EFFECTS OF PLANTING DENSITY AND SEED SOURCE ON JUVENILE WOOD FORMATION IN OKLAHOMA-GROWN LOBLOLLY PINE

By

BRANDON SCOTT ABBEY

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

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Graduate College of the
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PREFACE

The amount of juvenile wood is one major parameter in determining the quality of wood processed from harvested trees. The length of juvenile wood production for disparate sources of loblolly pine, and the variables that control this period are really the focus of this research. Data was collected from various plots of North Carolina coastal, and Oklahoma/Arkansas loblolly pine growing in southeastern Oklahoma. Of course, the North Carolina source was transferred from the east coast of the United States, in order to examine growth characteristics of an extreme eastern source of loblolly pine planted on the western fringe of its natural range. The two seed sources were initially planted at various densities in each of two sites.

Research was completed in order to quantify relationships between juvenile wood growth patterns, and wood characteristics of loblolly pine seed sources from extreme eastern and western edges of the natural range, growing in adjacent stands in southeastern Oklahoma. It is notable to mention that these two disparate seed sources originate from approximately the same latitude. Therefore, east-west trends are under investigation rather than trends in a north-south manner. The period of juvenility, as influenced by planting density, was estimated from wood specific gravity of growth increments at breast height.

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INTRODUCTION

One problem facing many timber producers is how to effectively respond to the possibility of future timber shortages. Forest industry grows genetically improved trees in intensively managed plantations to produce bigger and faster growing trees. Increased growth rates and shorter harvest rotation ages may produce sufficient quantities of timber to satisfy the increasing demand for wood products, correlating with an increase in population. However, the problem is maintaining wood strength and dimensional stability (associated with less juvenile wood) while maximizing wood production (Senft et al. 1985).

Over the past 20 years, wood producers and those who purchase wood products have been concerned with the quality of wood coming from fast-grown pine plantations, primarily in the South. Specifically, concerns center around wood being milled into various products requiring structural strength (Senft et al. 1985). The objective of producing maximum timber volume per acre cannot ignore the consumers' needs for quality wood products, which are best supplied from slower grown trees. Future wood supplies in the South will increasingly come from young fast-growing pine plantations (Clark and Saucier 1989). In fact, it is estimated that 50% of Georgia's pine harvest come from managed plantations. Because intensively managed plantations are now being used to provide fiber from rotations as short as 12 years, wood quality issues such as density and juvenile wood are becoming increasingly important to the paper industry (Faust et al. 1997). Wood from these plantations has physical and mechanical properties that make it inferior to wood from older, natural and/or unmanaged stands.

The distinction is that trees coming from fast-grown pine plantations contain higher proportions of juvenile wood in the bole. Juvenile wood is structurally weak, prone to warp, low in alpha cellulose, and is generally less desirable for conventional forest products (Senft et al. 1985). Juvenile wood is also associated with low specific gravity, which results in a low modulus of rupture (MOR) and a low modulus of elasticity (MOE). In addition, juvenile wood is associated with larger fibril angles, which leads to longitudinal shrinkage and subsequent warping, and with shorter tracheid lengths, which results in lower tensile strength (Senft et al. 1985). In contrast, studies have shown that faster growth rates do not always equate to trees having less dense, weak wood (Megraw 1985 and Cregg et al. 1988).

Therefore, more information is needed to understand the mechanisms controlling the length of juvenility in loblolly pine. In general, researchers have found variables such as tracheid length and specific gravity of juvenile wood to be under moderate to strong genetic control. Researchers have also discovered that the length of juvenility in loblolly pine is genetically inherited (Loo et al. 1985). These findings pave the way for genetic selection of trees that contain higher specific gravity wood, with a shorter period of juvenility, and are best suited for a particular location.

Consequently, much research has focused on identifying the optimum seed source, initial planting density, and geographic location that minimizes the length of juvenility and proportion of juvenile wood in the bole of harvest trees. Martin (1984) used growth and yield simulation to demonstrate that the proportion of the bole composed of juvenile wood is highly influenced by initial spacing. He used 7X7 and 12X12 feet spacings to illustrate the differences in the percentage of the bole containing juvenile wood for the two spacings. In addition, the 7X7 ft. spacing plots were thinned at age 16 and 27. At a harvest age of 35 years, the average diameters of the trees were the same for the two spacings. However, only 31% of the bole was comprised of juvenile wood for the 7X7 ft. spacing compared to 51% for the 12X12 ft. spacing. So, not only do closer spaced trees result in a smaller juvenile core diameter, but also a smaller percentage of their boles are comprised of juvenile wood (Martin 1984). Clark and Saucier (1989) conducted a study dealing with the influence of initial planting density, geographic location, and species on juvenile wood formation in southern pine, specifically loblolly pine. They found that the age of transition from juvenile wood to mature wood production does not vary significantly with planting density in unthinned stands.

Clark and Saucier (1989) also discovered that loblolly pine planted in the Piedmont of South Carolina at 6X6, 8X8, 10X10, and 12X12 feet spacings on the average produced juvenile wood through 14 rings from pith and began producing mature wood in ring 16 for all spacings sampled. However, the period of juvenility was only 6 years for loblolly pine planted on the Gulf Coastal Plain of Florida. Therefore, geographic variability, in terms of length of juvenility for loblolly pine planted at different locations, does exist in a north-south trend for loblolly pine. They also discovered that the size of the juvenile core in plantation trees is related to the rate of growth, which in turn is influenced by initial planting density. For example, wider spaced trees will tend to grow faster than more closely spaced trees. In loblolly pine, the average juvenile core diameter ranged from 5.2 in. in trees planted at the 6X6 ft. spacing to 7.7 in. in trees planted at the 12X12 ft. spacing (Clark and Saucier 1989).

While Clark and Saucier (1989) demonstrated a north-south trend in the length of juvenility in loblolly pine, little work has been done to determine whether an east-west trend exists. Furthermore, there has been limited research on eastern sources growing in southeastern Oklahoma. Even less research has investigated the performance of North Carolina coastal (NCC) sources planted on excessively drained, rocky soils. This type of study would reveal the growth characteristics of loblolly pine from the extreme eastern end of its natural range when grown on the extreme northwestern end of its range. Large-scale transfers of provenances have been performed without any knowledge of the implications on the quality of wood produced. Part of this study will also analyze the effects of such a large-scale transfer; whether it had positive or negative effects. Provenance tests in Oklahoma and Arkansas have exhibited a notable growth advantage of NCC sources of loblolly pine over local seed sources, when planted on soils having adequate moisture holding capacity (Lambeth et al. 1984; Wells and Lambeth 1983). This study will attempt to discover if the same trend is similar for NCC loblolly pine planted on soils with a more shallow soil profile and associated lower water holding capacity.

The objectives of this study are to: 1) determine the effect of initial planting density on the length of juvenility of two diverse loblolly pine sources planted at the northwestern edge of the natural range of loblolly pine; and 2) examine wood properties of diverse loblolly pine provenances grown under similar environmental conditions to evaluate if seed source differences exist.

MATERIALS AND METHODS

Site description

This study was conducted on two contrasting loblolly pine plantations in southeastern Oklahoma. One site (Carter Mountain) is located approximately 15 miles north of Broken Bow, Oklahoma. The soil on this site is classified as a Goldston-Carnasaw-Sacul association, which is an upland, gravelly, moderately steep, silt loam. The soil at Carter Mountain is primarily comprised of the Goldston series, which is well drained to excessively drained, where permeability is moderately rapid and available water capacity is low, 0.09 to 0.13 inches of water per inch of soil. The site exhibits a seasonal high water table of >6 feet, with an average annual temperature of 63°F (17°C), while the average annual rainfall of the area is 49 in. (125cm) (USDA 1974). Rainfall is generally adequate through May, however late growing season droughts are quite common. This site was planted in 1984 with North Carolina Coastal (NCC) 8-01 and Oklahoma/Arkansas (O/A) Mix 4213 seed sources. Plots with spacings of 6X6, 8X8, 10X10, and 12X12 feet were sampled.

The second site (Stateline) is located approximately 6 miles east and 4 miles north of Broken Bow, Oklahoma near the Arkansas border. The Stateline site is also comprised of a Goldston-Carnasaw-Sacul association, but has a greater water holding capacity when compared to the soil at the Carter Mountain site. Although, the two sites are mapped the same on the NRCS Soil Survey, the Stateline site soil is less gravelly, more developed and comprised primarily of the Sacul series compared to the soil at Carter Mountain. Furthermore, permeability is slower in the Sacul series than the Goldston and available water capacity is high, 0.10 to 0.22 inches of water per inch of soil, and the seasonal high water table is 2-3 feet (USDA 1974). In 1984, this site was planted with NCC 8-74 and O/A Howard County seed sources. Plots with spacings of 5X5, 8X8, 10X10, and 12X12 feet were sampled. The climate at the Stateline site is similar to that of the Carter Mountain site.

