton and Messina 1994, Seiler and Johnson 1985). Maximum stress levels of loblolly pine, longleaf, and shortleaf pines during periods of moderate moisture stress were also similar for Sword Sayer et al. in (2005).

Slower aboveground growth rates of all pines in Cherokee County could have been due to the dryer soil conditions compared to soils in Houston and Shelby counties, thus leading to higher levels of moisture stress (Hennessey and Dougherty 1984, Seiler and Johnson 1985). When exposed to long periods of low moisture availability, seedlings respond by allocating more carbon to the root system instead of the stem (Bongarten and Teskey 1987, McMurtie 1985). Depths to the B horizons containing clay content were more shallow in Houston and Shelby counties, allowing for more moisture availability to seedlings roots. In Shelby County, the depth to the B horizon was shallower than in Houston County, retaining more water for seedlings during periods of low precipitation.

Nutrients

Nutrient availability at the soil and foliar level were well above the critical thresholds for all four species (Dickens et al. 2003, Jokela et al. 1991). Foliar nutrient concentrations in loblolly pine were similar to those found on trees studied by Metz and Wells (1965). Faster growth rates of loblolly and slash pine was most likely due to their ability to uptake greater amounts of phosphorus from the soil than longleaf and shortleaf. Slash pine nutrient requirements are not as demanding as other pine species, allowing it to compete with the faster growth rates of loblolly pine on sites where nutrient availability is not optimum (Jokela and Martin 2000, Binkley and Giardinia 1998). Similar to slash pine, shortleaf has a much lower nutrient demand than loblolly pine (Fowells 1965). Soils at all three study sites provided adequate nutrients for shortleaf pine growth, but were not deficient enough to negatively affect the growth of loblolly pine.

Greater mean heights for all species in Shelby County may have been caused by high levels of potassium and phosphorus available in the soil. Dryer soil conditions in Houston County and the well-drained soils of Cherokee County could have been the cause of lower soil phosphorus values in these soils (Haywood et al. 1990, Fox et al. 2007).

Without adequate moisture, amounts of soil nutrients do not always produce higher growth yields in pine. This could be an explanation for the slower growth rates of the seedlings on well drained and excessively drained soils of Cherokee County and on the dryer soils in Houston County. Seedlings in Shelby County were able to take advantage of available nutrients because of the moderate moisture within the soil (Seigel-Issem et al. 2005).

CONCLUSIONS

The natural growth rates, genetic improvements, nutrient demands, and response to moisture stress of the southern pines resulted in different yields of above ground biomass across the study sites. Shelby County soils, with the most adequate soil moisture and nutrient availability, had the highest productivity for all four species at the end of three growing seasons. The well drained and deep sand soils in Cherokee County produced the least amount of aboveground growth. Based on these results, loblolly pine is recommended for planting on sites where soil moisture and nutrients are adequate and when timber production is the main objective. Loblolly pine has the capability to adapt and outcompete the other pine species when soil water and nutrients are available because of it's naturally faster growth rate. Slash pine can outcompete loblolly pine when planted on sites that have lower nutrient availability than loblolly demands, and on sites where soils are poorly drained. On soils that are excessively drained with low moisture and low nutrients, shortleaf should be considered. Because of longleaf pine's ability to retain needle moisture and surface area during periods of low soil moisture, longleaf pine is suggested to be planted on sites that are more prone to drought. Longleaf pine will require more active management on any soil type in order to decrease herbaceous plant competition. If properly managed, longleaf pine growth is comparable to the other southern pines after growing out of the grass stage. Continued measurements are required to determine if these growth and survival trends will continue over the lifespan of the trees.

LITERATURE CITED

Abrahamson, W.G., and Hartnett, D.C. 1990. Pine flatwoods and dry prairies. Ecosystems of Florida, University of Central Florida: pp. 103-149.

Albaugh, T.J., Allen, L.A., Dougherty, P.M., Kress, L.W., and King, J.S. 1998. Leaf area and above-and belowground growth responses of loblolly pine to nutrient and water additions. Forest Science 44(2):317-328.

Allen, H.L. 1987. Fertilizers: Adding nutrients for enhanced forest productivity. Journal of Forestry 85:37-46.

Aubertin, G.M. and Kardos, L.T. 1965. Root growth through porous media under controlled conditions. In: Proceedings of Soil Science Society of America 29:290-293.

Baker, J.B. and Balmer, W.E. 1983. Loblolly pine. Silvicultural systems for the major forest types of the United States. United States Department of Agriculture Forest Service, Agriculture Handbook 445:148-152.

Baker, J.B. and Langdon, O.G. 1990. Silvics of North America: Conifers; Agriculture Handbook 654. United States Department of Agriculture, Forest Service, Washington, D.C. 2:877.

Barnes, B.V., Zak, D.R., Denton, S.R., Spurr, S.H. 1998. Forest Ecology, 4th Edition. John Wiley and Sons Inc. New York, NY p. 264-265.

Barnet, J.P. 1989. Site preparation, containers, and soil typs affect field performance of loblolly and longleaf pine seedlings. In: Miller, J.H. Proceedings of the 5th biennial southern silviculture research conference. General Technical Report SO-74, United States Depertment of Agriculture, Forest Service, Southern Forest Expermental Station, New Orleans, Louisiana, pp. 155-158.

Barry, J.E. 2013. Storing, handling, and planting southern pine seedlings. Agriculture and Natural Resources FSA 5007.

Binkley, D. and Giardinia, C. 1998. Why do tree species affect soils? The warp and wood of tree-soil interactions. Biogeochemistry 42:89-106.

Bongarten, B.C., Teskey, R.O., and Boltz, B. 1985. Comparative physiology of loblolly pine seedlings from six geographic sources as related to seedling growth rate. In: Proceedings of the 18th Southern Forest Tree Improvement Conference, pp. 321-333.

