1-1-2012

Varietal Loblolly (Pinus Taeda L.) Response to Various Management Schemes and Comparison among Genetic Improvement Levels

Billy Landis Herrin

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By

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

Mississippi State, Mississippi

August 2012

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Title of Study: Varietal loblolly (*Pinus taeda* L.) response to various management schemes and comparison among genetic improvement levels

Pages in Study: 51

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Increased growth rates, wood quality, and disease resistance have been accomplished within loblolly pine (*Pinus taeda* L.) through genetic selection and improved management practices. Genetic engineering of trees has the potential to further improve these selections but also needs to be tested. Two studies were conducted. Study one compares three levels of genetic improvement: Mass-Control Pollinated (MCP), Second Generation Op (2^{nd} gen), and Varietal Material. After three years the MCP material had larger mean heights, mean diameters, and mean volume than the other two genetic entities. However the top five performing varietals were about 0.5 feet taller than the MCP material. Study two tested two contrasting loblolly pine ideotypes across different spacings and management intensities. After two years the crop tree ideotype and the intensive management plots had larger mean heights, mean ground-line diameters, mean volumes, and mean crown widths. Mean branch angle differed significantly between the two crown ideotypes.

ACKNOWLEDGEMENTS

I would like to thank Dr. Scott Roberts for giving me the opportunity to continue my education at Mississippi State University. I could not have completed this project without his guidance and support. He has been very patient and was always there for me when I had a question or needed help with anything. The times we spent together in the field, tailgating, and traveling were always fun. Thanks for everything Dr. Roberts.

Dr. Randall Rousseau has also been a major contributor in the completion of this project. I am very grateful to him for allowing me to work for him as a research associate during the writing stages of this thesis. He has been very helpful with the many questions I have had and a joy to work for. He allowed the completion of my thesis to remain a top priority even with me working full-time for him. He has taught me many things through the various types of research that I have been a part of. Thanks to Dr. Rousseau I have also enjoyed some of the best hunting and fishing trips that I have ever had.

I would also like to thank Dr. Andy Londo for serving on my committee and always being there for those spur of the moment signatures and meetings. He was always there when I needed assistance and always very helpful and kind. I am thankful that he always made time for me even when he had a full schedule.

My wife Stacey Herrin was also a very important part of this project and I owe and thank her tremendously for the encouragement, patience, and love that she has expressed to me throughout this process. I am most gracious for her persistent motivation and support. Without her I would not be the man I am today or have made it this far in

my education. I want to thank her for putting up with my severe procrastination and giving me just the boost I need to stay focused. She never complained and always knew what to say when I came to her with concerns and complaints. She was definitely the best support system I could ask for. I love and thank her very much for always being there for me.

I also need to thank my fellow graduate students that assisted me with my field work and classes. They should also be thanked for the many office debates, late night study sessions, and the great camaraderie that always field the office. I have made lifelong friends with several of these guys and I thank them very much for all they have done.

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CHAPTER I

INTRODUCTION

Over the past 50 years the utilization of loblolly pine (*Pinus taeda L.*) plantations has increased production dramatically (McKeand et al. 2003). Before the southern United States was settled by European immigrants, loblolly pine was a relatively minor part of a predominately mixed hardwood forest. This has changed due to extensive planting and natural regeneration of cutover forest and the abandonment of farmland between 1930 and 1990, which has led to loblolly pine becoming the leading timber species in the United States (Schultz 1999). Numerous improvements have been made in both management and seedling quality of loblolly pine, attaining large increases in growth throughout recent years (Borders and Bailey 2001, Jokela et al. 2004).

Over time, as demand for wood products has continued to increase, genetic improvement has been examined as a means of increasing productivity of loblolly pine forests. Early productivity and economic studies of genetically improved stock revealed lower cost and increased productivity. Since then a steady progression in genetic improvement has taken place. Genetic manipulation of loblolly pine through breeding and selection has improved wood quality, growth rates, and disease resistance (Fox et al. 2007b). While controlled pollination was originally only used in the breeding and testing phases of tree improvement programs, the forest industry has recently adopted this approach as a means of mass producing growing stock with faster growth rates, better tree form, and higher disease resistance. The techniques used in Mass-Controlled

Pollination (MCP), also known as Supplemental Mass-Pollination (SMP), provide the ability to produce large quantities of full-sib seed. The technique allows selection of both parents, potentially resulting in superior offspring.

Further gains may be obtained by the utilization of advanced vegetative propagation techniques, such as somatic embryogenesis. This approach uses superior crosses based on results from full-sib progeny tests. The megagametophyte containing the immature embryos are harvested from cones produced through full-sib breeding. From this material, an embryogenic culture is initiated and begins to multiply into what is termed embryogenic tissue. Somatic embryos are then formed by repetitive cleavage, also known as late stage maturation of somatic embryos (Burdon and Libby 2006). These somatic embryos are then grown into genetically identical clones, commonly referred to as varietal planting stock. Each individual embryo is a ramet of a specific clone, or variety. Tests are conducted and include a number of varieties and ramets per variety as to adequately determine performance levels. With the ability to identically reproduce a variety it is now possible to select specific phenotypic characteristics of a targeted product. For example, characteristics desirable for sawtimber might include superior stem form, good self-pruning ability, and wood characteristics favorable for quality structural grade lumber.

Further research is needed to attain greater genetic gains and will include increased breeding based upon observed traits followed by testing and genetic refinement of varieties, as well as testing across numerous sites to assess possible genotype by environmental interactions. Varietals will also need to be evaluated at different levels of management intensity and different stand densities to determine techniques that will optimize the potential gains from using this genetic material under current establishment methods. The deployment of varietal stock is expected to increase yields but research is needed to determine if gains are worth the additional costs associated with producing this planting stock.

Two studies located at two locations in Mississippi were used to address some of these research needs. The two studies are examining the performance of varietal loblolly pine planting stock at different management regimes and comparing growth and performance to two other genetic loblolly pine improvement levels. These studies will add to the current understanding of varietal loblolly pine performance.

Objectives

The overall objective of the two studies is to determine how loblolly pine varietal material performs relative to other stock types, and under different cultural practices. From these studies we can better understand the growth and performance of the different genetic entities used in this project. This thesis research involved the examination of early (two-three years) results from the two studies.

The initial study, established in 2007, is comparing seedlings produced through three different tree improvement systems. The objectives are to compare the performance of selected open-pollinated, mass-controlled pollinated, and varietal entities of loblolly pine. Additionally, the study is examining differences in performance among several loblolly pine varietals.

The second study was established in 2008 and is focused on the performance of two contrasting loblolly pine varietal ideotypes under different initial tree spacing and management intensities. The study is comparing both growth rates and crown form between the two loblolly pine ideotypes.

CHAPTER II

LITERATURE REVIEW

The forests of the southeastern United States were initially very different from the forests of today. Prior to the arrival of European immigrants, loblolly pine was a relatively minor component of the vast natural forests across the southeast United States. Following the arrival of immigrants land was cleared for agriculture and settlements were established (Fox et al. 2007b). Excessive timber harvesting and poor agricultural practices left much of the land in the southeast U.S. greatly degraded. This problem was partially addressed by the Civilian Conservation Corp which planted 1.5 million acres of trees across the South in the mid-1900's (Fox et al. 2007b). By 1952, almost two million acres had been planted in pine (Conner and Hartsell 2002). By the beginning of the 21st century there were approximately 32 million acres of loblolly pine plantations in the southeast (Fox et al. 2007b).

Pine plantations are more uniform in both structure and composition than natural stands; and because of this uniformity plantation management is more efficient than in natural loblolly pine stands. However, in recent years there has been a decrease in the total acreage of pine plantations across the southeast due to increasing population, urban/suburban expansion, environmental concerns and other factors (Martin and Jokela 2004). At the same time, demand for wood and fiber has increased over this time frame. Growing wood more efficiently has therefore become a greater concern. To meet increased demands, both industrial and nonindustrial private landowners use intensive management practices to reduce rotation lengths, increase yields, and increase profitability of their forested land (Martin and Jokela 2004). New management techniques have resulted in significant production gains over the past 20 years (Borders and Bailey 2001). These production gains stem from improvements in silviculture, genetics, competition control, and a better understanding of species-site relationships.

Stand establishment costs generally represent the largest outlay of capital in plantation management and can greatly influence profitability (Varelides et al. 2005). Site preparation is the initial step in stand establishment, and when properly done is an important aspect in improving growth rates (Varelides et al. 2005). Site preparation can be classified into two general categories; mechanical, and chemical. Mechanical site preparation includes such activities as bedding, disking, chopping, and shearing (Shiver et al. 1990a, Lacascio et al. 1990). Fire can also be used to clear debris and burn debris piles created during some mechanical site preparation procedures. Chemical site preparation uses herbicides to control undesirable species and reduce competition. Both chemical and mechanical site preparation are commonly utilized to increase growth rates in loblolly pine (Shiver et al. 1990b).

Fertilization can also be an effective way to increase production of loblolly pine across a variety of site conditions (Jokela et al. 2000). The effects of fertilization can vary across different sites making fertilization very site specific (Borders and Bailey 2001). Initially fertilization was used to correct phosphorus deficiencies on poorly drained, clayey soils in the lower Coastal Plain (Fox et al. 2007a). According to Pritchett and Comerford (1982), one application of phosphorus could last for 20 or more years, and may increase volume production by more than 100% (Jokela et al. 1991).