Experimental design

Both sites are configured in a randomized complete block design, and arranged in a 2X4 factorial arrangement of treatments. The Stateline site sampling design was setup where all planting densities contained six 0.10ac(0.04ha) plots, with 30 trees from each seed source replicated over those six plots (see appendix). Carter Mountain sampling design consists of adjacent plots containing both seed sources within each planting density. The 6X6, 8X8, and 10X10 ft. planting densities each contain six 0.10ac(0.04ha) plots each, while the 12X12 ft. planting density only contains two plots (see appendix). For both sites each plot represents each seed source within the various spacings. This equates to 3 reps of each source per spacing with 10 trees/rep for a total of 30 trees from each source, replicated over six plots. In effect, there are 60 trees from each planting density, which translates into 240 trees from each site, for a combined grand total of 480 trees for this study.

and then cut into two pieces at the pith, and the best half was chosen (based on clearness of wood) and marked. The chosen and marked portions of the cores were then placed into wooden holders and dried in an oven for 24 hours at approximately 60°C. The wooden holders protected the cores from warping during the drying process. Once the cores were dried, they were glued between two larger hardwood holders (which held about 6-8 core samples). Finally, C-clamps were fastened around the holders, in order to secure the cores firmly against the walls of the holders. This process ensured that the cores were not ripped or shredded when run through the table saw. Holders containing the sample cores were allowed to cure for 24 hours while the glue dried and hardened. They were cut into radial strips with a table saw, bearing two high-speed blades (separated by 1.7mm). Next, each radial strip was cut separate from the remaining middle portion of the holder.

Subsequently the cores were placed into the X-ray densitometer density-profiling machine (model QTRS-01X), manufactured by Quintek Measurement Systems, Inc. Knoxville, Tennessee. This machine runs the cores through an X-ray tube and projects a color image of the sample cores onto a computer monitor. It calculates average ring specific gravity, percent latewood, ring width, latewood width, earlywood density, and latewood density.

It would be prudent here to go through some preliminary discussion, in terms of how those aforementioned variables were used to estimate whole core specific gravity and the period of juvenility. Annual rings can be classified as juvenile wood (crown-formed and transition) or mature wood on the basis of cell structure and the proportions of earlywood and latewood tracheids (Clark and Saucier 1989). These factors determine the average specific gravity of the ring. Therefore, specific gravity of a particular ring is a weighted average of the proportions and specific gravities of earlywood and latewood present in each ring (Clark and Saucier 1989). For this study, specific gravity was used to distinguish juvenile wood from mature wood, simply because it is more practical and more effective to measure compared to various other tracheid properties.

The data provided by the X-ray densitometer created graphic plots of average specific gravity against rings from pith. Using this data, each ring from individual trees was grouped with corresponding rings from other trees representing each source and spacing, so that each point on the graph represented 30 trees. This process was performed using SAS System Version 7.0 (SAS Institute Inc., Cary, N.C.). There are rather complicated methods for estimating demarcation age, such as segmented modeling, iterative solution, and constrained solution (Tasissa and Burkhart 1998). Another method involves segmented regression models based on latewood density profiles. This model was used to evaluate age of transition from juvenile wood to mature wood production for scots pine (Sauter et al. 1999). Furthermore, segmented regression models are better suited for slower grown stands.

For this study, the period of juvenility was estimated from visual examinations of plots of average ring specific gravity over rings from pith. The point of inflection on the S-shaped curve determined the transition period. Latewood percentage for each ring was also plotted over rings from pith, in order to examine relationships between the amount of latewood in each ring and the average ring specific gravity.

Next, the weighted average specific gravity for the whole core was calculated, using the following equation.

$$\sum(RW*RAD)/CSL$$

Where:

RW = ring width
RAD = ring average density
CSL = core sample length

These values allow for comparison of specific gravities across seed sources and planting densities. The specific gravities of the juvenile and mature wood were also individually calculated, in order to determine if differences existed among these variables across seed sources and planting densities. In addition, plots of average annual basal area growth over rings from pith were created, so that growth characteristics could be examined between sources and spacings. Finally, the width of the juvenile core was also calculated. Juvenile core diameter helps explains the proportion of juvenile wood contained in the bole.

RESULTS AND DISCUSSION

A summary of weighted average specific gravities of the juvenile wood, mature wood, and all wood combined for NCC and O/A loblolly pine seed sources, represented by a wide range of planting densities for both Stateline and Carter Mountain sites, is provided in Tables 1 and 2, respectively. Based on analysis of variance and Duncan's Multiple–Range Test (using the MIXED procedure and LSMEANS and DIFF options in SAS), there was no statistically significant interaction between source and spacing for either site, at the p=.05 percent level. However, the analysis of variance indicates significant seed source differences when averaged with values for planting densities combined for juvenile wood and all wood combined specific gravities at the Stateline site. In addition, significant differences for mature wood specific gravity were found when averaged for each planting density with seed sources combined (Table 1). At the Carter Mountain site, no significant seed source differences were discovered when planting density values were combined. These findings suggest that the faster growing NCC seed sources were not less dense than the slower growing O/A seed sources. Similarly, no significant planting density differences were found when seed source values were combined (Table 2).

The values for juvenile, mature, and all wood combined weighted average specific gravities revealed in this study are somewhat lower for those found in Clark and Saucier (1989) study. This is most likely due to limited late summer rainfall experienced by trees encompassed in this study, compared to relatively plentiful late summer rainfall experienced by trees in their study. Higher summer rainfall and low evaporative demand result in wood with a higher percentage of latewood and corresponding higher specific gravity, than wood produced in areas with lower summer rainfall and high evaporative demand (Cregg et al. 1988). In other words; the transition from earlywood to latewood production most likely occurs earlier for trees growing in an area prone to early summer drought periods. In addition, latewood production stops sooner because of more severe moisture stress. In contrast, trees growing in areas with greater summer rainfall experience sustained growth in the late growing season, which may result in a larger proportion of latewood and thus a corresponding higher specific gravity (Cregg et al. 1988).

Similar to past studies, initial planting density did influence wood specific gravity during plantation development. In early developmental stages of the stands, before crown closure, wider spaced trees had only a slightly higher average wood specific gravity in first rings, and for the most part the reverse was true later in stand development, particularly after age 11 or 12 (Figure 1-2). A possible explanation for these trends seen at the Stateline site could be that young trees growing at wide spacing experience less competition for available site resources and therefore produce more photosynthate and denser earlywood than trees growing at closer spacing (Clark and Saucier 1989). As the stands develop, specific gravity is then more strongly influenced by the proportions of earlywood and latewood tissues produced. During this time wider-spaced trees have a tendency to produce larger percentages of earlywood, thus wood of lower specific gravity (Clark and Saucier 1989). This trend is not well represented at Carter Mountain (Figure 3). At the Carter Mountain site, lower soil water holding capacity could have possibly masked this phenomenon.

In general, planting density did influence percent latewood of mature wood (Figures 4-7). These figures, especially at the Stateline site, revealed that the wider-spaced trees contained less latewood on a percentage basis, and therefore lower specific gravity in the mature wood, as suggested in the previous paragraph.

Plots of specific gravity data against rings from pith for each spacing revealed that length of juvenility is not significantly influenced by initial planting density in unthinned plantations. It is notable to mention that the inflection points shown in these plots are not quite as discernible as those observed by Clark and Saucier (1989). This anomaly is most likely due to erratic rainfall patterns that existed in this study area (particularly at stand ages 15-17), compared to the relatively steady rainfall patterns at their study area. Nevertheless, the transition period can still be discerned from our data. Both seed sources produced juvenile wood through the first 9 rings and began producing mature wood after ring 10 (Figures 1-3). In addition, the period of juvenility of an extreme eastern source of loblolly pine (NCC) grown at the northwestern fringe of its natural range, did not deviate from the period of juvenility exhibited by extreme western sources of loblolly pine (O/A) when grown at the same locations in Oklahoma.