Bongarten, B.C. and Teskey, R.O. 1987. Dry weight partitioning and its relationship to productivity in loblolly pine from seven sources. Forest Science 33(2):255-267.

Boyer, W.D. 1970. Shoot growth patterns of young loblolly pine. Forest Science 16(4):472-482.

Boyer, W.D. 1993. Long-term development of regeneration under pine seedtree and shelterwood stands. Southern Journal of Applied Forestry 17:10-15.

Boyer, W.D. and Peterson, D.W. 1990. Longleaf Pine-Silvicultural systems for the major forest types of the United States. Technical Compilation, United States Department of Agriculture, Forest Service Agricultural Handbook 445:153-156.

Branan, J.R. and Porterfield, E.J. 1971. A comparison of six species of southern pines planted in the Piedmont of South Carolina. United States Department of Agriculture, Forest Service, Southeastern Forest Experiment Station- Asheville, North Carolina. Research Note 171.

Brissette, J.C. and Chambers, J.L. 1992. Leaf water status and root system water flux of shortleaf pine (Pinus echinata Mill.) seedlings in relation to new root growth after transplanting. Tree Physiology 3:289-303.

Brissette, J.C., Barnett, J.P., and Landis, T.D. Container Seedlings 1991. Forest Regeneration Manual 36:117-141.

Brockway, D.G. and Outcalt, K.W. 1998. Gap-phase regeneration in longleaf pine wiregrass ecosystems. Forest Ecology and Management. 106:125-139.

Chandler, J.W. 2003. Regenerating southern pines. In Landowner's Handbook for Managing Southern Pines. United States Department of Agriculture, Forest Service, Southern Region p. 1-67.

Comerford, N.B., Fisher, R.F., and Pritchett, W.L. 1983. Advances in forest fertilization on the southeastern Coastal Plain. In: I.U.F.R.O. symposium on Forest Site and

Continuous Productivity, United States Forest Service General Technical Report PNW-163:370-378, Portland. Oregon.

Creighton, J.L., Zutter, B.R., Glover, G.R. and Gjerstad, D.H. 1987. Planted pine growth and survival responses to herbaceous vegetation control, treatment duration, and herbicide application technique. Southern Journal of Applied Forestry 11:223-227.

Croker, T.J. 1990. Longleaf pine-myths and facts. In: Proceedings of the Symposium on the Management of Longleaf Pine, Long Beach, Mississippi p. 2-10.

De Ronde, C. 1982. The resistance of *Pinus* species to fire damage. South African Forestry Journal 122:22-27.

Daddow, R.L. and Warrington, G.E. 1983. Growth-limiting soil bulk densities as influenced by soil texture. United States Department of Agriculture, Forest Service, Watershed Systems Development Group WSDG Report WSDG-TN-00005.

Dalton, C.T. and Messina, M.G. 1994. Water relations and growth of loblolly pine seedlings planted under shelterwood and in a clear-cut. Tree Physiology 15:19-26.

Dickens, E.D., Moorhead, D.J., and McElvany, B. 2003. Pine plantation fertilization. Better Crops 87(1):12-15.

Dickens, E.D., Van Lear, D.H., Marsinko, A.P.C., and Sarigumba, T.I. 1988. Long-term effects of soil drainage, spacing, and site preparation on height and stand volume growth of slash pine. In: Proceedings of the fifth biennial southern silviculture research conference, New Orleans, Louisiana. United States Department of Agriculture, Forest Service, Southern Forest Experiment Station, p. 225-230.

Dicus, C.A. and Dean, T.J. 2008. Tree-soil interactions affect production of loblolly and slash pine. Forest Science 54(2):135-139.

Eckert, A. J., Bower, A. D., Gonzalez-Martinez, S.C., Wegrzyn, J.JL, Coop, G, Neale, D.B. 2010. Back to nature: ecological genomics of loblolly pine. Molecular Biology 19: 3789-3805.

Faust, T.D., Clark III, A.C., Courchene, C.E., Shiver, B.D., and Belli, M.L. 1999. Effect of intensive forest management practices on wood properties and pulp yield of young, fast growing southern pine. Proceedings of the International Environmental Conference, Nashville, TN, USA 2:501-512.

Fisher, R.F. 1983. Silvical characteristics of slash pine (*Pinus elliottii* Engelm var. elliottii). In: The Managed Slash Pine Ecosystem, Stone, E.L. University of Florida, Gainesville, Florida, p. 48-55.

Fisher, R.F., and Garbett, W.S. 1980. Response of semimature slash and loblolly pine plantations to fertilization with nitrogen and phosphorous. Soil Science Society of America Journal 44:850-854.

Fisher, R.F. and Binkley, D. 2000. Ecology and Management of Forest Soils, 3rd Edition. John Wiley and Sons Inc., New York, NY, p. 76-77.

Flanagan, P.W. and Van Cleve, K. 1983. Nutrient cycling in relation to decomposition and organic-matter quality in taiga ecosystems. Canadian Journal of Forest Research 13(5):795-817.

Fowells, H.A. 1965. Silvics of forest trees of the United States. United States Department of Agriculture, Agriculture Handbook 271:762.

Fox, T.R., Jokela, E.J., and Allen, H.L. 2007. The development of pine plantation silviculture in the southern United States. Journal of Forestry 105(7):337-347.

Fox, T.R., Allen, H.L., Albaugh, T.J., Rubilar, R., and Carlson, C.A. 2007. Tree nutrition and forest fertilization of pine plantations in the southern united states. Southern Journal of Applied Forestry 31(1):5-11.

Franklin, R.M. 2008. Stewardship of longleaf pine forests: a guide for landowners. Longleaf Alliance Report no. 2. A Joint Project of the Longleaf Alliance. Auburn University and Clemson University Cooperative Extension Service.