Fertilization does not just have to be applied at time of planting. Nutrient additions have also been shown to increase growth when applied periodically throughout the rotation (Jokela et al. 2000). Many sites around the South have adequate amounts of nutrients when trees are small, but nutrients can become limiting later in stand development. A mid-rotation fertilization, typically of nitrogen and phosphorus, can be applied around the time of crown closure to supplement the limiting supplies of these nutrients (Fox et al. 2007a). Fertilization of pine plantations increased from approximately 200,000 acres in 1990, primarily phosphorus at time of plantation establishment, to over 1.2 million acres fertilized annually in the early 2000s (Fox et al. 2007a). Recently, however, fertilization has decreased due to dramatic increases in the cost of fertilizer.

Fertilization is generally not recommended on newly established pine plantations without the concurrent use of herbicides (Ross et al. 2005). When fertilization is used in combination with herbaceous weed control and/or woody competition release, substantial gains in growth have often been realized. Both herbaceous weed control and woody release control undesirable species and allow the increase in nutrients from fertilization to be available to desirable species (Schimleck et al. 2008). In addition to nutrients, competition control also affects the availability of light and water therefore increasing tree growth rates (Jokela et al. 2000).

Planting density is one of the more important managerial decisions when it comes to pine plantation management in the southeast (Schimleck et al. 2008). Planting density can affect diameter growth and volume accumulation of individual trees, as well as overall stand development throughout the life of the stand. Initial stand density also affects harvesting and thinning schedules (Huang et al. 2005). Manipulation of stand density, both at time of planting and through intermediate thinnings, is used to increase the quality of loblolly pine plantations.

Genetic tree improvement has significantly impacted southern pine forestry (Schultz 1999). Loblolly pine tree improvement efforts have resulted in increased growth rates, greater disease resistance, and reduced rotation lengths (Martin et al. 2001). Due to the large number of acres being artificially regenerated in the mid-1900s, the seed orchard concept was initiated to provide seed for seedling nurseries (Fox et al. 2007b). The first southern pine seed orchard was established in 1952 by the Texas Forest Service, and produced drought hardy loblolly pine seed (Fox et al. 2007b). First-generation seed from seed orchards started becoming available in large quantities in the 1960s and 1970s (Fox et al. 2007b). These seed orchards not only provided seed for production seedling nurseries, but also provided for the transfer of desirable genetic characteristics to the progeny of the selected species, which in this case was loblolly pine. The ability to realize gains through genetics led to the creation of tree improvement programs at both the cooperative and company levels.

Tree improvement cooperatives started in the United States in 1951 at Texas A&M University. Cooperatives have since been established at different land grant universities in the major timber-growing regions of the United States. Tree improvement cooperatives have long term breeding plans, often developed by forest geneticists. Information and material are often shared among cooperative organizations to minimize duplication of efforts and to maximize improvements (Lantz 2008).

Tree improvement programs began by selecting trees from natural stands that exhibited favorable phenotypic characteristics, and then testing the progeny of those selections (Martin et al. 2001). The initial focus was on selecting trees with superior form, growth rates, wood characteristics, and both pest and disease resistance (McCrady and Jokela 1996). Significant gains in these areas were made during the first generation of genetic improvement (Schultz 1999). At maturity first-generation loblolly pine plantations achieved 7-13 percent increases in yields compared to unimproved plantations (Schultz 1999).

Further gains in growth have resulted from continued breeding and testing of the first-generation off-spring. This ultimately led to the establishment of second-generation seed orchards in the 1980s (Fox et al. 2007b). Second-generation gains have been estimated to be approximately double than that of the gains from first-generation seed (McKeand et al. 2006a). By the early 2000s, over half of the seedlings deployed in the South were produced from second-generation seed (Fox et al. 2007b). The genetic worth of parents in second-generation orchards has been evaluated by extensive progeny testing across the Southeast (Li et al. 1999).

Tree improvement programs continue to make gains on the breeding side, but deployment of production seedlings is shifting towards specific crosses to capture additional genetic gains. Full-sib families have shown up to 50 percent increases in volume compared to unimproved seed (McKeand et al. 2006a). Mass-controlled pollination (MCP), a technique used to create full-sib seedlings on a large-scale basis, is a system where female flowers of a selected genotype are isolated (in most cases with paper bags) and pollinated with pollen from a favorable selected genotype. The seed are then collected from these crosses and operationally deployed. The resulting progeny, while not genetically identical, are much more uniform than half-sib open-pollinated families.

Further genetic gains can be realized by selecting the best crosses from the testing phase of controlled crosses and cloning these genotypes using some form of vegetative propagation. The Chinese have been practicing vegetative propagation for over 800 years by the use of rooted cuttings (Minghe and Ritchie 1999). However, this technique is generally not well-suited for mass production of clonal material because donor plants are usually no longer suitable for use in producing rooted cuttings by the time field testing has been completed (Park et al. 1998). Hedging or serial propagation can be a better alternative for producing rooted cuttings because it extends the time of rooting ability, but again not long enough for extensive field testing (Park et al. 1998). These limitations have made the deployment of clonal stock in loblolly pine difficult. The development of somatic embryogenesis techniques for loblolly pine provided the ability to field test clones while storing genetic material in the form of callus tissue in cryopreservation.

Future increases in southern pine plantation productivity may increasingly rely on varietal forestry (Fox et al. 2007b). Deployment of well tested, genetically superior varieties is attractive because of a presumed greater potential than full-sib families for attaining genetic gains (Baltunis et al. 2009). Trees that perform well in varietal tests are good candidates to be cloned using vegetative propagation procedures. Recent improvements in somatic embryogenesis make it the current technique of choice for cloning loblolly pine selections (Park et al. 1998). Each varietal must be thoroughly tested to determine genetic superiority for the selected traits. Once varietal testing is completed, mass production for deployment can begin (Gleed et al. 1995). The use of varietal material could result in productivity gains of greater than 60 percent (McKeand et al. 2006b); however, the use of clonal varieties may be risky. A plantation established with a single genotype that does not perform well in that location could result in a substantial loss of time and money (McKeand et al. 2006b). Fortunately, as long as climatic zones are matched with genotypes that perform well, these risks can be avoided (McKeand et al. 2006a).

The utilization of varietal material could also lead to the development of loblolly pine ideotypes. An ideotype is effectively an ideal phenotypic model that will perform in a predictable manor within a defined environment (Leaky and Page 2006). The development and utilization of loblolly pine ideotypes would allow predictable phenotypic characteristics. This would enable the selection of ideotypes based on characteristics of a desired target tree. For example, crop tree ideotypes could be selected for phenotypic characteristics desirable for sawtimber, which include superior stem form, good self-pruning ability, and wood characteristics desirable for quality structural lumber grades (Wright and Dougherty 2006). Crown characteristics could also be important in the development of a crop tree ideotype. Crown structure is an important determinant of tree-level and stand-level productivity (McCrady and Jokela 1996). Branch angle, branch diameter, and branch frequency are key elements for many wood products (Bowyer et al. 2002).

CHAPTER III

GENETIC COMPARISON AND VARIETAL TRIAL

Introduction

Demand for wood products is growing every year, due to increasing population. These needs are being addressed by management techniques and genetic tree improvement. As a result, increases in the growth and performance of loblolly pine have been recorded for different management techniques and different genetic tree improvement levels (Borders and Bailey 2001, Fox et al. 2007b).

Genetic tree improvement efforts have resulted in increased growth rates, greater disease resistance, better form, and reduced rotation lengths. In most cases, tree improvement programs begin by selecting trees from natural stands that exhibit favorable phenotypic characteristics, and then testing the progeny of those selections (Martin et al. 2001). From these selections significant gains of up to 13 percent where recorded for mature first-generation stands (Schultz 1999). Further improvements in growth were made from breeding and testing within first-generation off-spring, which led to the development of second-generation seed orchards and approximately double the gains of first-generation material (Fox et al. 2007b, McKeand et al. 2006a).

Gains for full-sib families of up to 50 percent in volume have been reported when compared to unimproved stock (McKeand et al. 2006a).The ability to produce large numbers of full-sib crosses for testing and production was made possible by the development of efficient approaches of using Mass-Controlled Pollination (MCP) techniques. Further gains may be obtained through the utilization of advanced vegetative propagation techniques such as somatic embryogenesis. This approach uses superior crosses based on results from full-sib progeny tests. Somatic embryogenesis is the process of embryo initiation and development from vegetative or non-gametic cells. In culture, the embryogenic tissue is initiated and begins to multiply in mass numbers. The somatic embryos resulting from the megagametophyte are identical and can be held in cryopreservation until testing is completed. These varieties are tested to determine which varieties display superior performance.

A comparison study was conducted among second-generation open-pollinated (OP) material, MCP material, and varietal material to determine differences in their relative performances. The specific objectives of the study were to compare the growth performance of the different loblolly pine genetic improvement levels, compare the performance of individual varieties, and examine the performance of the best performing varieties relative to the MCP and second-generation OP material.

Methods

A genetic comparison and varietal trial was established in 2007 on Mississippi State University's North Mississippi Branch Experiment Station near Holly Springs, Mississippi (34°48'56" N89°25'40"W). Soils at the site are classified as Loring silt loam, and due to past management there existed a compacted layer at a depth of 14-16 inches. The approximate site index at base age 50 for loblolly pine is 85 feet. The study location had previously been in dairy pasture, and contained several varieties of grasses with high concentrations of Bermuda grass on the western end of the site.