Other studies have confirmed that geographic location and/or environmental factors play the determining role in period of juvenility, not initial planting density. In 1998, Tasissa and Burkhart found that trees growing in coastal plains had lower ages of demarcation than trees from other areas. Clark and Saucier (1989) discovered a North-South trend, in terms of length of juvenility for loblolly and slash pine. The period of juvenile wood formation decreased from 14 years in the Piedmont to 6 years in the Gulf Coastal Plain. For this study, the length of juvenility of loblolly pine, when grown at the northwest end of its natural range, was 9-10 years. Thus, it appears that the age of demarcation for loblolly pine grown in the northwest fringe of its range is intermediary when compared to demarcation age of loblolly pine in the northeast and southeast portions of its natural range. The variation in length of juvenility with geographic location appears to be related to length of growing season and climatic factors such as temperature and seasonal rainfall patterns (Clark and Saucier 1989). The climate at our site is more similar to that found in the Piedmont than at coastal locations.

The diameter of the juvenile wood core or zone was significantly related to initial planting density. The size of the juvenile core in plantation trees is related to rate of growth, which in turn is influenced by planting density (Clark and Saucier 1989). For the Carter Mountain site, the juvenile core diameters (with sources combined) ranged from 4.7 inches for trees planted at 6X6 feet spacing to 6.3 inches for trees planted at 12X12 feet spacing. Likewise, the average juvenile core diameters (with sources combined) ranged from 4.2 inches at 5X5 feet spacing to 6.7 inches at 12X12 feet spacing at the Stateline site (Table 3). There was also a significant effect of seed source on sampled trees at Stateline site. The average juvenile core diameters for the NCC and O/A seed sources, with spacing combined, were 5.8 inches and 5.3 inches, respectively (Table 4). So the NCC seed source had a slightly wider juvenile core diameter.

Trees producing large annual increments after converting to mature wood will contain proportionally less basal area in juvenile wood than slower growing trees (Clark and Saucier 1989). Trees planted at wider spacings grew faster and accumulated more annual basal area growth than those planted at closer spacings (Figures 8-11). In addition, the NCC seed sources accumulated more annual basal area growth than the O/A seed sources across all planting densities. Figures 12 and 13 depict average annual tree basal area growth for each seed source with spacings combined. The NCC seed sources outperformed the O/A seed sources at the Stateline site (Figure 12). However at the Carter Mountain site, the O/A seed sources slightly outperformed the NCC seed sources up to ring 6 from pith; beyond that the two sources exhibited similar growth (Figure 13). This is further evidence that the NCC seed sources outperformed local sources when grown in Southeast Oklahoma on better sites and maybe even on marginal sites as well.

As expected, there were significant differences in average diameter at breast height (DBH) values for the respective planting densities (Table 3). Average DBH for trees at Carter Mountain ranged from 6.5 inches for the 6X6 feet spacing to 9.1 inches for the 12X12 feet spacing (Table 3). Average DBH for trees at Stateline site ranged from 5.7 inches for the 5X5 feet spacing to 9.6 inches at the 12X12 feet spacing (Table 3). DBH, total height and crown height (height to base of live crown of tree) values were also measured for every tree of each source. These values and statistical analysis are summarized in Table 4. When growth was averaged across all planting densities, there were no significant differences in average DBH attributable to seed source at Carter Mountain (Table 4). This suggests that the NCC seed sources did as well as local sources, in terms of diameter growth, even on a droughty site. However, there was a significant difference for DBH attributable to seed source alone at the Stateline site. The average DBH for the NCC source was 8.3 inches compared to 7.5 inches for the O/A source (Table 4).

The greater diameter growth exhibited by the trees grown at the Stateline site and the wider range of DBH values between the planting densities is most likely attributed to the higher water holding capacity of the site, leading to earlier crown closure and reduced vegetative competition. The NCC seed sources slightly outperformed the O/A seed sources, in terms of diameter growth (Table 4).

Planting density did not significantly affect total height of trees (Table 3). However, seed source differences were found for trees at both sites. In either case, the NCC seed sources were 9% taller than the O/A seed sources (Table 4), which is consistent with previous studies (Wells and Lambeth 1983). As expected, planting density significantly affected the crown height of trees sampled at both sites (Table 3). The closer-spaced trees experienced a higher crown height with less limb retention caused by fiercer competition for site resources and subsequent natural pruning. At the Stateline site, seed source significantly affected the crown height of sampled trees. The crown height for NCC seed sources was 5.5 ft. higher compared to the crown height for O/A seed sources (Table 4). This equates to less limbs and fewer knots, which improves the quality of wood harvested from the NCC seed sources. There were no such differences found at Carter Mountain (Table 4).

This study presents evidence of greater diameter growth, height growth, and higher pine wood quality (in terms of less knots) of NCC seed sources, and suggests the emergence of a distinct advantage of favoring NCC seed sources over local sources in southeastern Oklahoma and southwestern Arkansas, especially on better sites, perhaps even on marginal sites.

CONCLUSIONS

Results of this study show that initial planting density, in unthinned plantations, had no effect on the period of juvenility for any of the loblolly pine seed sources. All sources of loblolly pine planted at spacings ranging from 5X5 feet to 12X12 feet had similar juvenile/mature wood patterns among all spacing treatments. This provides further evidence that the length of juvenile wood production for loblolly pine is strongly influenced by geographical location and environmental conditions, rather than initial planting density. However, planting density did have a significant impact on the size of the juvenile wood core. The wider spaced trees produced a significantly bigger juvenile core. This provides evidence that planting density can be employed to influence the size of the juvenile core by regulating radial growth. This can be accomplished by planting closely and thinning after the trees are producing mature wood, which will minimize the diameter of the juvenile core. In addition, resource managers can decrease the proportion of juvenile wood harvested by lengthening the rotation age.

There were no statistical differences found in the specific gravity of the wood for any of the planting densities at Carter Mountain (Table 2). There were, however, significant differences shown among the seed sources in terms of specific gravity of the juvenile wood and all wood combined at the Stateline site (Table 1). The specific gravities of these variables were slightly higher for the local sources; possibly explained by better adaptability to the site and a corresponding advantage in competing for site resources early in plantation development. In addition, the amount of latewood present in each ring was very similar for both seed sources. Therefore, an extreme eastern source of loblolly pine planted at the extreme northwestern fringe of its natural range produced wood of similar quality to that of the local sources.

This study also examined the performance and growth characteristics of two diverse sources of loblolly pine. The North Carolina Coastal sources continually outperformed the more local Oklahoma/Arkansas seed sources in several different traits. In terms of annual growth, the NCC seed sources accumulated more annual tree basal area growth in relation to the O/A seed sources. This trend was somewhat similar even under more droughty conditions, which are present at the Carter Mountain site. In addition, the NCC seed sources at the Stateline site had a significantly larger diameter at breast height, consistent with more accumulation of annual basal area.

The NCC seed sources were 9% taller than the local sources at both the droughty site and the site with a better water holding capacity, consistent with Wells 1983 study. In his study, North Carolina coastal seed sources outperformed local continental seed sources when all were planted in southeast Oklahoma and southwest Arkansas.

There were also some advantages to the NCC seed sources in terms of crown dynamics. They had a greater crown height, which clearly suggests fewer branches per tree and demonstrates their inclination to naturally prune better than the local sources. This natural process decreases knots per log, which would tend to improve wood quality from a sawtimber standpoint, and could possibly even decrease pruning costs incurred at some point in the rotation.

In the past, resource managers have been hesitant about large-scale planting of NCC seed sources on droughty sites in southeast Oklahoma. Concerns of increased mortality rates and decreased growth rates often hamper such plantings of NCC seed sources in southeast Oklahoma. However, a study conducted on just these sites suggested near equivalent survival of NCC seed sources and O/A seed sources (Blazier 1999). This evidence coupled with evidence of higher growth rates in this study supports claims, although with not absolute certainty, of the superiority of NCC seed sources over O/A seed sources, when planted on better sites and perhaps even on marginal sites in southeastern Oklahoma and southwestern Arkansas. Further research in this area to examine the performance of additional NCC genotypes is required to support such claims with maximum certainty.