Frost, C.C. 2006. History and future of the longleaf pine ecosystem. In: Jose, S., Jokela, E.J. and Miller, D.L. The longleaf pine ecosystem- ecology, silviculture, and restoration. Springer, New York, NY pp. 9-48.

Gent, J.A. Jr., Allen, H.L., Campbell, R.G., and Well, C.G. 1986. Magnitude, duration, and economic analysis of loblolly pine growth response following bedding and phosphorus fertilization. Southern Journal of Applied Forestry 10:124-128.

Gibson, M.D., McMillin, C.W., and Shoulders, E. 1986. Moisture content and specific gravity of the four major southern pines under the same age and site conditions. Wood and Fiber Science 18(3):428-435.

Guldin, J.M. 1986. Ecology of shortleaf pine. Symposium on the shortleaf pine ecosystem, United States Forest Service pg. 25-40.

Greacen, W.R. and Sands, R. 1980. Compaction of forest soils- a review. Australian Journal of Soil Research 18:163-189.

Griffing, C.G. and Elam, W.W. 1971. Height growth patterns of loblolly pine saplings. Forest Science 17(1): 52-54.

Grissom, J.E. and Schmidtling, R.C. 1997. Genetic diversity of loblolly pine grown in managed pine plantations: evidence of differential response to climatic events. In: Proceedings of the 24th southern forest tree improvement conference.

Hainds, M.J. 2004. Determining the correct planting depth for container-grown longleaf pine seedlings. Longleaf Alliance Report 6:66-68.

Hainds, M.J., Johnson, E.E., and Gjerstad, D.H. 2004. Longleaf Alliance Report 6:69.

Hainds, M.J., Johnson, E.E., and Gjerstad, D.H. 2005. Container-grown longleaf (Pinus palustris) seedling survival at four planting depths. Longelaf Alliance and the School of Forestry and Wildlife Sciences, Auburn University Bulletin pp:1.

Haines, L.W., Gooding, J., and Wilhite, L. 1981. Site selection: slash pine versus other species. In The Managed Slash Pine Ecosystem. Institute of Food and Agricultural

Science, University of Florida, Gainesville, Florida pp. 47. Hallgren, S.W. and Tauer, C.G. 1989. Root growth potential, fires-year survival, and growth of shortleaf pine seedlings show effects of lift date, storage, and family. Southern Journal of Applied Forestry 13:163-169.

Hamilton, R.A. 2003. Importance of soil to tree growth. In Landowner's Handbook for Managing Southern Pines. United States Department of Agriculture, Forest Service, Southern Region, 1-67.

Haywood, J.D. and Tiarks, A.E. 2002. Response of second-rotation southern pines to fertilizer and planting on old beds-fifteenth year results. Proceedings of the eleventh biennial Southern Silviculture Research Conference. United States Department of Agriculture Forest Service, Southern Research Station, Asheville, North Carolina pp. 497-502.

Haywood, J.D., Tiarks, A.E., and Shoulders, E. 1990. Loblolly and slash pine height and diameter are related to soil drainage in winter on poorly drained silt loams. New Forests 4:81-96.

Hebb, E.A., Clewell, A.F., Andre, F. 1976. A remnant stand of old-growth slash pine in the Florida panhandle. Bulletin of the Torrey Botanical Club 103:1-9.

Hellkvist, J., Richards, G.P., and Jarvis, P.G. 1974. Vertical gradients of water potential and tissue water relation in sitka spruce trees measured with the pressure chamber. Journal of Applied Ecology 11(2):637-667.

Hennessey, T.C. and Dougherty , P.M. 1984. Characterization of the internal water relations of loblolly pine seedlings in response to nursery cultural treatments: implications for reforestation success. In: Seedling Physiology and Reforestation Success, Eds. M. Duryea, and G.N. Brown, Martinus Nijhoff/Dr. W. Junk Publishers, The Netherlands pp. 225-243.

Jokela, E.J., Wilson, D.S., and Allen, J.E. 2000. Early growth responses of slash and loblolly pine following fertilization and herbaceous weed control treatments at establishment. Southern Journal of Applied Forestry 24(1):23-30.

Jokela ,E.J. ,and Martin, T.A. 2000. Effects of ontongeny and soil nutrient supply on production, allocation, and leaf area efficiency in loblolly and slash pine stands. Canada Journal of Forest Research 30:1511-1524.

Jokela, E.J., Allen, H.L., and McFee, W.W. 1991. Fertilization of southern pines at establishment. Forest Regeneration Manual, Kluwer Academic Publishers, Dordrecht, The Netherlands p. 263-277.

Jose, S., Merritt, S., and Ramsey, C.L. 2003. Growth, nutrition, photosynthesis, and transpiration responses of longleaf pine seedlings to light, water, and nitrogen. Forest Ecology and Management 180:335-344.

Kaufmann, M.R. 1968. Water relations of pine seedlings in relation to root and shoot growth. Plant Physiology 43:281-288.

Knox, R.G., Harcombe, P.A., and Elsik, S.I. 1995. Contrasting patterns of resource limitation in tree seedlings across a gradient in soil texture. Canadian Journal of Forest Research 25:1583-1594.

Kramer, P.J. 1943. Amount and duration of growth of various species of tree seedlings. Plant Physiology 18(2): 239-251.

Laird, C.R. 1972. Fertilization of slash pine on poorly drained soils in northwest Florida. Florida Cooperative Extensive Service, University of Florida, Gainesville, Florida 378:12.

Lambeth, C., Mcknead, S., Rousseau, R., and Schmidtling, R. 2005. Planting nonlocal seed sources of loblolly pine-managing benefits and risks. Southern Journal of Applied Forestry 29:96-104.