In January 2007, prior to planting, the site was sub-soiled in an east-west direction to a depth of 14 inches. Razor Pro® (Glyphosate) was applied at a rate of 64-ounces per treated acre in March 2007 in three-foot-wide bands centered on the areas that were sub-soiled. The site was hand planted on April 9, 2007 with seedlings planted on 12 ft x 9 ft spacing. Each planted seedling received one tablet (20mg) of Silvashield® (imidacloprid) for control of the Nantucket pine tip moth (*Rhyacionia frustrana*). A banded application of Select® (Clethodim) herbicide was applied in 2007 for control of Bermuda grass at a rate of 32-ounces per treated acre. The site was sprayed again in May 2008 with a broadcast application of Oustar® (hexazinone and sulfometuron methyl) at a rate of 6-ounces per acre. Due to substantial tip moth damage in the first growing season, PTM® insecticide (fipronil) was applied in late April 2009 at a rate of 1.4ml per tree. The insecticide was injected into the ground at the base of each tree at a depth of three to six inches.

Three types of genetically improved loblolly pine seedlings were included in the study. These included an open-pollinated second-generation family (MWV356), a full-sib family developed through mass-control pollination (M0023), and an array of 56 varietal lines of somatic embryogenic (SE) seedlings. The second-generation OP and the MCP seedlings were produced by MeadWestvaco Corporation and planted as bare-root stock. The varietal material was produced by ArborGen, LLC and planted as containerized stock.

The experimental design was a randomized complete block with treatments being the improved genetic levels. Each treatment (i.e., genetic stock type) was replicated six times in 100-tree (10 x 10 tree) block plots, with an internal 64-tree (8 x 8 tree) measurement plot. Each varietal plot contained one ramet of each of the 56 varietal lines and various check individuals within the measurement plot, and was surrounded by a 1-tree border of 2nd-Gen. seedlings. A separate analysis was conducted on the varietal plots to examine the variation in performance among the varietals.

Percent survival of each of the three genetic entities was tracked for each of the first three years following planting. Total height of each tree was measured after each of the first two growing seasons. Third-year measurements consisted of diameter at breast height (dbh), and total height. A stem volume index was computed using the formula for the volume of a cone ($D^2H/3$) with both height and diameter expressed in inches.

Statistical Analysis

Statistical analyses for year one, two, and three were conducted using standard analysis of variance (ANOVA) techniques. Measurements were analyzed on a plot mean basis. General linear modeling (GLM) techniques were used to test for significant differences among the overall performances of the three genetic entities.

Individual varieties within the varietal plots were analyzed as single tree plots, again using GLM. This analysis compared the growth performance of the individual varieties, using only those varieties with at least five surviving ramets. Twenty of the varieties were not included in the analysis because they had fewer than five surviving ramets at year three. Individual varietals were then ranked by height and the top five performing varietals were compared to plot means of both the MCP material and second-generation OP material. The study design did not allow for a direct statistical comparison of the plot means for the MCP and second-generation OP plots to the individual varieties of the varietal plots. However, the analysis did provide an indication of the performance of the superior varietals relative to the mean performance of all three of the genetic entities. All analyses used a critical value of α=0.05 to test for treatment differences.

Results

Survival

Overall survival in year one for the study was 92.4 percent. Among the three genetic entities, the second-generation OP material had the highest survival rate at 96.6 percent, followed by the MCP material at 94.5 percent and the varietal material at 86.0 percent (Table 1). Survival of the varietal material was significantly lower than both the MCP and the second-generation OP material (P=0.0184). Block one had particularly low survival, which was likely due to intense Bermuda grass competition. However, even when block one was removed from the analysis the survival rate of the varietal material was still significantly lower than both MCP and the second-generation OP material. There was no significant difference in survival between the MCP material and the second-generation OP material.

Overall survival at the end of the third growing season was 91.8 percent. Age-three survival means showed that the second-generation OP material remained the highest of the three genetic entities at 96.1 percent, followed by the MCP material at 94.0 percent and the varietal material at 85.3 percent (Table 1). Again, there was a significant difference among the three genetic entities (P=0102), with survival of the varietal material still significantly lower than both the MCP and the second-generation OP material. There was no significant difference in third-year survival between the MCP material and the second-generation OP material (Table 1).

Table 1 Percent survival for years one and three for the three genetic entities.

	Overall	2nd-Generation	MCP	Varietal
Year One	92.4%	96.6%(a)	94.5%(a)	86.0%(b)
Year Three	91.8%	96.1%(a)	94.0%(a)	85.3%(b)

Different letters within a row indicate significantly different survival rates for that year.

Comparison of genetic entities

The analysis of tree heights recorded at the end of the first growing season showed a significant block effect (P=0.0461), likely caused by the large amount of Bermuda grass found in block one. When block one is removed from the analysis block is no longer significant (P=0.1166). There were no significant differences in year one heights among the three genetic entities. Overall mean height for year one for the three genetic entities was 1.9 feet (Figure 1).

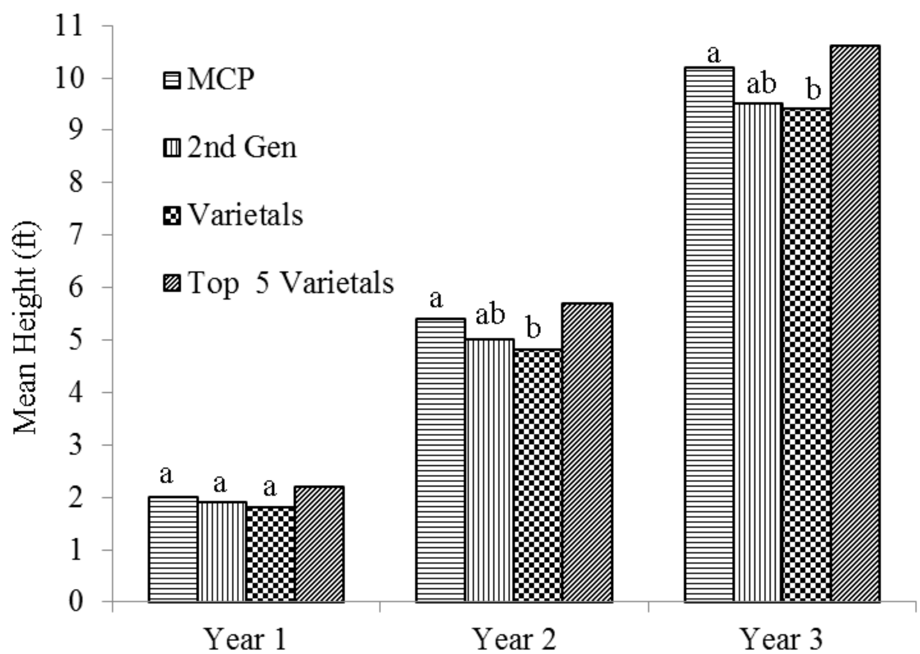

Figure 1 Mean heights for years one, two, and three comparing the three genetic entities and the top five performing varietals.

Top five performing varietals were not included in the statistical comparison. Different letters above the bars indicate significant differences for that year.

Year three heights for the three genetic entities showed a significant difference (P=0.0476). Average height for the three genetic entities ranged from 9.3ft to 10.1ft with varietals being the shortest and MCP being the tallest (Figure 1, Table 2). The varietal material differed significantly from the MCP material (P=0.0176) but not from the second-generation OP material (P=0.3782). The MCP material also did not differ significantly from the second-generation OP material (P=0.0843).

Table 2 Year three mean height, mean diameter and mean volume index for the three genetic entities and the top five performing varietals.

	Height	**Diameter**	**Volume Index**
MCP	10.2 ft (a)	1.9 in (a)	167.7 in^3 (a)
2nd Gen OP	9.5 ft (ab)	1.6 in (b)	123 in^3 (b)
Varietals	9.5 ft (b)	1.4 in (c)	90.8 in^3 (b)
Top 5 Varietals	10.6 ft	1.8 in	143.8 in^3

Different letters within a column indicate significantly different means.

Statistically significant differences were observed among the three genetic entities (P=0.0019) for year three diameters (Figure 2, Table 2). Average diameters for the three genetic entities ranged from 1.4 to 1.9 inches with varietals being the smallest and MCP being the largest.

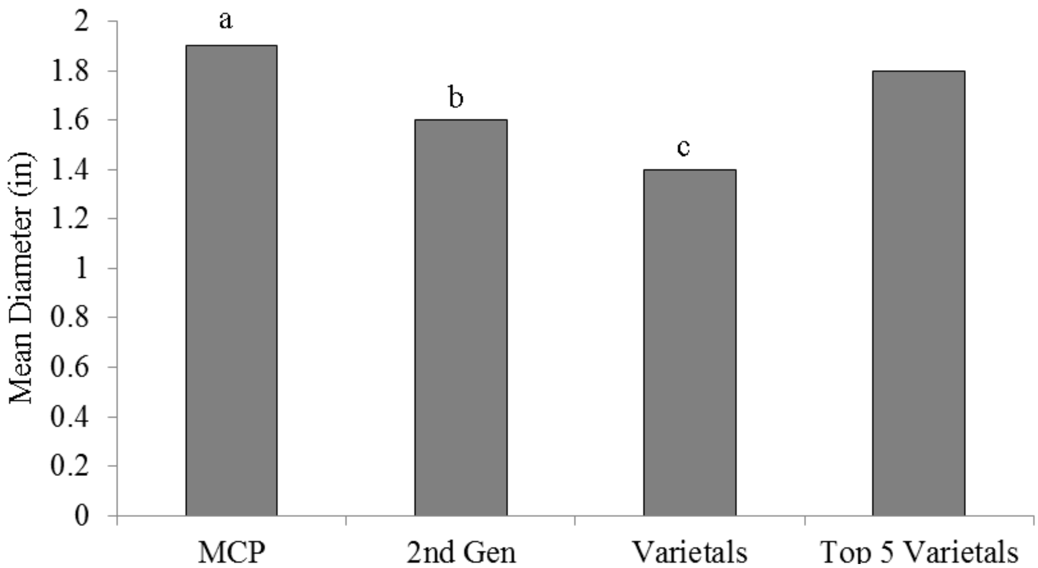

Figure 2 Mean diameters for year three among the three genetic entities and the top five performing varietals.