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TABLE 2

EFFECT OF PLANTING DENSITY ON WEIGHTED SPECIFIC GRAVITY AT BREAST HEIGHT OF LOBLOLLY PINE JUVENILE, MATURE, AND ALL WOOD AT CARTER MOUNTAIN SITE

	Weighted Specific Gravity		
Spacing	Juvenile Wood	Mature Wood	All
----ft.----			
NCC			
6X6	.40A[1]	.45A	.41A
8X8	.41A	.43A	.42A
10X10	.42A	.45A	.42A
12X12	.41A	.44A	.42A
O/A			
6X6	.39A	.44A	.39A
8X8	.39A	.43A	.39A
10X10	.40A	.44A	.41A
12X12	.42A	.44A	.42A

[1]Values with the same capital letter within a column do not differ significantly at the p=.05 level according to Duncan's Multiple Range Test.
NCC= North Carolina Coastal seed source
O/A= Oklahoma/Arkansas seed source

TABLE 3

STATISTICAL COMPARISON OF TOTAL HEIGHT, CROWN HEIGHT, DIAMETER AT BREAST HEIGHT, AND JUVENILE CORE DIAMETER OF EACH SPACING WHEN GROWN AT TWO SITES IN OKLAHOMA

	Carter Mountain Site		Stateline Site	
DBH	6X6	6.50A[1]	5X5	5.70A
	8X8	7.40B	8X8	7.50B
	10X10	8.40C	10X10	8.50C
	12X12	9.10D	12X12	9.60D
TOTHT	6X6	42.8A	5X5	46.1A
	8X8	43.7A	8X8	47.2A
	10X10	45.5A	10X10	48.9A
	12X12	42.9A	12X12	46.3A
CRNHT	6X6	23.6A	5X5	30.1A
	8X8	22.9A	8X8	27.2B
	10X10	21.1AB	10X10	27.5AB
	12X12	16.4B	12X12	22.0C
JCD	6X6	4.7A	5X5	4.2A
	8X8	5.5B	8X8	5.3B
	10X10	6.0CD	10X10	6.0C
	12X12	6.3D	12X12	6.7D

[1] Values with the same capital letter within a column do not differ significantly at the p=.05 level according to Duncan's Multiple Range Test.
DBH= Diameter at breast height (in in.)
TOTHT= Total Height of the tree (in ft.)
CRNHT= Height to the base of the live crown (in ft.)
JCD= Juvenile core diameter (in in.)

TABLE 4

STATISTICAL COMPARISON OF AVERAGE TREE DIAMETER, TOTAL HEIGHT, AND CROWN HEIGHT OF NORTH CAROLINA COASTAL AND OKLAHOMA/ARKANSAS SEED SOURCES WHEN GROWN AT TWO SITES IN OKLAHOMA

	Carter Mountain Site	Stateline Site
DBH	NCC 7.90A[1]	NCC 8.30A
	O/A 7.90A	O/A 7.50B
TOTHT	NCC 46.2A	NCC 50.0A
	O/A 41.3B	O/A 44.2B
CRNHT	NCC 21.8A	NCC 29.5A
	O/A 20.2A	O/A 24.0B
JCD	NCC 5.50A	NCC 5.80A
	O/A 5.70A	O/A 5.30B

[1]Values with the same capital letter within a column do not differ significantly at the p= .05 level according to Duncan's Multiple Range Test.
DBH= Diameter at breast height (in in.)
TOTHT= Total Height of the tree (in ft.)
CRNHT= Height to the base of the live crown (in ft.)
JCD= Juvenile core diameter (in in.)

FIGURE 1

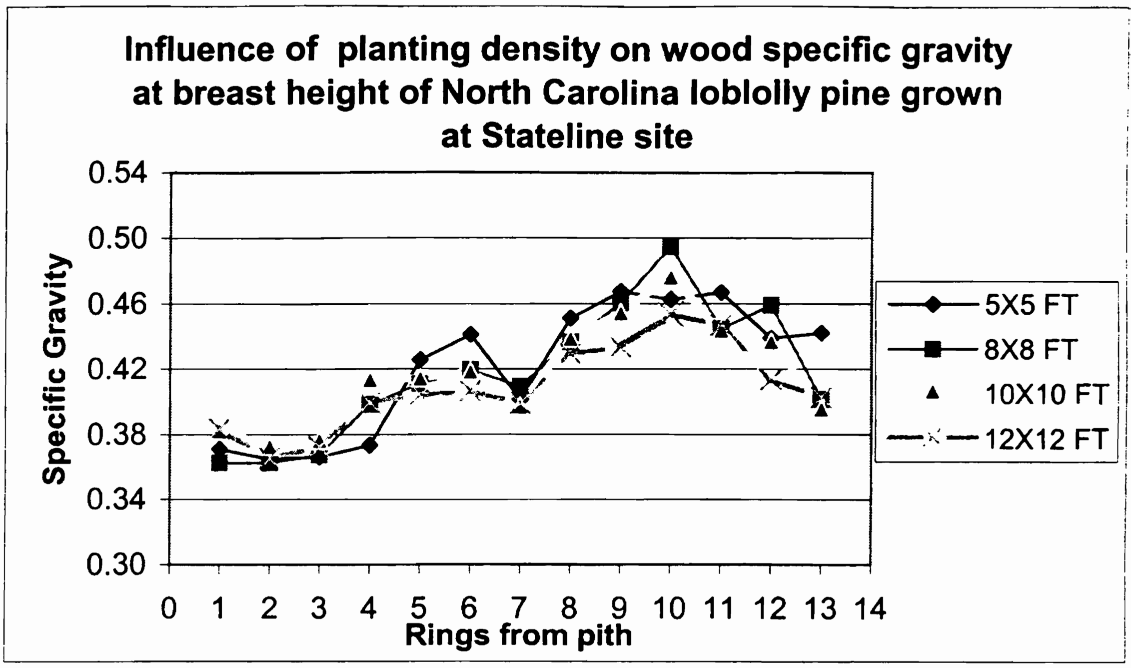

Influence of planting density on wood specific gravity at breast height of North Carolina loblolly pine grown at Stateline site
Specific Gravity
0.54
0.50
0.46
0.42
0.38
0.34
0.30
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Rings from pith
5X5 FT
8X8 FT
10X10 FT
12X12 FT

FIGURE 2

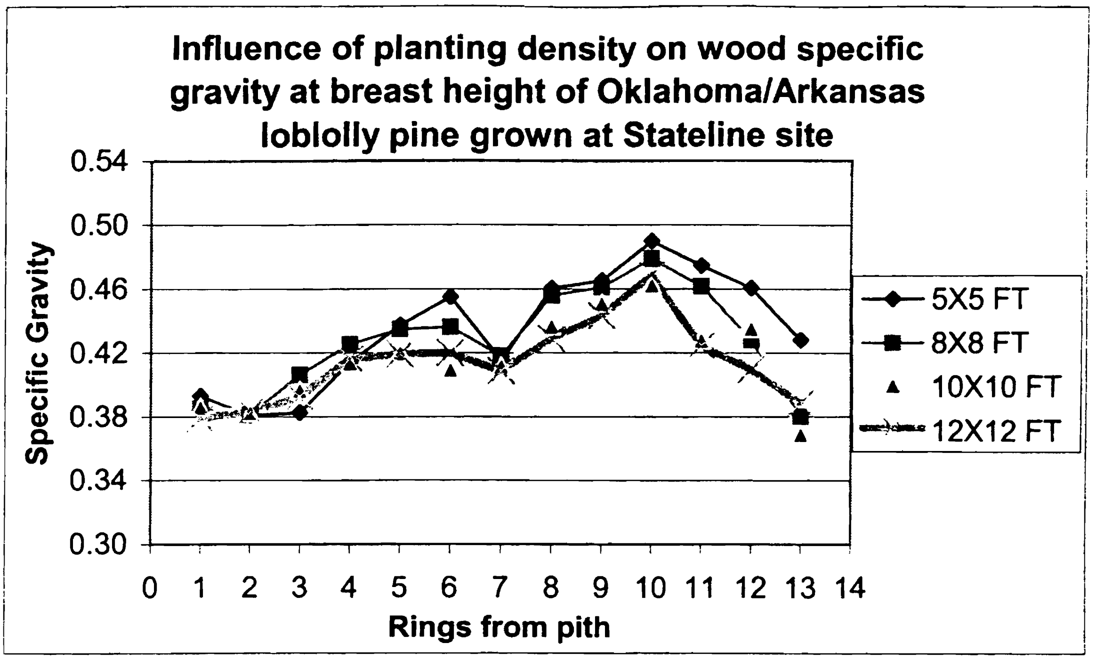

Influence of planting density on wood specific gravity at breast height of Oklahoma/Arkansas loblolly pine grown at Stateline site
Specific Gravity
0.54
0.50
0.46
0.42
0.38
0.34
0.30
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Rings from pith
5X5 FT
8X8 FT
10X10 FT
12X12 FT