Landers, J.L., Van Lear, D.H., Boyer, W.D. 1995. The longleaf pine forests of the southeast: requiem or renaissance? Journal of Forestry 93(11): 39-44.

Lantz, C.W. and Kraus, J.F. 1987. A guide to southern pine seed sources. United States Department of Agriculture Forest Service, Southeastern Forest Experiment Station, Asheville, North Carolina Technical Report 43.

Lantz, C.W., Biesterfeldt, R.C., Moorhead, D.J., Aycock, O.E., Barham, R.O., Brissette, J.C., Dierauf, T.A., Dougherty, P.M., Fryar, R.D., Ross, O.E., Schroeder, R.A., Stauder, A.F. 1996. A guide to care and planting of southern pine seedlings. United States Department of Agriculture, Forest Service, Management Bulletin R8-MB39:1-44.

Larson, D.R. 2002. Field planting containerized longleaf pine seedlings. Proceedings of workshops on growing longleaf pine in containers, General Technical Report SRS-56.

Lawson, E.R. 1990. Shortleaf pine-Silvics of North America: conifers. United States Department of Agriculture, Forest Service Agricultural Handbook 2:877.

Lilly, C.J., Will, R.E., Tauer, C.G., Guldin, J.M., Spetich, M.A. 2012. Factors affecting the sprouting of shortleaf pine rootstock following prescribed fire. Forest Ecology and Management 265: 13-19.

Little, E.L. 1980. The Audubon Society field guide to North American trees, eastern region p. 291.

Little Jr., E.L. and Dorman, K. 1954. Slash pine (*Pinus elliottii*), including south Florida slash pine-nomenclature and description. United States Department of Agriculture, Forest Service, Southeastern Forest Experiment Station 36:82.

Little, S. and Mergen, F. 1966. External and internal changes associated with basal-crook formation in pitch and shortleaf pines. Forest Science 12(3): 268-275.

Little, S. and Somes, H.A. 1956. Buds enable pitch and shortleaf pines to recover from injury. United States Department of Agriculture Forest Service, Northeastern Forest Experiment Station, Station Paper 81:1-14.

Lohrey, R.E. and Kossuth, S.V. 1990. Slash pine-Silvics of North America: conifers.United States Department of Agriculture, Forest Service Agricultural Handbook 2:877.

Long, E.M. 1980. Texas and Louisiana loblolly pine study confirms importance of local seed sources. Southern Journal of Applied Forestry 4(3):127-132.

Lopushinsky, W. 1969. Stomatal closure in conifer seedlings in response to leaf moisture stress. Botanical Gazette 130:258-263.

Lorio Jr., P.L., Howe, V.K., and Martin, C.N. 1972. Loblolly pine rooting varies with microrelief on wet sites. Ecological Society of America 53(6):1134-1140.

Maier, C.A., Dougherty, P.M., and Zarnoch, S.J. 1998. Modelling the effects of temperature and tissue nitrogen on dormant season stem and branch maintenance respiration in a young loblolly pine (*Pinus taeda* L.) plantation. Tree Physiology 18:11-20.

Mattoon, W.R. 1915. Life history of shortleaf pine. United States Department of Agriculture Bulletin 244: 46.

McCrady, R.L. and Jokela, E.J. 1998. Canopy dynamics, light intercepetion, and radiation use efficiency of selected loblolly pine families. Forest Science 44:64-72.

McKee Jr., W.H., and Shoulders, E. 1970. Depth of water table and redox potential of soil affect slash pine growth. Forest Science 16:399-402.

McKee Jr., W.H. and Wilhite L.P. 1986. Loblolly pine response to bedding and fertilization varies by drainage class on lower Atlantic Coastal Plain sites. Southern Journal of Applied Forestry 10:16-21.

McKellar, A.D. 1942. Ice damage to slash pine, longleaf pine, and loblolly pine plantations in the Piedmont section of Georgia. Journal of Forestry, 40(10), 794-797.

McMinn, J.W. 1981. Site preparation for natural regeneration of slash pine. Southern Journal of Applied Forestry 5(1):10-12.

McMurtie, R.E. 1985. Forest productivity in relation to carbon partitioning and nutrient cycling: a mathematical model. In: Attributes of Trees as Crop Plants, pp 194-206.

Metcalfe, C.S. 1985. 1984 secondary screening in pine plantations: Oust and Velpar rate studies. Auburn University, Herbicide Cooperative Research, Note 85-4, Auburn.

Metz, L.J. and Wells, C.G. 1965. Weight and nutrient content of the aboveground parts of some loblolly pines. US Forest Service Research Paper SE-17 p.20.

Alabama, p 15.

Mexal, J.G., Timmis, R., and Morris, W.G. 1979. Cold-hardiness of containerized loblolly pine seedlings-its effect on field survival and growth. Southern Journal of Applied Forestry 3(1):15-19.

Morgenstern, E.K. 1996. Geographic variation in forest trees: genetic basis and application of knowledge in silviculture. UBC Press, Vancouver pp. 209.

Murthy, R., Dougherty, P.M., Zarnoch, S.J., and Allen, H.L. 1996. Effects of carbon dioxide, fertilization, and irrigation on photosynthetic capacity of loblolly pine trees. Tree Physiology 16:537-546.

Nambiar, E.K.S., Bowen, G.D., and Sands, R. 1979. Root regeneration and plant water stress on *Pinus radiata* D. on seedlings transplanted to different soil temperatures. Journal of Experimental Botany 30:1119-1131.

Nelson, L.R., Zutter, B.R., and Gjerstad, D.H. 1985. Planted longleaf pine seedlings respond to herbaceous weed control using herbicides. Southern Journal of Applied Forestry 9(4):236-240.

Nemeth, J.C. and Davey, C.B. 1974. Site factors and the net primary productivity of young loblolly pine and slash pine plantations. Soil Science Society of America Journal 38(6):968-970.