Different letters above the bars indicate significant differences. The top five performing varietals were not included in the statistical comparison.

Year three mean volume index for the three genetic entities were significantly different (P=0.0043). Average volumes among the three genetic entities ranged from 90.8 to 167.7 cubic inches with the varietal plots being the lowest and the MCP plots being the highest (Figure 3, Table 2).

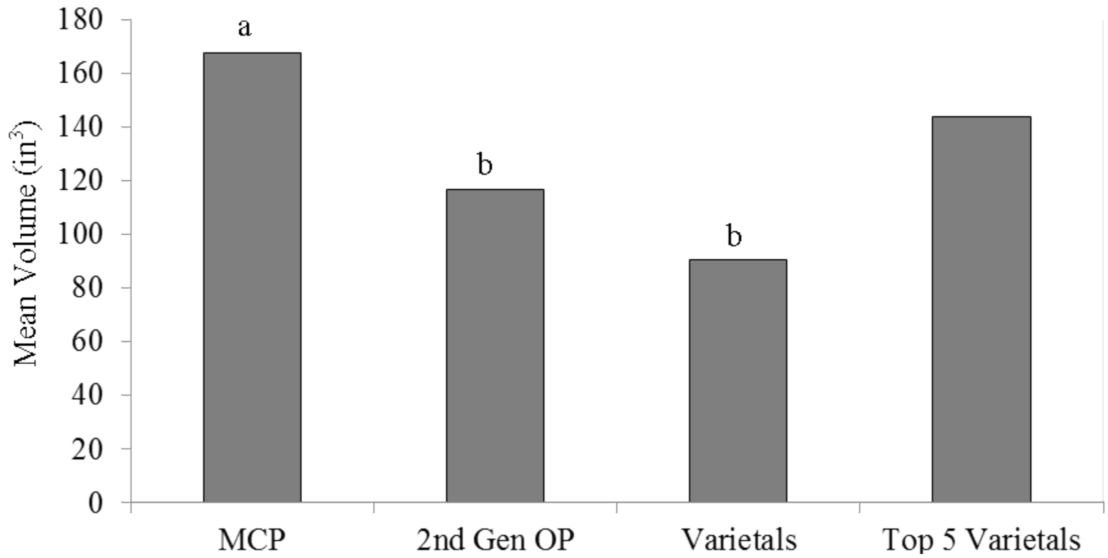

Figure 3 Year three mean volume for the three genetic entities and the top five performing varietals.

Different letters above the bars indicate significant differences for that year. The top five performing varietals were not included in the statistical comparison.

Comparison among varietal material

Of the 36 varieties included in the analysis no significant differences were observed in year one heights (P= 0.3946); however, block one was significantly shorter than the other five blocks (P=<0.001) which, again, was likely caused by the large amount of Bermuda grass that inhabits block one. Year one height averaged 1.8 feet with a maximum of 2.3 feet and a minimum of 1.3 feet.

Mean height for year three differed significantly among the varietals (P=0.0039). The overall mean height among the varietals was 9.4 feet, with individual varietal heights ranging from 7.8 feet to 11.3 feet. Varietal 228 was the tallest while varietal 520 was the shortest at age three (Figure 4).

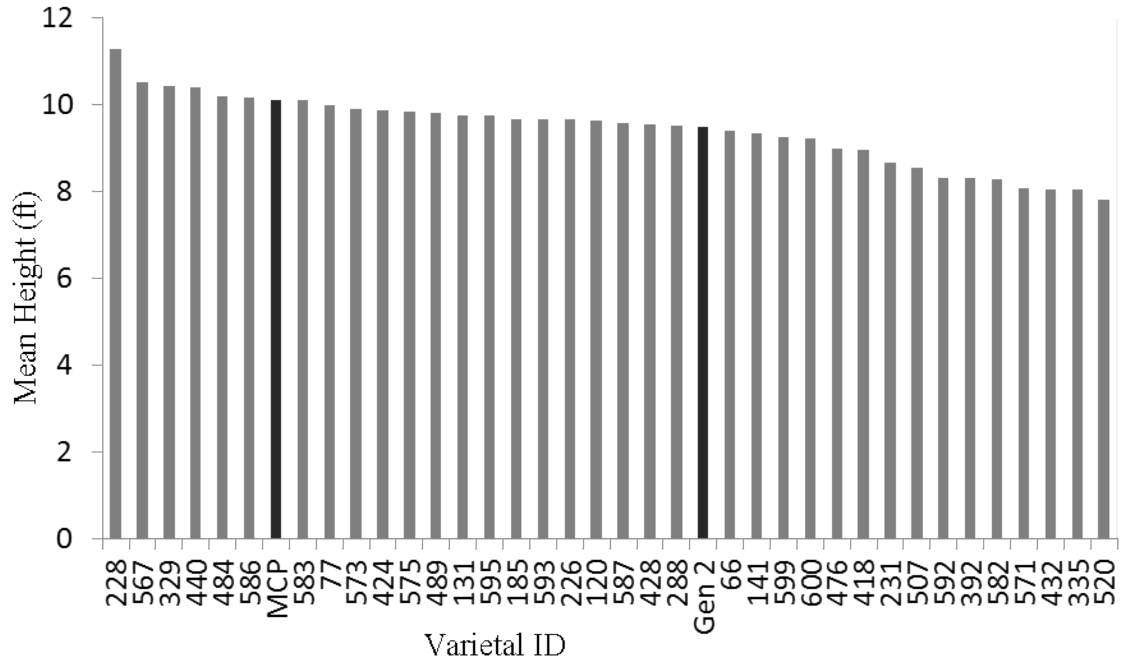

Figure 4 Mean year three heights for varietals with at least five surviving individuals ranked from largest to smallest.

Mean diameter for year three was significantly different among the varietals (P=0.0021). The overall mean diameter among the varietals was 1.4 inches, with individual varietal diameters ranging from 0.9 inches to 1.8 inches. Varietal 228 exhibited the largest age-three diameter while varietal 520 was the smallest.

Mean volume indices for varietals within the varietal plots were significantly different for year three (P=0.0083). Varietal 228 had the largest volume index, with an average volume of 156.5 cubic inches. Varietal 520 had the smallest volume index, with an average volume of 18.6 cubic inches.

Top performing varietals

At the end of year one, the five best performing varietals had a mean height of 2.2 feet. This was taller than the mean heights of both the MCP and the second-generation OP seedlings. The age-one mean height of the MCP seedlings was 2.0 feet while the second-generation OP seedlings were 1.9 feet (Figure 1). After three years, the five best performing varietals had a mean height of 10.6 feet. Varietal 228 had the tallest mean height of the top five individuals at 11.3 feet. Both the MCP (10.1 ft) and the second-generation OP seedlings (9.5 ft) age-three mean heights were shorter than the best performing varietals (Figure 1, Table 2).

After three years, the five best performing varietals had a mean diameter of 1.8 inches, which was smaller than the mean diameter of the MCP seedlings but larger than that of the second-generation OP seedlings (Figure 2, Table 2). Varietal 228 had the largest individual mean diameter of 1.8 inches.

Mean stem volume following year three for the five best performing varietals was 143.8 cubic inches, approximately14 percent (23.9 in^3) less than the average volume for the MCP material, although larger than the second-generation OP material (Figure 3, Table 2). The average volume of the top performing varietals was 37 percent (53 in^3) larger than the overall average volume for the varietal plots. Varietal 228 had the highest mean volume of the varietals at 156.5 cubic inches, which was still seven percent lower than the average volume of the MCP material.

Discussion

Both the second-generation OP and the MCP seedlings were planted as bare-root stock while the varietal stock was planted as containerized stock. Improved survival rates are normally expected from containerized seedlings over bare-root seedlings (Ruehle et al. 1981, South et al. 2005); however, survival rates in this study show the containerized stock with at least a seven percent lower survival rate than the bare-root stock. This outcome may be attributed to the condition of the planting stock. Prior to planting, some of the containerized stock inadvertently became moisture stressed, which may have contributed to the lower survival rate. In addition, the bare-root seedlings were older and larger than the containerized stock, which may have also provided a survival advantage.

Mean heights for the three genetic entities did not differ after one growing season, but were significantly different following year three. Heights for the MCP seedlings were consistently taller than both second-generation OP and varietals for years one, two, and three but were only significantly taller than the second-generation OP seedlings at age two and the varietal stock at ages two and three. Diameter and volume index results for year three follow the same trend as the third-year height measurements. The MCP seedlings outperformed both the second-generation OP seedlings and the varietal stock.

The mean heights of individual varieties varied substantially, with some taller and some shorter than the mean heights of both the MCP and second-generation OP seedlings. However, the varietal plots were represented by 36 different genotypes and if the top performing varietals are compared to that of the MCP and the second-generation OP seedlings, the results indicate that the best varietals have outperformed both the MCP and second-generation OP stock in height growth over the first three years (Figure 1). The top varieties changed over the three years. In year two, the top five varietals were all different than the top five varietals in year one, although between years two and three the top five varietals remained the same with the exception of one variety.

The top five varietals after three years averaged about one-half foot taller than the MCP material even though the mean height of the MCP material was 1.8 feet taller than the overall mean height of all of the varietal stock. The tallest varietal had a mean height of 11.3 feet, which was one foot taller than the mean height of the MCP material.