FIGURE 3

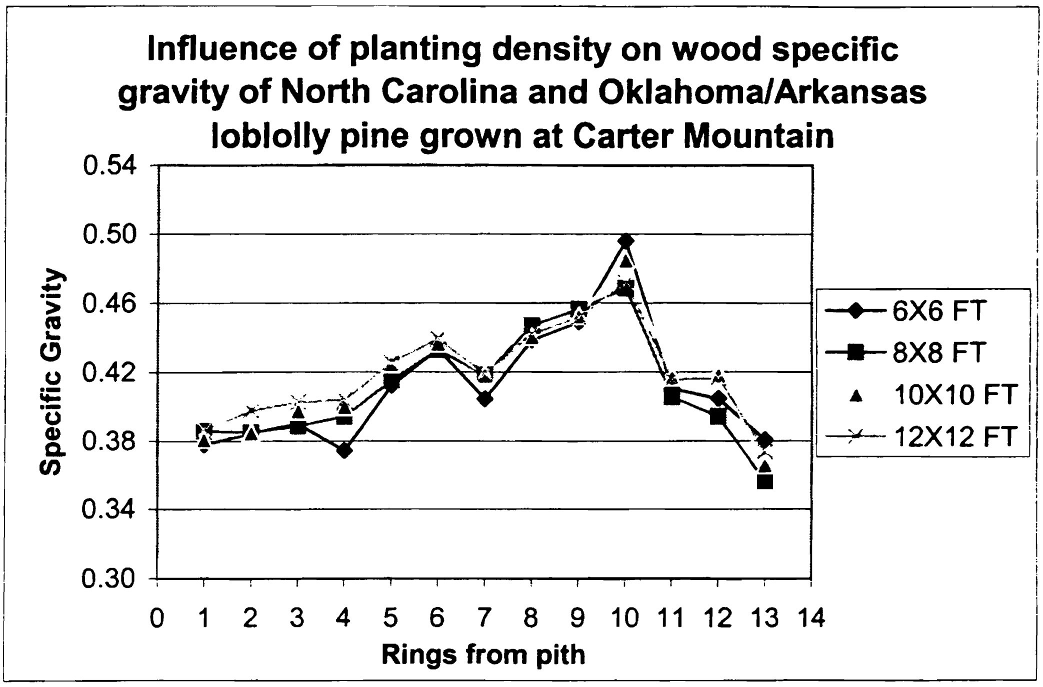

Influence of planting density on wood specific gravity of North Carolina and Oklahoma/Arkansas loblolly pine grown at Carter Mountain
Specific Gravity
0.54
0.50
0.46
0.42
0.38
0.34
0.30
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Rings from pith
6X6 FT
8X8 FT
10X10 FT
12X12 FT

FIGURE 4

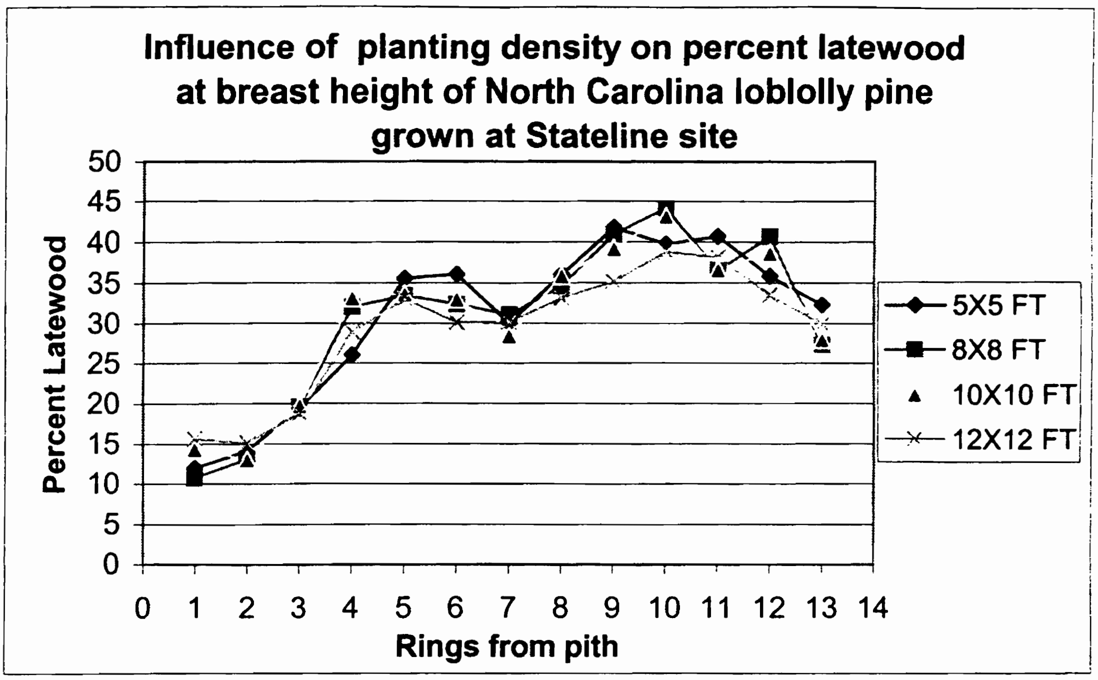

Influence of planting density on percent latewood at breast height of North Carolina loblolly pine grown at Stateline site
Percent Latewood
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Rings from pith
5X5 FT
8X8 FT
10X10 FT
12X12 FT

FIGURE 5

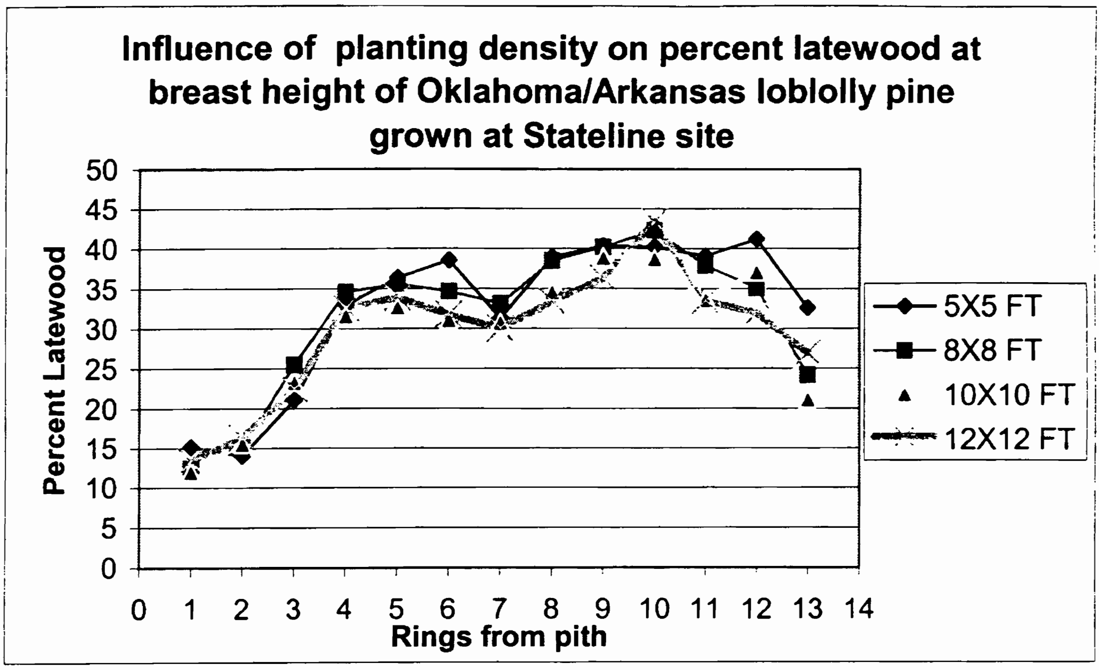
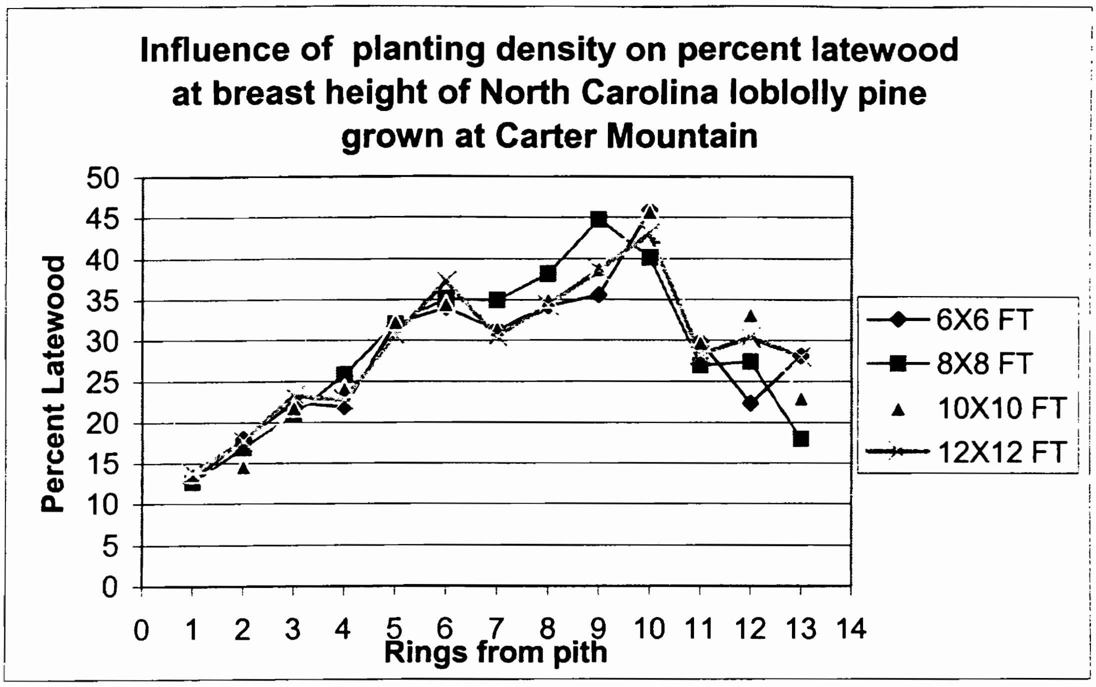