O'Connell, D.J. 1975. The measurement of apparent specific gravity of soils and its relationship to mechanical composition and plant root growth. In: Soil Physical Conditions and Crop Production, Technical Bulletin 29 p. 398-313.

Outcalt, K.W. 2000. The longleaf pine ecosystem of the south. Native Plants Journal 1:43-53.

Osborne, J.G. and Harper, V.L. 1937. The effect of seedbed preparation in first-year establishment of longleaf and slash pine. Journal of Forestry 35(1):63-68.

Pastor, J., Aber, J.D., McClaugherty, C.A., and Melillo, J.M. 1984. Aboveground production and N and P cycling along a nitrogen mineralization gradient on Blackhawk Island, Wisconsin. Ecology 65:256-268.

Pessin, L. J. 1939. Root habits of longleaf pine and associated species. Ecology 20(1):47-57.

Powers, H.R. and Matthews, F.R. 1987. Five fusiform rust-resistant seed sources in Coastal South Carolina: a field comparison. Southern Journal of Applied Forestry 11:198-201.

Pritchett, W.L. and Comerford, N.B. 1982. Long-term response of phosphorus fertilization on selected southern Coastal Plain soils. Soil Science Society of America Journal 46:640-644.

Pritchett, W.L., Llewellyn, W.R., and Swinford, K.R. 1961. Response of slash pine to colloidal phosphate fertilization. Soil Science Society of America Proceedings 25:397-400.

Ramos, C. and Kaufmann, M.R. 1979. Hydraulic resistance of rough lemon roots. Plant Physiology 45:311-314.

Ramsey, C.L., Jose, S., Brecke, B.J., Merritt, S. 2003. Growth response of longleaf pine (*Pinus palustris* Mill.) seedlings to fertilization and herbaceous weed control in an old field in southern USA. Forest Ecology and Management 172:281-289.

Runion, G.B., Mitchell, R.J., Green, T.H., Prior, S.A., Rogers, H.H., and Gjerstad, D.H. 1999. Longleaf pine photosynthetic response to soil resource availability and elevated atmospheric carbon dioxide. Journal of Environmental Quality 28:880-887.

Rutter, A.J. and Sands, K. 1958. The relation of leaf water deficit to soil moisture tension in *Pinus sylvestris* I. The effect of soil moisture on diurnal changes in water balance. New Phytologist 57:50-65.

Schmidtling, R.C. 1973. Intensive culture increases growth without affecting wood quality of young southern pines. Canadian Journal of Forestry 3:565-573.

Schmidtling, R.C. 1997. Using provenance tests to predict response to climatic change. In: Cheremisinoff, P.N. (ed.) Ecological Issues and Environmental Impact Assessment. Gulf Publishing, Houston TX pp: 633-654.

Schmidtling R.C. 1999. Genetics of longleaf pine. In: Kush, J.S. compilation. Proceedings of the 2nd Longleaf Alliance Conference, Charleston, South Carolina 4:24-26.

Schmidtling, R.C. 2001. Southern pine seed sources. United States Department of Agriculture Forest Service SRS-44.

Schmidtling, R.C. 2007. Genetic variation in the southern pines: evolution, migration, and adaptation following the Pleistocene. In: Kabrick, J.M., Dey, D.C., Gwaze, D. Shortleaf pine restoration and ecology in the Ozarks: Proceedings of a symposium, Springfield, Missouri. United States Department of Agriculture Forest Service 15:28-32.

Schultz, R.P. 1999. Loblolly-the pine for the twenty-first century. New Forests 17:71-88.

Schuurman, J.J. 1964. Influence of soil density on root development and growth of oats. Plant and Soil 22:352-374.

Schwilk, D., Ackerly, D.D. 2001. Flammability and serotiny as strategies: correlated evolution in pines. Oikos 94: 326-336.

Scott, A.D. and Burger, J.A. 2014. Longleaf and loblolly pine seedlings respond differently to soil compaction, water content, and fertilization. Plant Soil 375:225-265.

Seiler, J.R. and Johnson, J.D. 1985. Photosynthesis and transpiration of loblolly pine seedlings as influenced by moisture-stress conditioning. Forest Science 31(3):742-749.

Shelton, M.G. and Cain, M.D. 2000. Regenerating uneven-aged stands of loblolly and shortleaf pines: the current state of knowledge. Forest Ecology and Management 129: 177-193.

Shiver, B.D., Rheney, J.W., and Hitch, K.L. 2000. Loblolly pine outperforms slash pine in southeastern Georgia and northern Florida. Southern Journal of Applied Forestry 24(1):31-36.

Shoulders, E. 1976. Site characteristics influence relative performance of loblolly and slash pine. United States Department of Agriculture, Forest Service, Southern Forest Experimental Station. 16p.

Shoulders, E. and Parham, G. 1983. Slash pine. Silvicultural systems for the major forest types of the United States. United States Department of Agriculture Forest Service, Agriculture Handbook 445:162-166.

Siegel-Issem, C.M., Burger, J.A., and Powers, R.F. 2005. Seedling root growth as a function of soil density and water content. Soil Science Society of America Journal 69:215-226.

Smith, L.F. and Schmidtling, R.C. 1970. Cultivation and fertilization speed early growth of planted southern pines. Tree Planters' Notes 21(1):1-3.

Smith, W.R., Farrar Jr., R.M., Murphy, P.A., Yeiser, J.L., Meldahl, R.S., and Kush, J.S. 1992. Crown and basal area relationships of open-grown southern pines for modeling competition and growth. Canadian Journal of Forestry 22(3):341-347.

Snyder, B.E., Wakeley, P.C., and Wells, O.O. 1976. Slash pine provenance tests. Journal of Forestry 65(6):414-420.