The top performing varietals were expected to out-perform the MCP material, which they did for height. However, the top varietals ranked slightly below the MCP material for mean diameter (0.1in) and mean volume index (23.9 in^3). Varietal 228, again ranked at the top of the varietals for both mean diameter and mean volume, but was smaller than the mean diameter and mean volume for the MCP material. McKeand et al. (2006b) state that the use of varietal material could result in gains in production of greater than 60 percent over unimproved planting material. However, the results of this study suggest that the top five performing varietals are not performing as well as the MCP material in terms of volume growth after three years. This may have been due to the condition of the varietal planting stock, the limited population of the varietals tested, or the test not including known high performance varietals for the specific geographic area. These results highlight the need for increased testing of varietals over a wide range of sites prior to recommendations for deployment.

I expected that the MCP material would outperform the second-generation OP material by approximately 20 to 25 percent over an entire rotation (McKeand et al. 2006b, Li 1999). Although gains were not computed the MCP material has consistently outperformed the second-generation OP seedlings. In each of the first three years the MCP material has increased its gains over the second-generation OP material. As of year three the MCP material was 6.9 percent taller than the second-generation material. The steady increase in MCP performance over the second-generation material in this study may eventually lead to the types of gains discussed by McKeand et al. (2006b) and Li (1999) by the end of the rotation.

Mean heights in block one were consistently shortest among the six blocks. Although the block effect for height was not significant in years two (P=0.1425) and three (P=0.0584), block one consistently ranked below the other blocks. The difference between block one and the shortest of the other five blocks (0.8 ft) was greater than the difference between the tallest and shortest (0.6 ft) of those five blocks. The reduced height growth in block one was most likely due to high densities of Bermuda grass. In pine production systems Bermuda grass is often considered to be among the worst herbaceous competition problems (Ferrell et al. 2005). Ground coverage of Bermuda within this block was nearly 100 percent while the other blocks ranged from mixtures of Broomsedge/Bermuda to high densities of Broomsedge. Smith (1989) showed that common Bermuda grass reduced loblolly pine stem heights and stem diameters by 66 and 70 percent, respectively, after one year of competition.

Both the MCP material and the second-generation OP material were planted as bare-root seedlings, while the varietal material was planted as containerized seedlings which were younger and smaller than the other two genetic entities. However, there were no significant differences in height at the end of year one. According to Isik et al. (2005) differences in planting stock size may create an underestimation of the amount of growth for the planting stock that was initially smaller than the other planting stocks. This could be an explanation for some of the height differences observed in the study. Containerized stock is not always smaller than bare-root stock. Barnett and McGilvray (1993) report that the containerized material used in their study was initially taller than the bare-root seedlings used. Containerized seedling sizes can vary by season, the nursery producing the stock, and the cultural treatments used in production (Barnett 1984). The primary advantage of containerized seedlings is the intact root system that limits transplant shock which is common in bare-root seedlings (Barnett 1984). This study specifically addressed the first three years and while this early growth is just the beginning of the study, it is also the period of time when we would expect to see the greatest amount of change.

These results show the MCP material to be the overall best performing of the three genetic entities over the three years observed in this study. The MCP material was the tallest and had the largest diameters, therefore having the highest volumes. The MCP material was also visually more uniform than both the second-generation OP lot and the varietal material. This might not have been the case if the varietal plots had contained pure blocks of a single high performance variety.

CHAPTER IV

VARIETAL, SPACING, AND MANAGEMENT INTENSITY STUDY

Introduction

Dramatic gains in the productivity of southern pine plantations have been realized over the past 30-40 years (Fox et al. 2007b). A major reason for these increases has been the genetic improvements that have been achieved in loblolly pine through tree improvement programs. Loblolly pine tree improvement efforts have resulted in increased growth rates, greater disease resistance, lowered costs, and reduced rotation lengths (Martin et al. 2001). However, achieving these increased yields has also required increased management intensity of pine plantations including improved site preparation techniques, more effective competition control, better understanding of forest nutritional requirements, and greater attention to density management.

Primarily through the work of tree improvement cooperatives, loblolly pine productivity has been increased by up to 50 percent over non-improved material (McKeand et al. 2006a). First-generation material has exhibited gains of approximately13 percent, while second-generation material showed gains of around 25 percent (Schultz 1999, McKeand et al. 2006a). Even further genetic gains have been realized by planting full-sib families produced using mass-controlled pollination (MCP) techniques (Bramlett 2007). Jansson and Li (2004) show potential volume gains from full-sib families of up to 60 percent over unimproved stock.

Future southern pine plantation production increases will increasingly rely on varietal forestry (Fox et al. 2007b). The utilization of varietal material could also contribute to the development of loblolly pine ideotypes. The development and utilization of loblolly pine ideotypes would allow predictable phenotypic characteristics to be selected to coincide with targeted products. For example, phenotypic characteristics desirable for sawtimber might include superior stem form, good self-pruning, and wood characteristics favorable for quality structural grades (Wright and Dougherty 2006). Crown characteristics are also important in the development of a crop tree ideotype. Crown structure is an important determinant of tree-level and stand-level productivity (McCrady and Jokela 1996). Branch angle, branch diameter, and branch frequency are key elements of stem quality for many forest products (Bowyer et al. 2002).

Field testing of potential ideotypes is needed to compare the performance of varietal stock with that of other planting stock options as well as performance relative to specific intended purposes. The objective of this study was to compare the performance of two contrasting loblolly pine varietal ideotypes at different initial tree spacings and management intensities. The performance of the two ideotypes was observed at both normal and reduced stem densities to determine their ability to retain quality crown and stem form characteristics.

Methods

A loblolly pine varietal spacing and management intensity study was established in 2008, on Mississippi State University’s Coastal Plain Branch Experiment Station near Newton, Mississippi (32°20’19”N 89°05 51”W). Soils on the site are classified as a Prentiss, very fine sandy loam. The approximate site index for loblolly pine is 88 feet at base age 50. The site had previously been in agriculture to support a dairy operation. Prior to year 2005, the site had been in corn production. Following closure of the dairy the site was planted to soybeans in 2006. The site was simply mowed in 2007.

Initial site preparation consisted of a broadcast application of Razor Pro® (glyphosate) at a rate of 64 ounces per acre in September 2007. The field was sub-soiled to a depth of approximately 14 inches in a north-south direction at 14 foot intervals in early October 2007. In March 2008, a second application of Razor Pro® was broadcast at a rate of 32 ounces per acre. Trees were hand planted on May 7, 2008.

The study is set up as a 2x2x3 factorial design with split plots. Main effects treatments included the two levels of management intensity and the two genetic varieties, with main effects treatment plots split by three initial planting spacings. Trees within the spacing subplots were planted in 64 tree blocks (8 x 8 trees) with the inner 36 trees constituting the measurement plots. Each treatment combination was replicated four times.

The two loblolly pine genetic varieties (GE-34 and PM-51) used in the study were produced by ArborGen, LLC and were provided as containerized seedlings. GE-34 is considered to be a competitor ideotype, with a wide spreading crown. PM-51 is considered to be a crop ideotype, with a narrow compact crown. Management intensity levels consisted of normal intensity and intensive management. Each tree in the intensive management plots received one tablet (20mg) of Silvashield® (imidacloprid) at the time of planting in 2008 to prevent damage from pine tip moth. In addition, PTM® (fipronil) another pine tip moth insecticide was applied at a rate of 1.4 ml per tree in April 2009 and then again in mid-August 2010. The insecticide was injected into the ground at the base of the tree at a depth of between three and six inches. The intensive management plots also received an application of Escort® (metsulfuron methyl) (1 oz per acre) and a tank mix of Arrow® (clethodim) (16 oz per acre) and Goal® (oxyfluorfen) (32 oz per acre) on June 30, 2009. In addition to the chemical site preparation and subsoiling described above, both the intensive and normal management intensity plots received herbaceous competition control in year one (May 2008) through a broadcast application of Oustar (hexazinone and sulfometuron methyl) (10 oz per acre). Seedlings were planted at 6'x14', 9'x14', and 16'x14', representing 519, 346, and 194 trees per acre, respectively. Trees not surviving at the end of year one were replaced with the same variety of tree in February 2009.

Tree survival was assessed following years one and two. Year two survival did not include replacement trees planted following mortality in year one. Initial heights were recorded following planting in May 2008. Age-one heights were recorded in December 2008. Year-two measurements taken at the end of the 2009 growing season consisted of ground line stem diameters, height to the base of the live crown, and total height on all trees. A stem volume index was computed using the formula for the volume of a cone ($D^2H/3$) with both height and diameter expressed in inches. Crown and branch measurements were recorded on trees within an inner 16 tree (4x4 tree) measurement plot. Crown width in two directions, branch angle, branch length, and basal diameter one inch from the main stem were recorded on the two longest branches in the first primary whorl from the base of the tree. Branch angle was measured using a protractor to judge the angle of the branch from the main stem and recorded to the nearest five degrees. The two measurements taken for each variable for crown characteristics were averaged and the mean values were used in the statistical analysis.

Statistical Analysis

Statistical analyses for year one heights and year two heights, diameters, volume indices, and crown characteristics were conducted using a standard general linear models (GLM) approach. Measurements were analyzed on a plot mean basis. All analyses used a critical value of $\alpha=0.05$ in testing for significant treatment-related differences.

Results

Survival

Overall first year survival was 94.1 percent. Survival of the two genetic varieties differed significantly ($P<0.0001$) with GE-34 averaging 89.7 percent survival and PM-51 averaging 98.5 percent survival. Management intensity also significantly affected year one survival ($P=0.0161$). Survival in the normal intensity plots was 96.3 percent survival while the intensively managed plots averaged 91.9 percent survival. There was a significant interaction between block and management intensity ($P=0.0004$) on survival. Survival in the intensively managed plots in blocks one and two was approximately ten percent lower than in the intensively managed plots in blocks three and four. Initial spacing did not significantly affect year one survival ($P=0.1918$). However, the 16-foot spacing had only 91.8 percent survival, while the nine foot spacing had a 95.7 percent survival and the six foot spacing each had 94.8 percent survival.