Influence of planting density on percent latewood at breast height of Oklahoma/Arkansas loblolly pine grown at Stateline site
Percent Latewood
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Rings from pith
5X5 FT
8X8 FT
10X10 FT
12X12 FT

FIGURE 6



Influence of planting density on percent latewood at breast height of North Carolina loblolly pine grown at Carter Mountain
Percent Latewood
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Rings from pith
6X6 FT
8X8 FT
10X10 FT
12X12 FT

FIGURE 7

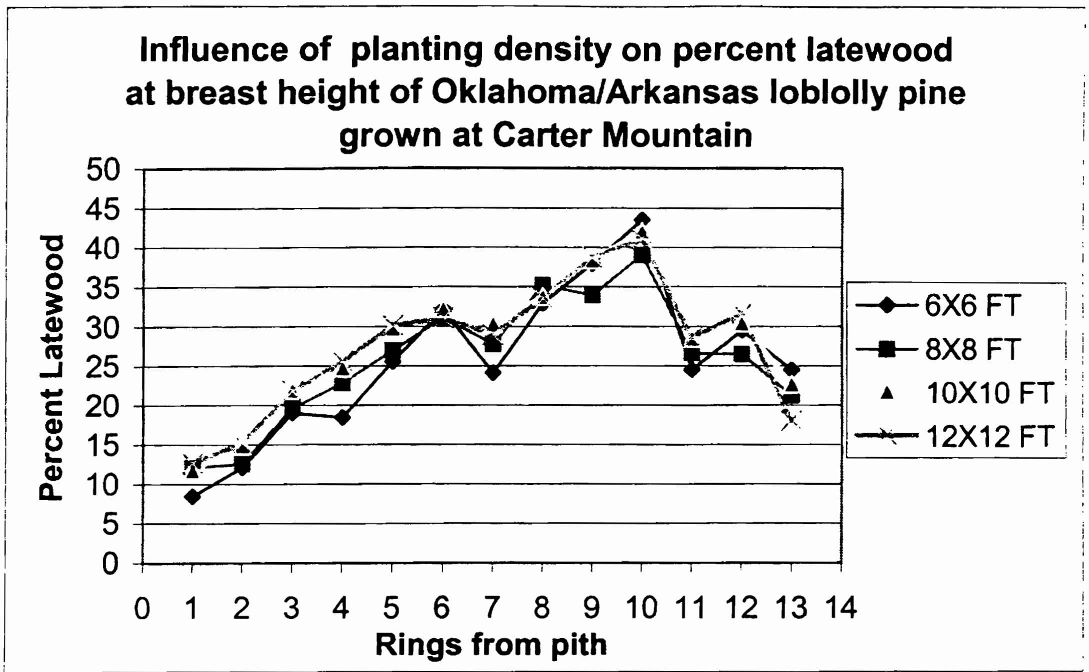

Influence of planting density on percent latewood at breast height of Oklahoma/Arkansas loblolly pine grown at Carter Mountain
Percent Latewood
50
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Rings from pith
6X6 FT
8X8 FT
10X10 FT
12X12 FT

FIGURE 8

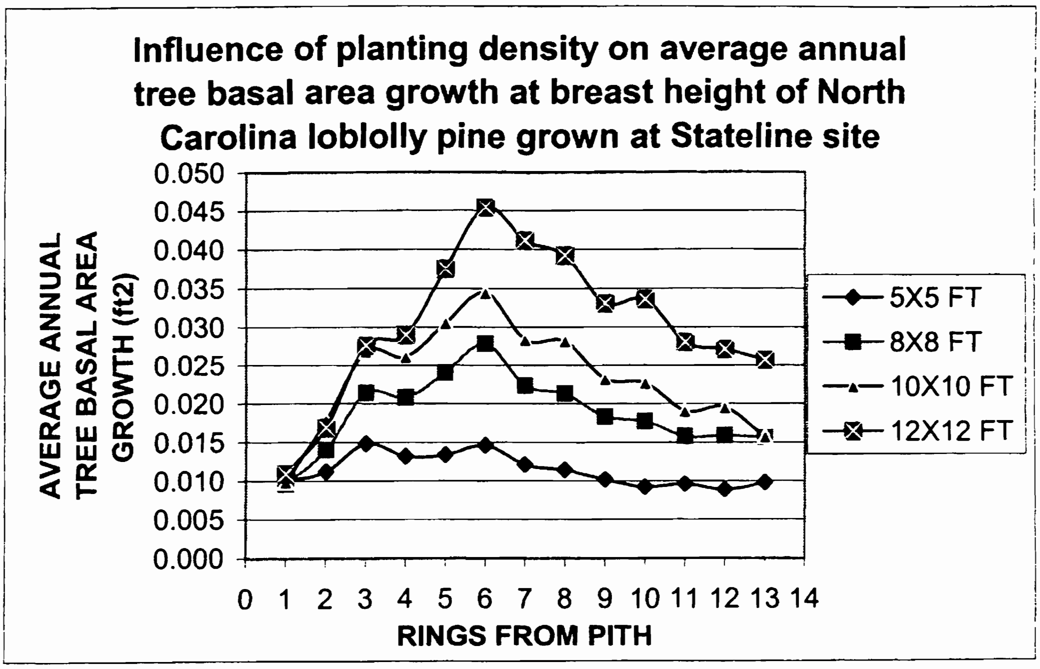
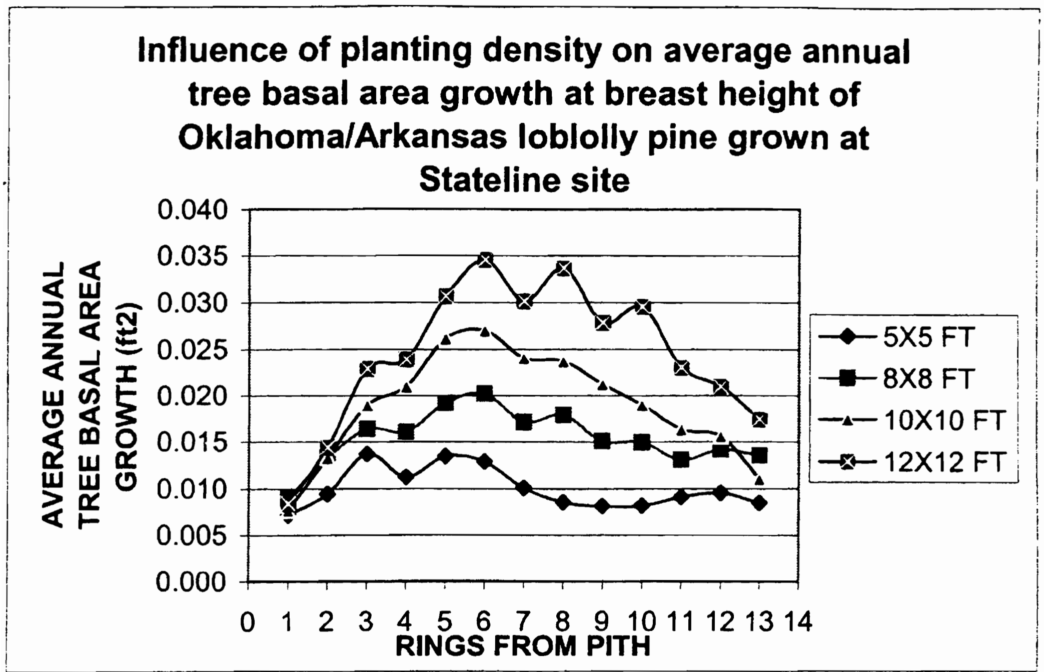