South, D.B., Jackson, D.P., Starkey, T.E., Enebak, S.A. 2012. Planting deep increases early survival and growth of *Pinus echinata* seedlings. The Open Forest Science Journal 5:33-41.

Stone, E.L. 1968. Micronutrient nutrition of forest trees: a review. In: Forest fertilization-theory and practice, Tennessee Valley Authority, Knoxville, Tennessee, pp.132-175.

Stransky, J.J. and Wilson, D.R. 1964. Terminal elongation of loblolly and shortleaf pine seedlings under soil moisture stress. Soil Science Society of America Proceedings 28:439-440.

Swindell, B.F., Neary, D.G., Comerford,N.B., Rockwood, D.L., and Blakeslee, G.M. 1988. Fertilization and competition control accelerate early southern pine growth on flatwoods. Southern Journal of Applied Forestry 12:116-121.

Sword Sayer, M.A.S., Brissette, J.C., Barnett, J.P. 2005. Root growth and hydraulic conductivity of southern pine seedlings in response to soil temperature and water availability after planting. New Forests 30:253-272.

Taylor, E.L., Holley, A.G., and Blazier, M. 2006. New pine planting strategies for the western gulf coast states. Southern Regional Extension Forestry Technical Report FM: 003.

Teskey, R.O., Bongarten, B.C., Cregg, B.M., Dougherty, P.M., and Hennessey, T.C. 1987. Physiology and genetics of tree growth response to moisture and temperature stress: an examination of the characteristics of loblolly pine (*Pinus taeda* L.). Tree Physiology 3:41-61.

Tiarks, A.E. and Shoulders, E. 1982. Effects of shallow water tables on height growth and phosphorus uptake by loblolly and slash pines. United States Deparments of Agriculture, Forest Service Research Station, Forest Experiment Station, New Orleans, Louisiana. Note SO-285, 5p.

Turner, J., Dice, S.F., Cole, D.W., and Gessel, S.P. 1978. Variations of nutrients in forest tree foliage-a review. Institute of Forest Product Control, College of Forest Resources, University of Washington, Seattle Washington.

Tyree, M.C., Seiler, J.R., and Maier, C.A. 2009. Short-term impacts of nutrient manipulations on leaf gas exchange and biomass partitioning in contrasting 2-year-old *Pinus taeda* clones during seedling establishment. Forest Ecology and Management 257:1847-1858.

Veihmeyer, F.J. and Hendrickson, A.H. 1948. Soil density and root penetration. Soil Science 65:487-493.

Wade, D.D. 1983. Fire management in the slash pine ecosystem. Proceedings of the managed slash pine ecosystem, University of Florida: School of Forest Resources and Conservation 290-294.

Wakeley, P.C. 1963. How far can seed be moved? Seventh Southern Forest Tree Improvement Conference: pp.38-43.

Ware, S., Frost, C.C., and Doerr, P.D. 1993. Southern mixed hardwood forest: the former longleaf pine forest. In: Martin, W.H., Boyce, S.G., Echternacht, A.C. Biodiversity of the southeastern United States, lowland terrestrial communities. John Wiley & Sons, New York, NY pp. 447-493.

Wells, O.O. 1983. Southwide pine seed source study-loblolly pine at 25 years. Southern Journal of Applied Forestry 7(2):63-71.

Wells, O.O. and Wakeley, P.C. 1970. Variation in longleaf pine from several geographic sources. Forest Science 16(1):28-42.

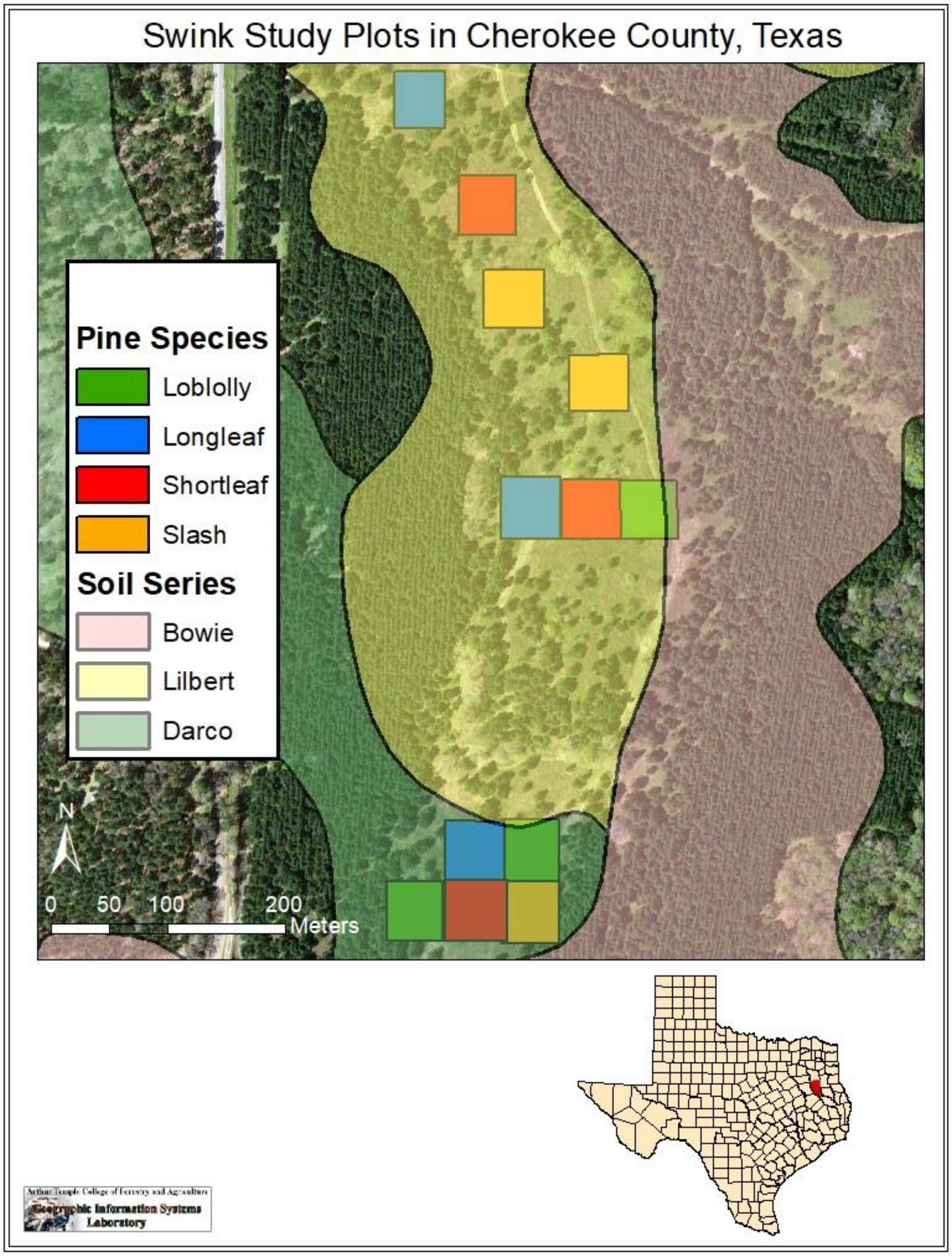
Wells, C.G., Crutchfield, D.M., Berenyi, N.M., and Davey, C.B. 1973. Soil and foliar guidelines for phosphorus fertilization of loblolly pine. United States Forest Service, Southeast Forest Experimental Station, Asheville, North Carolina, Research Paper SE 110:17.