Second year survival was 92.4 percent overall, and significant differences remained between the two varieties ($P<0.0001$). GE-34 averaged 87.0 percent survival and PM-51had a 97.8 percent survival rate. Year two survival did not differ between the two management intensities, with intensively managed plots averaging 91.7 percent survival compared to the normal intensity plots with 93.2 percent survival. Initial spacing again had no significant effect on year-two survival, although the 16-foot spacing was still slightly lower with 88.9 percent survival while the nine foot spacing had 94.6 percent survival and the six foot spacing had 93.8 percent survival. One of the 16-foot spacing plots in replication four had excessively high mortality due to an infestation of red-headed sawfly which contributed to the overall lower survival rate for the sixteen foot spacing.

Height

At the time of planting, there was a slight, but significant difference in mean height between the two varieties. Variety PM-51 seedlings had a mean height of 0.7 feet and GE-34 had a mean height of 0.5 feet. No significant differences in height at time of planting existed between the management or spacing treatments.

Mean height following the first growing season did not differ significantly between variety GE-34 and variety PM-51 (P=0.5543). Both varieties averaged 1.7 feet. Again there were no significant differences in height associated with either initial spacing or management intensity.

At the end of the second growing season there were significant height differences associated with genetic variety (P=0.0013) and management intensity (P=<0.0001), but not initial spacing (P=0.1579). Variety PM-51 had a mean year two height of 5.1 feet and was approximately one half foot taller than variety GE-34 with a mean height of 4.6 feet (Figure 5). Intensively managed plots had a mean height of 5.4 feet and were 1.1 feet taller than the normal management plots (Figure 6).

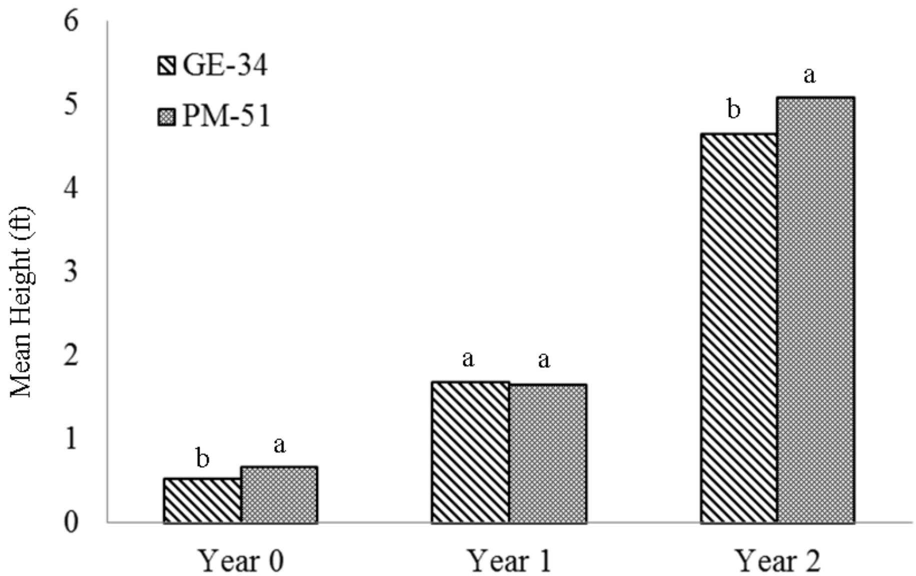

Figure 5 Comparison of mean heights by variety for years zero, one, and two.

Different letters above the bars indicate significant differences for that year.

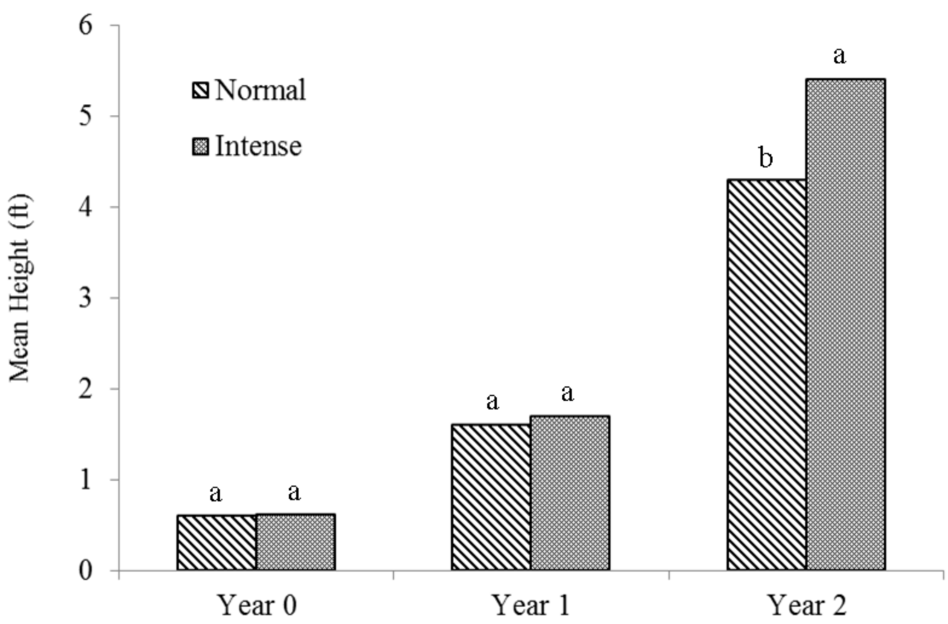

Figure 6 Comparison of mean heights by management intensity for years zero, one, and two.

Different letters above the bars indicate significant differences for that year.

Ground-Line Diameter

Year two ground-line diameter measurements showed significant differences for genetic variety (P=<0.0001) and management intensity (P=<0.0001). There were no significant differences associated with initial spacing (P=0.4125). Variety PM-51 had a significantly larger average ground-line diameter than GE-34 (1.5 in vs.1.3 in). Intensively managed plots had a significantly larger mean ground-line diameter than the normal management plots (1.5 in vs. 1.3 in) (Table 3).

Volume Index

Average volume index for year two showed significant differences associated with genetic variety and management intensity. Variety PM-51 had a mean volume index of 51 cubic inches compared to 37 cubic inches for variety GE-34 (P=<0.0001). The intensively managed plots had a mean volume index of 56 cubic inches compared to 33 cubic inches for the normal intensity plots (P=<0.0001) (Table 3).

Table 3 Year two mean ground-line diameter and D^2H volume by variety and management intensity.

	Variety		**Management Intensity**	
	GE-34	PM-51	Normal	Intensive
Mean Ground-line Diameter	1.3in(b)	1.5in(a)	1.3in (b)	1.5in (a)
Mean Volume Index	37in^3(b)	51in^3(a)	33in^3(b)	56in^3(a)

Different letters within rows indicate significantly different mean values.

Crown Measurements

Mean crown width measurements from year two displayed significant differences associated with genetic variety and management intensity, but not with initial spacing. There was also a significant block x management intensity interaction (P=0.0148), possibly due to slightly larger seedlings being planted in blocks one and two. During planting, seedlings were sorted by size to insure that similar size seedlings were planted within each block. Blocks one and two were planted with the slightly larger seedlings, which is possibly the reason for the larger mean crown widths in blocks one and two. The slightly larger seedlings in blocks one and two may have been able to respond to the lower vegetative competition levels within the intensive plots better than the slightly smaller seedlings in blocks three and four. Variety PM-51 had significantly wider crowns than GE-34 (P=<0.0001) (Figure 7). Variety PM-51 had a mean crown width of 2.7 feet, 0.4 feet wider on average than GE-34. Crowns in the normal management intensity plots were significantly narrower than those in the intensively managed plots (P=<0.0001) (Figure 7). Normal management intensity plots had a mean crown width of 2.2 feet and intensively managed plots had a mean crown width of 2.8 feet.

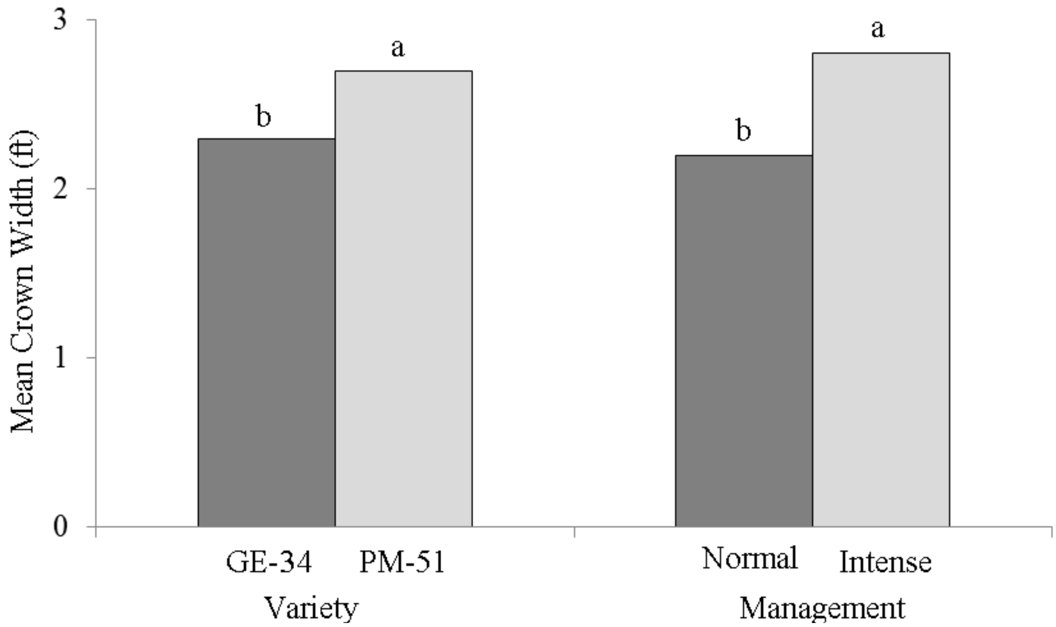

Figure 7 Average mean crown widths for both varieties and management intensities for year two.