Influence of planting density on average annual tree basal area growth at breast height of North Carolina loblolly pine grown at Stateline site
AVERAGE ANNUAL TREE BASAL AREA GROWTH (ft2)
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
RINGS FROM PITH
5X5 FT
8X8 FT
10X10 FT
12X12 FT

FIGURE 9



Influence of planting density on average annual tree basal area growth at breast height of Oklahoma/Arkansas loblolly pine grown at Stateline site
AVERAGE ANNUAL TREE BASAL AREA GROWTH (ft2)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
RINGS FROM PITH
5X5 FT
8X8 FT
10X10 FT
12X12 FT

FIGURE 9

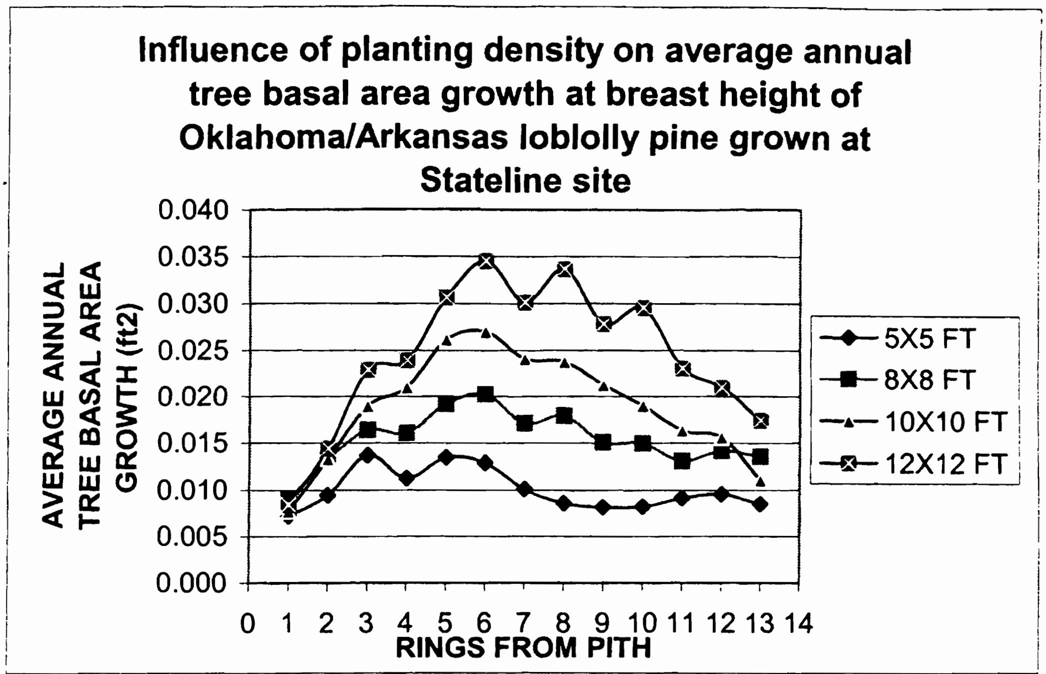

Influence of planting density on average annual tree basal area growth at breast height of Oklahoma/Arkansas loblolly pine grown at Stateline site
AVERAGE ANNUAL TREE BASAL AREA GROWTH (ft2)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
RINGS FROM PITH
5X5 FT
8X8 FT
10X10 FT
12X12 FT

FIGURE 10

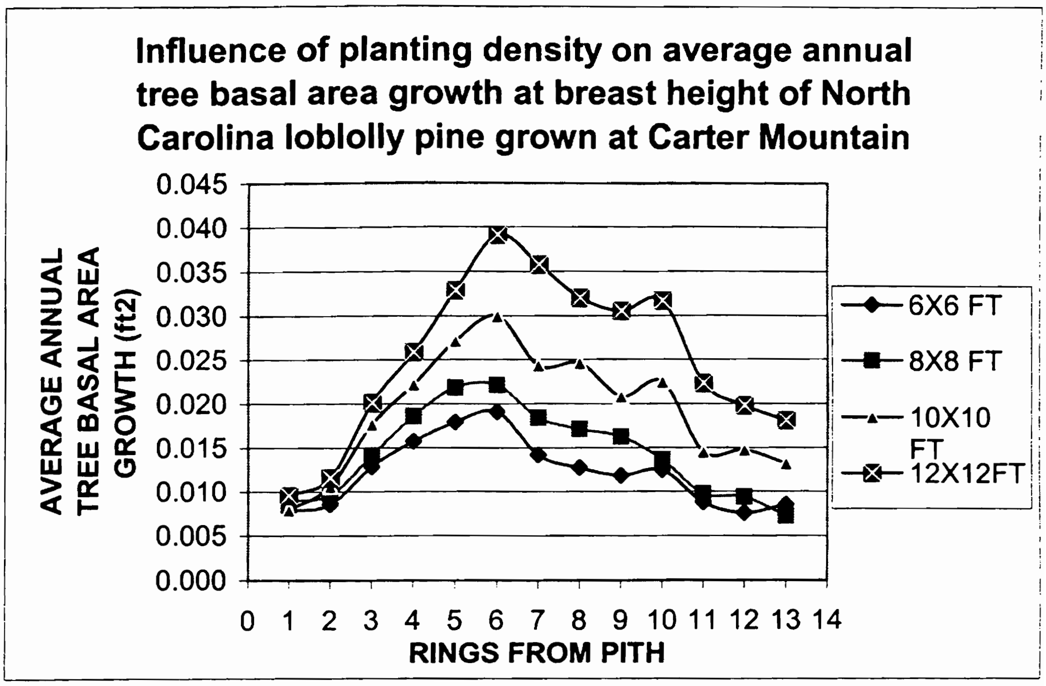

Influence of planting density on average annual tree basal area growth at breast height of North Carolina loblolly pine grown at Carter Mountain
AVERAGE ANNUAL TREE BASAL AREA GROWTH (ft2)
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
RINGS FROM PITH
6X6 FT
8X8 FT
10X10 FT
12X12FT

FIGURE 11

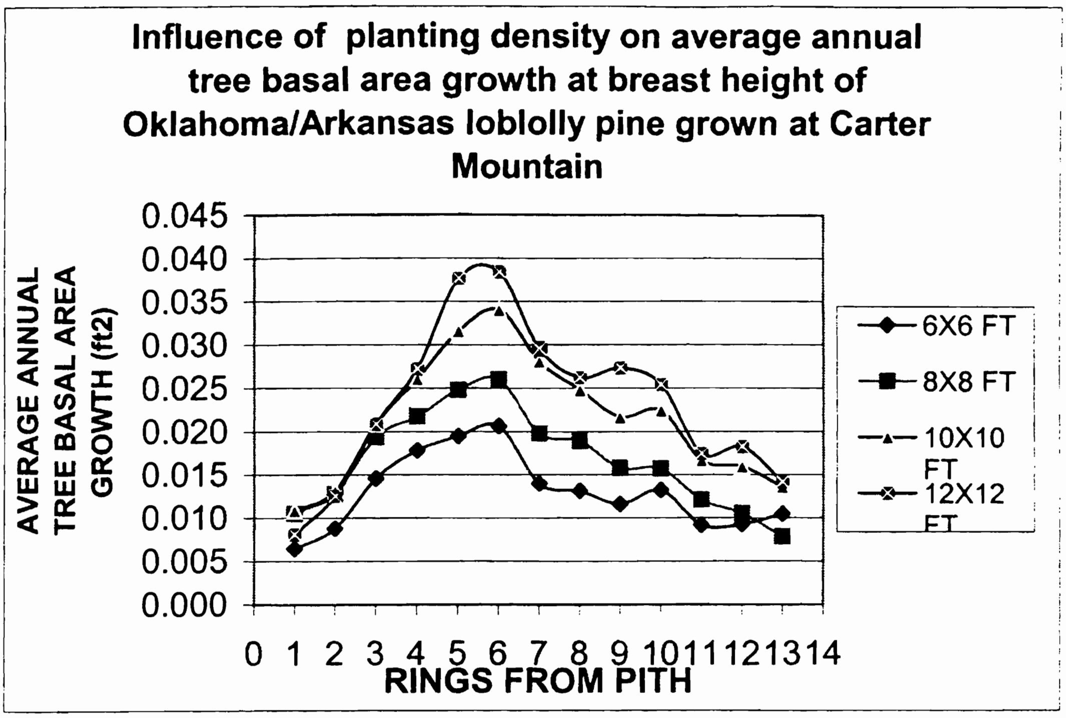

Influence of planting density on average annual tree basal area growth at breast height of Oklahoma/Arkansas loblolly pine grown at Carter Mountain
AVERAGE ANNUAL TREE BASAL AREA GROWTH (ft2)
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
RINGS FROM PITH
6X6 FT
8X8 FT
10X10 FT
12X12 FT