Wiersum, L.K. 1957. The relationship of the size and structural rigidity of pores and their penetration by roots. Plant and Soil 9:75-85.

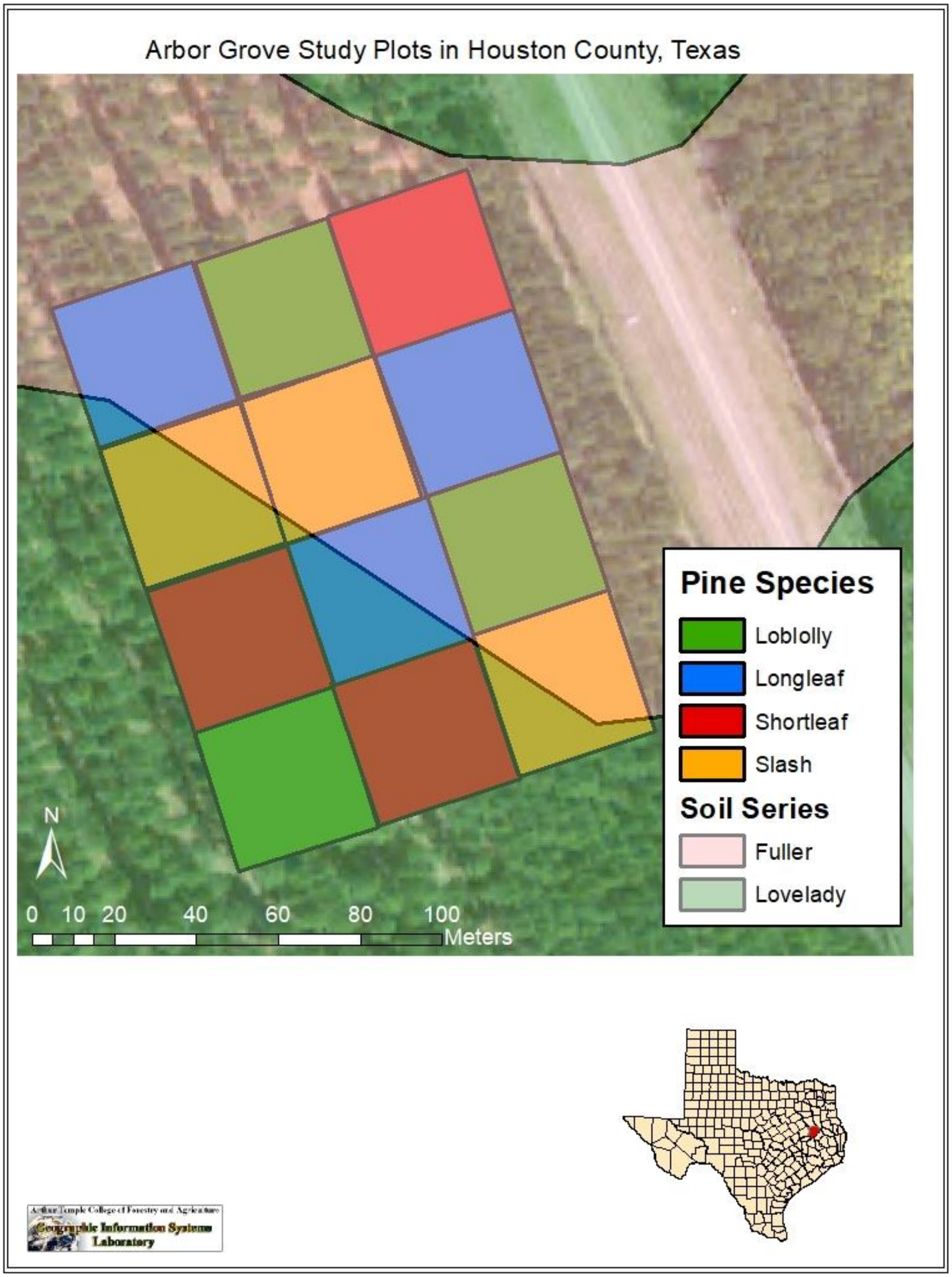
Zahner, R. 1968. Water deficits and the growth of trees. In water deficits and plant growth 2:191-254.