Different letters above the bars indicate significantly different means for varieties within the management intensity treatment

Mean branch angles in year two suggest that genetic variety was the only treatment that resulted in a significant difference (P=< 0.0001). Variety GE-34 had a mean branch angle of 46.0˚ which was more acute than the mean branch angle for PM-51 that was 48.6˚ (Figure 8). There was also a significant interaction between block and variety (P=0.0014).

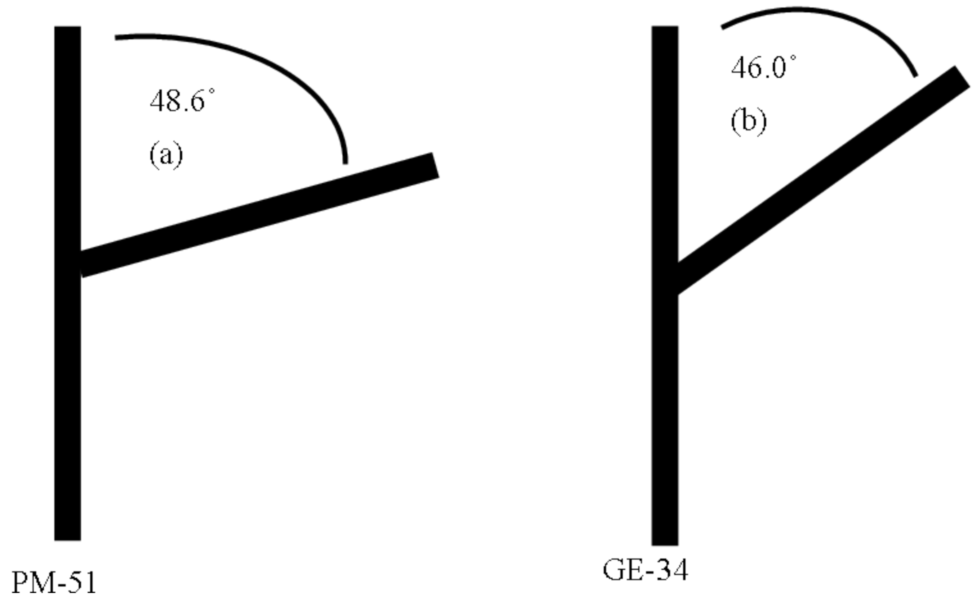

Figure 8 Year two average mean branch angles for two varieties of loblolly pine. Means with different letters are significantly different.

Mean branch length was significantly different between management intensities (P=<0.0001). There were no significant differences in mean branch length with any of the other variables. Trees in the intensively managed plots had mean branch lengths of 2.0 feet which was significantly longer than those in the normal intensity plots with mean branch lengths of 1.6 feet (Figure 9). There was also a significant block effect (P=0.0036), with mean branch lengths for blocks one and two significantly longer on average by 0.3 feet than branches in blocks three and four. This, again, may have been due to the sorting of seedlings prior to planting to ensure that similar sized seedlings were planted within each block.

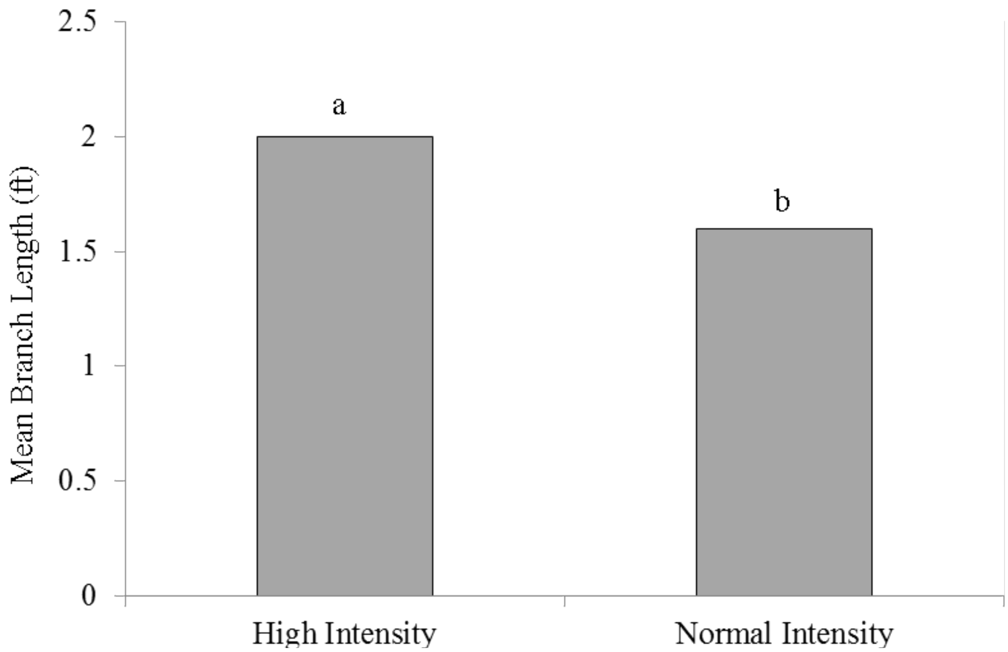

Figure 9 Mean branch length for year two for both high intensity and normal intensity management plots.

Different letters above the bars indicate significantly different treatment means.

Mean branch diameters also differed significant with management intensity (P=0.0011), and there was a significant interaction between block and management intensity (P=0.0165), again likely explained by the sorting of seedlings before planting. Branch diameters in blocks one and two were on average 0.03in larger than in blocks three and four. Intensively managed plots had a mean branch diameter of 0.36 inches which was significantly larger branch diameters than normal management plots that had a mean branch diameter of 0.30 inches (Figure 10). There were no significant differences in branch diameter associated with spacing or genetic variety.

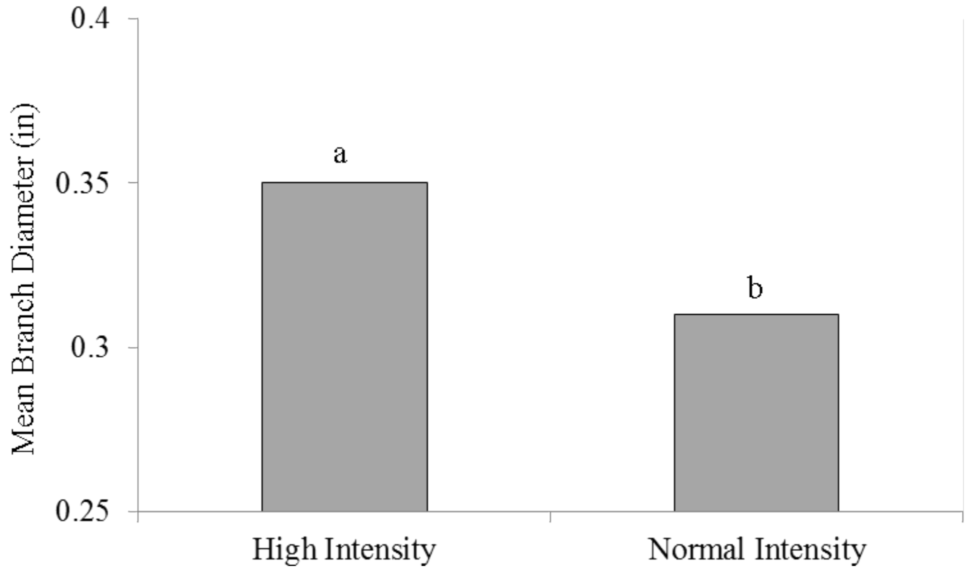

Figure 10 Year two mean branch diameter for both high intensity and normal intensity management plots.

Different letters above the bars indicate significantly different treatment means.

Discussion

Survival

Overall survival for this study at the end of year two was 98 percent. High survival rates are important in spacing trials to ensure proper spacing and subsequent growth rates within the plots, thus allowing accurate comparisons of the effects of different spacings. Without the replacing of dead trees by replanting, year two survival rate would have been 96.5 percent. The presence of the Red-headed pine sawfly (*Neodiprion lecontei* (Fitch)) was a contributing factor to the lower survival rate for year two. This insect defoliates the tree often causing death before dispersing to adjacent trees. Red-headed sawfly damage mainly occurred within the normal management intensity plots. The utilization of Silvashield® insecticide at the time of planting and the application of PTM® insecticide in years 1 and 2 likely contributed to the lack of insect damage within the intensively managed plots. At the time of application, it was unclear if either product would protect trees from species of insects other than Pine tip moth. Results from this study suggest that either the Silvashield® or the PTM® (or both) provided some protection against attack from Red-headed pine sawfly. The insecticide treatments within the intensively managed plots also deterred pine tip moth as expected. Although pine tip moth was not likely a factor for mortality, tip moth presence and damage was evident within normal management plots at much higher rates in the intensively managed plots.