FIGURE 12

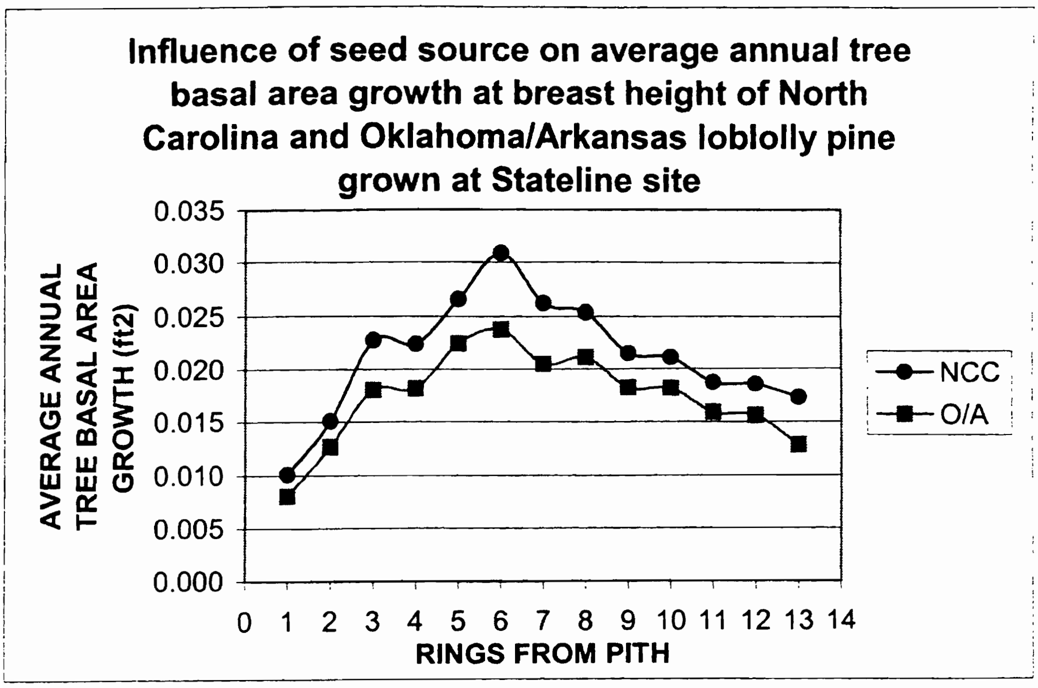
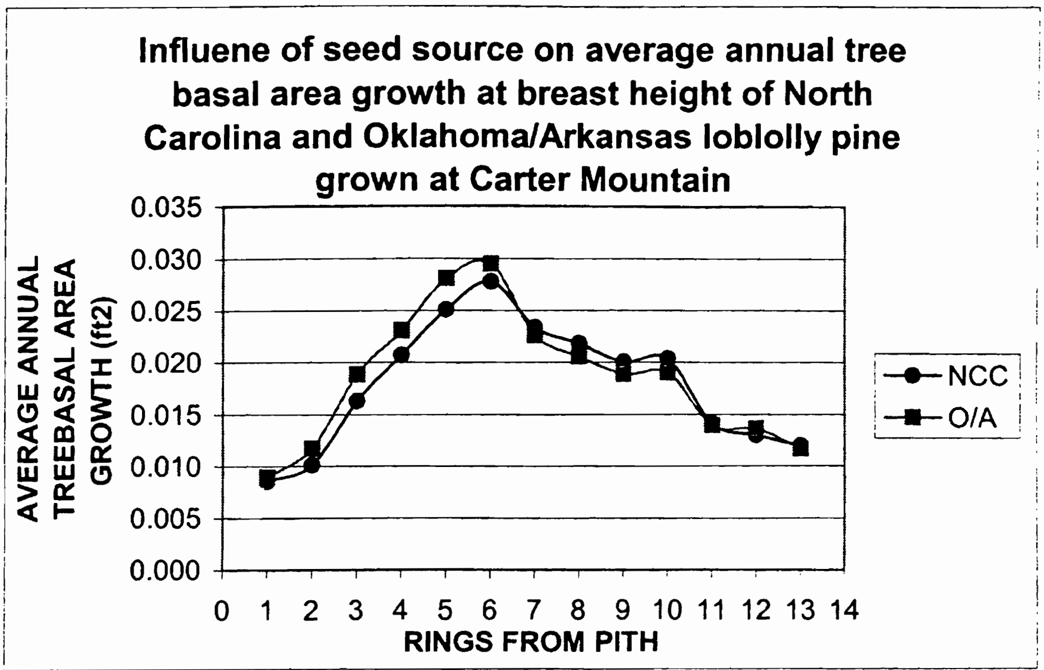

Influence of seed source on average annual tree basal area growth at breast height of North Carolina and Oklahoma/Arkansas loblolly pine grown at Stateline site
AVERAGE ANNUAL TREE BASAL AREA GROWTH (ft2)
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
RINGS FROM PITH
NCC
O/A

FIGURE 13



Influene of seed source on average annual tree basal area growth at breast height of North Carolina and Oklahoma/Arkansas loblolly pine grown at Carter Mountain
AVERAGE ANNUAL TREEBASAL AREA GROWTH (ft2)
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
RINGS FROM PITH
NCC
O/A

APPENDIX

SAMPLING DESIGNS OF CARTER MOUNTAIN AND STATELINE SITES

STATELINE SAMPLING DESIGN

Spacing	# plots	O/A	NCC
5X5	6	30	30
8X8	6	30	30
10X10	6	30	30
12X12	6	30	30
Totals	24	120	120

CARTER MOUNTAIN SAMPLING DESIGN

Spacing	# plots	O/A	NCC
5X5	6	30	30
8X8	6	30	30
10X10	6	30	30
12X12	2	30	30
Totals	20	120	120

VITA

Brandon Scott Abbey

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF PLANTING DENSITY AND SEED SOURCE ON JUVENILE WOOD FORMATION IN OKLAHOMA-GROWN LOBLOLLY PINE

Major Field: Forest Resources

Biographical:

Personal Data: Born in Woodward, Oklahoma, on November 9, 1975, the son of Larry and Annola Abbey.

Education: Graduated from Woodward High School, Woodward, Oklahoma, in May 1994; received Bachelor of Science degree in Forestry from Oklahoma State University in December 1998. Completed requirements for the Master of Science degree at Oklahoma State University in May, 2002.

Experience: Field Forester, Smith Flooring Incorporated, Mountain View, Missouri, Summer 1997; Student Employee for United States Forest Service, Lowman, Idaho, Summer 1998; Graduate Research Assistant, Department of Forestry, Oklahoma State University, January 1999 to May 2001.

Professional Memberships: Society of American Foresters, Xi Sigma Pi

The distinction is that trees coming from fast-grown pine plantations contain higher proportions of juvenile wood in the bole. Juvenile wood is structurally weak, prone to warp, low in alpha cellulose, and is generally less desirable for conventional forest products (Senft et al. 1985). Juvenile wood is also associated with low specific gravity, which results in a low modulus of rupture (MOR) and a low modulus of elasticity (MOE). In addition, juvenile wood is associated with larger fibril angles, which leads to longitudinal shrinkage and subsequent warping, and with shorter tracheid lengths, which results in lower tensile strength (Senft et al. 1985). In contrast, studies have shown that faster growth rates do not always equate to trees having less dense, weak wood (Megraw 1985 and Cregg et al. 1988).

Therefore, more information is needed to understand the mechanisms controlling the length of juvenility in loblolly pine. In general, researchers have found variables such as tracheid length and specific gravity of juvenile wood to be under moderate to strong genetic control. Researchers have also discovered that the length of juvenility in loblolly pine is genetically inherited (Loo et al. 1985). These findings pave the way for genetic selection of trees that contain higher specific gravity wood, with a shorter period of juvenility, and are best suited for a particular location.

Consequently, much research has focused on identifying the optimum seed source, initial planting density, and geographic location that minimizes the length of juvenility and proportion of juvenile wood in the bole of harvest trees. Martin (1984) used growth and yield simulation to demonstrate that the proportion of the bole composed of juvenile wood is highly influenced by initial spacing. He used 7X7 and 12X12 feet spacings to illustrate the differences in the percentage of the bole containing