Zhang, S. 1993. The effects of nitrogen availability on leaf area, photosynthesis and foliar nutrient status of loblolly pine. Ph.D. Dissertation, North Carolina State University, Department of Forestry, Raleigh, North Carolina.

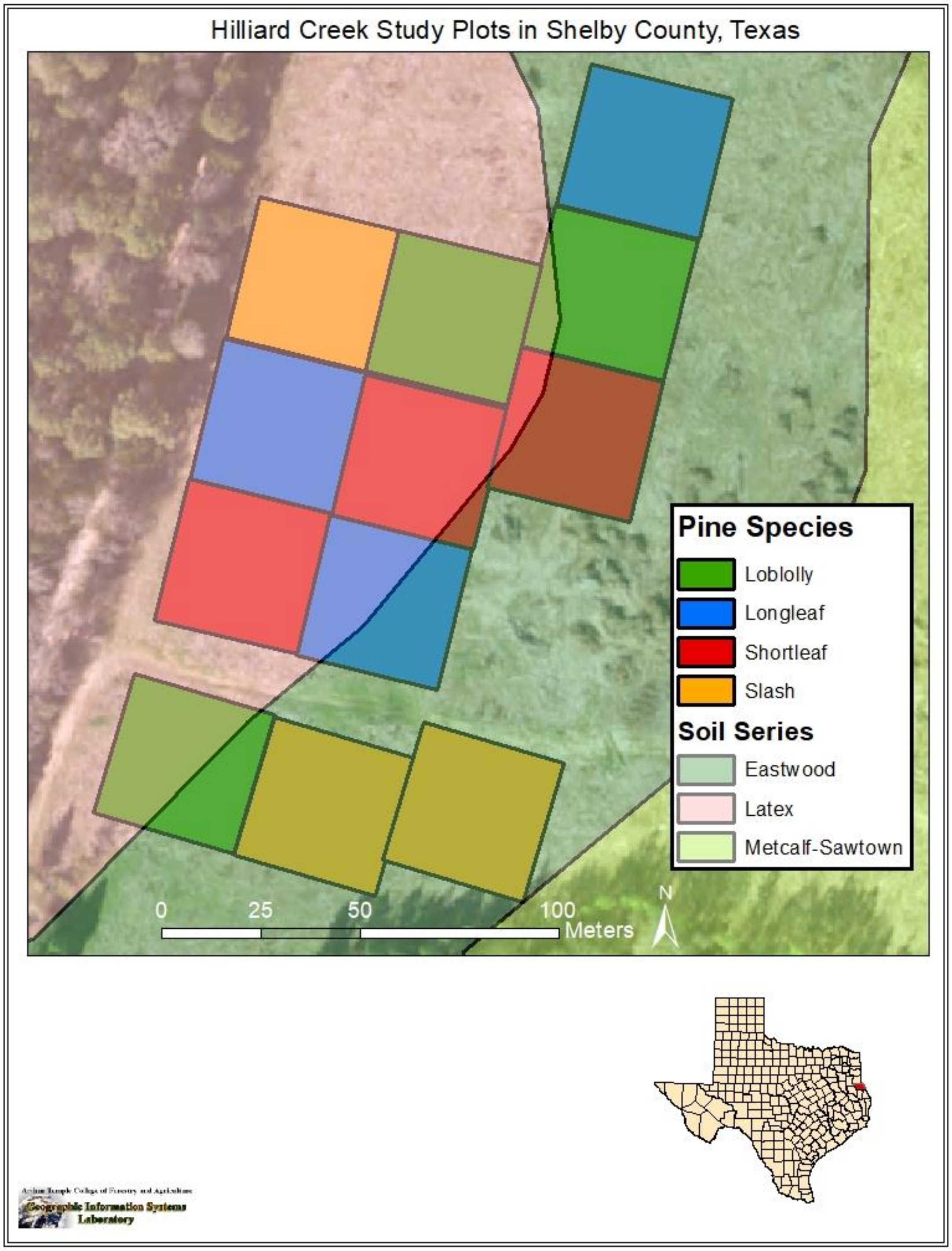
APPENDIX A


Swink Study Plots in Cherokee County, Texas
Pine Species
Loblolly
Longleaf
Shortleaf
Slash
Soil Series
Bowie
Lilbert
Darco
N
0
50
100
200
Meters
Geographic Information Systems
Laboratory

APPENDIX B


Arbor Grove Study Plots in Houston County, Texas
Pine Species
Loblolly
Longleaf
Shortleaf
Slash
Soil Series
Fuller
Lovelady
N
0 10 20 40 60 80 100
Meters
Arthur Temple College of Forestry and Agriculture
Geographic Information Systems
Laboratory

APPENDIX C


Hilliard Creek Study Plots in Shelby County, Texas
Pine Species
Loblolly
Longleaf
Shortleaf
Slash
Soil Series
Eastwood
Latex
Metcalf-Sawtown
0
25
50
100
Meters
N
Geographic Information Systems
Laboratory

VITA

Jamie Hooker, daughter of James and Debbie Hooker, was born on September 27, 1992. She grew up in Mauriceville, Texas and graduated from Little Cypress-Mauriceville High School in 2011. She moved to Nacogdoches, Texas and began attending Stephen F. Austin State University in 2012 and graduated with a Bachelor of Science in Forestry in 2015. Immediately after, Jamie was accepted into the graduate program at Stephen F. Austin and completed her Master of Science in Forestry degree in August 2019.

Permanent Address: 1025 Cedar Ridge
Orange, TX 77632

APA Style

This thesis was typed by Jamie Hooker.