The higher infestation of the Red-headed pine saw fly within the normal intensity plots may also have been the result of a more desirable habitat than existed in the nearby intensively managed plots. Nowak and Berisford (2000) suggest that intensive management practices may disturb the balance between predator and prey relationships by changing habitat conditions thereby displacing natural enemies. The intensively managed plots had minimal vegetative competition relative to the normal management plots, which could have deterred the infestation of Red-headed pine sawfly. Beal (1942) also shows that open grown pine stands were able to withstand defoliation from red-headed pine sawfly damage better than pine stands with greater levels of competing vegetation.

Variety GE-34 had a lower survival rate than variety PM-51 at the end of year one. Survival of variety GE-34 decreased an additional three percent in year two whereas variety PM-51 decreased an additional one percent. Some of the increased mortality between years one and year two for variety GE-34 may be credited to the Red-headed pine sawfly, particularly within one spacing subplot in block four. Half of the trees within in this subplot were killed primarily as a result of sawfly damage. This difference suggests that the lower survival rate of variety GE-34 may be attributed to an environmental factor rather than a genetic effect, but the cause was uncertain.

Varietal Performance

Variety PM-51 was significantly taller than variety GE-34 at time of planting and that difference held after year two, although the two varieties did not differ significantly in height following year one. PM-51 was 9.5 percent taller (0.4 feet) than GE-34 at the end of year two (Figure 5). This might be attributed to PM-51 being selected as a crop tree ideotype whereas GE-34 was selected as a competitor ideotype. Staudhammer et al. (2009) state that crop ideotypes perform best when grown in pure plots rather than mixed plots, whereas competitor ideotypes perform better in mixed plots where they can out-compete adjacent trees. This may be what we're seeing in the results of our study. Variety GE-34, the competitor ideotype, did not perform as well as variety PM-51, possibly because all plots in the study were planted as single-variety plots.

Trees in the intensively managed plots were significantly taller than those in normal management intensity plots following two years of growth. This was most certainly due primarily to the additional herbaceous weed-control along with the application of tip moth control (Figure 6). Fox et al. (2007b) explain that the benefits of herbaceous weed-control were relatively unappreciated until Terry and Hughes (1975) showed that height growth of seedlings increased significantly following control of herbaceous vegetation, a result that has been demonstrated in numerous studies since then. Glover et al. (1989) stated that herbaceous weed-control has long-term effects on pine growth, suggesting that the early gains observed in this study will likely be retained through the rotation.

Insecticide applications within the intensively managed plots possibly aided in greater height growth within those plots. Pine tip moth larva bore into and feed on inner tissues of the buds and shoots which can decrease tree growth in early years after stand establishment (Yates et al. 1981, Nowak and Berisford 2000). Pine tip moth control has been reported to increase height and diameter within treated areas (Cade and Hedden 1987, Fettig et al. 2000). The combination of the weed-control and the insecticide application resulted in an approximately 20 percent increase in height (1.1 feet) for the intensively managed plots.

Year two ground-line diameter and volume index results correlated well with height measurements. PM-51 had significantly larger height, ground-line diameter, and volume index than GE-34. Nelson and Johnsen (2008) state that the development of an ideotype is complex and that multiple attributes play a role in the selection process. An example they give for the selection of a general purpose loblolly pine ideotype consists of eight main attributes with several minor attributes within the main attributes. They show growth as a major attribute with rapid diameter growth and height growth as minor attributes, and suggest selections be based on stem volume index. Other major attributes they discuss include development of desirable rooting characteristics, ecological tolerances (drought, cold, competition, and efficient nutrient usage), crown form, stem form, wood quality, disease resistance and insect resistance. Based on their growth attributes, our results suggest that PM-51 would be a better selection as a superior ideotype than GE-34 when utilized in pure family plantings.

The same factors that contributed to significant height differences between management intensity plots also contributed to significant differences in mean ground-line diameter and mean volume index. The reduction in vegetative competition and insect damage within intensively managed plots likely aided in the significantly higher stem diameters and volume indices within the intensively managed plots.

Crown Characteristics

PM-51 was selected for this test as a purported crop tree ideotype, while GE-34 was purported to perform as a competitor ideotype. Initial observations led to questions about whether the trees were performing as selected. However, analysis of year two data suggests that the trees actually were performing as expected. PM-51, on average, was taller, had longer and wider crowns, greater stem volumes, and less acute branch angles than GE-34. Based on Cannell (1978), PM-51 performed as expected for a crop tree ideotype. Crop trees are efficient users of locally available resources but do not compete strongly with neighboring trees. These characteristics enable the crop tree ideotype to produce greater tree and stand-level yields than trees of a competitor ideotype (GE-34) in intensively managed monocultures.

Varietal differences were noted from time of planting, and became very apparent after the year two crown measurements were analyzed. Significant differences between the two varieties were recorded for height, ground line diameter, stem volume index, crown width, and branch angle. These early results suggest that the varietal material utilized in this study has continued to exhibit the selected stem and crown characteristics across a range of environmental effects related to spacing and management intensity.

Greater tree height was usually correlated with wider crowns, longer branches, and larger branch diameters. Intensively management plots had significantly taller trees than the normal intensity plots. Therefore it was expected that crown width, branch length, mean branch diameter would also be affected by management intensity. Trees on the intensively managed plots did, in fact, exhibit significantly wider crowns, longer branches, and larger branch diameters. This outcome was likely due to the reduced competition allowing for greater crown development. Xiao et al. (2003) state that crown structure is an important factor affecting both individual tree and stand-level growth. Results from this study certainly support the idea that crown development affects individual tree growth.

The interactions found between blocks and management intensity for mean crown width and mean branch diameter are likely the result of sorting the seedlings before planting. Seedlings were sorted by size so that similar size seedlings would be planted together within blocks. After sorting the seedlings the larger seedlings were planted in blocks one and two, possibly contributing to the greater mean tree sizes found within these blocks. The larger seedlings in blocks one and two may have been better able to respond to the lower levels of competing vegetation within the intensively managed plots better than the somewhat shorter seedlings in blocks three and four. However, the average mean crown width of blocks one and two are only 0.4 feet wider than the average mean crown width of blocks three and four, therefore the significant interaction may be of little practical importance. The reasons why the significant interactions only occurred within the crown measurements and not in the tree size measurements is unclear. Through year two these interactions were not significant enough to affect height, ground-line diameter, and volume index but may become significant over time.

Variety PM-51 mean branch angles were significantly greater than the mean branch angles for variety GE-34, but only by 2.6˚. There was also a significant interaction between block and variety. Variety PM-51 mean branch angles for blocks one, two, three, and four ranged from 46˚ to 50.3˚ a difference of 4.3˚, whereas variety GE-34 mean branch angles ranged from 44.5˚ to 46.5˚, a difference of 2.0˚, across the four blocks. Also block four mean branch angle for variety PM-51 was significantly more acute than the other three blocks on average by 3.4˚. These inconsistent mean branch angles across blocks for variety PM-51 may be the cause of the significant block by variety interaction. However, the significant difference in branch angle for variety and the significant block by variety interaction may be of little practical significance.

Conclusions

Genetic variety and management intensity were the two treatment factors that had the greatest impacts on the results of this study. At age two, spacing had no significant effects on any of the response variables examined within this study. This was expected as the trees were still too small to be having competitive effects on one another, even at the tightest spacing. Eventually density effects will begin to be observed, with the performance in the six by fourteen foot spacing being affected first. Branch widths are currently approaching six feet so we would expect competitive interactions to begin occurring within the next few years. Variety PM-51 is outperforming variety GE-34 to date but further analysis will be required to determine long-term effects. Trees are not competing with each other at this time, and it is uncertain how the two varieties will respond to the intraspecific competition that will soon start taking place. These results are based on age two measurements and outcomes may change in future measurements.

CHAPTER V

GENERAL CONCLUSIONS

A genetic comparison and varietal trial was established in 2007 near Holly Springs, Mississippi. Study results through age three showed that the MCP material outperformed both the second generation material and the varietal material in all instances. However, the top performing varietals within the varietal trial outperformed the MCP material in some instances. These findings may indicate that a pure varietal plot containing only top performing varieties could outperform the MCP material all-around. Increased test populations of varietals could lead to the identification of varieties that exhibit greater gains. Early performance comparisons from this study may have been more meaningful if the planting stocks used in the study were more comparable (type, age, size, and condition). It is expected that differences in the planting stock at the time of planting will become less important as the study ages.

A varietal, spacing, and management intensity study was established in 2008 near Newton, Mississippi. Results from that study clearly showed that the two genetic varieties tested were significantly different in most instances. Variety PM-51 was selected as a crop-tree ideotype and performed as expected with less acute branch angles, wider crown widths, taller heights, and larger ground-line diameters than variety GE-34 over the first two years. This supported variety PM-51 as a crop tree ideotype. Management intensity was also significant in most instances throughout the study. High intensity management resulted in wider crowns, longer branches, larger branch diameters, and taller trees with larger stem diameters than normal intensity management after two years of growth. The results suggest that insecticide applications combined with intensive competition control can result in larger trees compared to no insecticide application and minimal competition control. Spacing had no effect on any of the variables examined in this study over the first two years of growth, but is expected to begin exerting significant effects within the next few years.

The results from these two studies show the importance of varietal selection, and management techniques. By selecting a well performing varietal with a preferred ideotype and using appropriate management regimes, greater growth rates can be achieved along with other desirable attributes (ie. wood quality, stem form, crown form, insect resistance, and disease resistance). The utilization of carefully selected varietals and intensive management techniques could allow lower planting densities and the elimination of a mid-rotation thinning. The results in this study are based on two and three year growth. Test results should more accurately correlate in the future with the expected results as the tests age.

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