EFFECTS OF GENETICS, MANAGEMENT INTENSITY, AND SEEDLING DENSITY ON EARLY STOCKING IN LOBLOLLY PINE

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Abstract--Rapid establishment and early tree growth can be key factors in successful plantation management. This generally entails planting good quality planting stock at a seedling density appropriate for the management objectives and then managing at an appropriate intensity with a goal of fully occupying the site as quickly as possible within the context of those objectives. We established a study to examine the performance of two varietal lines of loblolly pine (*Pinus taeda* L.) planted at three spacings and managed at two levels of intensity. After five growing seasons, management intensity and genetic variety were both significantly affecting tree height and diameter growth. This has resulted in significant differences in stocking, with relative density (%SDI_{max}) ranging from 4 to 31 percent. Initial tree spacing has yet to begin affecting individual tree growth, but higher relative densities in the tighter spacing suggest that these plots will soon start experiencing the effects of inter-tree competition.
Robinson, C.; Duinker, P.N.; Beazley, K.F. 2010. A conceptual framework for understanding, assessing, and mitigating ecological effects of forest roads. Environmental Reviews. 18: 61-86.

INTRODUCTION

Many of the decisions made at the time of stand establishment and early in the stand's rotation have important long-term consequences. For example, decisions concerning what planting stock to use, what seedling density to plant, and what silvicultural practices to employ prior to or immediately after planting can all have substantial effects on early tree and stand growth and set the stage for the entire silvicultural regime. These decisions affect rates of tree growth and therefore the time to reach full site occupancy, the timing of thinnings and final harvest, the quality of products produced, and other operational logistics of stand management. All of these decisions ultimately affect the overall economics of the management regime.

Growth rates of southern pine plantations have increased substantially over the past 30 to 40 years. Yields from loblolly pine (*Pinus taeda* L.) plantations now often exceed 300- and in some cases 400-cubic feet per acre per year (Fox and others 2007). A significant portion of this greater productivity is due to genetic gains that have been made in loblolly pine over the past half century. Achieving these gains, however, requires greater plantation management intensity involving improved site preparation, more effective competition control, better understanding of forest nutritional requirements, and greater attention to density management.

Formal efforts at genetic improvement of southern pines began in the early 1950s, and by the mid-1980s virtually all southern pine plantations were being established with seedlings produced from genetically improved seed. Volume gains from plantations established using first-generation improved seedlings generally ranged from 7 to 12 percent (Li and others 2000), with gains in harvest value estimated to be > 20 percent (Fox and others 2007). Over half of all southern pine plantations planted in the early 2000s were established with second-generation seedling stock, with volume gains estimated to range from 7 to 23 percent over first-generation plantations (Fox and others 2007; Li and others 1997, 1999, 2000; McKeand and others 2003, 2006a). Additional genetic gains have been realized through the deployment of the single half-sib family blocks (Duzan and Williams 1988, McKeand and others 2006b), and even further gains are possible through the utilization of full-sib families produced using mass-controlled pollination (MCP) techniques (Bramlett 2007). Volume gains from full-sib families over unimproved stock may be as high as 60 percent (Jansson and Li 2004).

The development of techniques for mass production of varietal (i.e., clonal) loblolly pine planting stock has led to the potential for even further plantations gains. The use of varietal planting stock has grown over the past decade,

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Citation for proceedings: Holley, A. Gordon; Connor, Kristina F.; Haywood, James D., eds. 2015. Proceedings of the 17th biennial southern silvicultural research conference. e–Gen. Tech. Rep. SRS–203. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 551 p.

although it is still not widely planted due to a variety of issues that need further investigation. The cost of varietal planting stock is high, currently much higher than other planting stock options. Field testing is needed to compare the performance of varietal stock to that of other planting stock options. In addition, studies are needed to identify the appropriate silvicultural regimes for maximizing gains when using varietal planting stock.

In 2008, we installed a study in central Mississippi to examine the effects of different silvicultural practices on the performance of varietal loblolly pine. The specific objectives of this study were to examine the performance of two selected loblolly pine varieties established at different initial seedling spacing and subjected to different levels of management intensity.

METHODS

In 2008, a study was established at the Mississippi State University Coastal Plain Branch Experiment Station Experiment Station near Newton, MS (32°20'19" N, 89°05' 51" W) to examine the effects of spacing and management intensity on the performance of two contrasting genotypes of loblolly pine. Soils at the site are a Prentiss very fine sandy loam. In September 2007, the site was treated with broadcast application of Glyphosate (64 ounces per acre) and in October was subsoiled to a depth of approximately 14 inches. The site received a second broadcast application of Glyphosate (32 ounces per acre) in March 2008 prior to planting of the seedlings. The site was hand planted with containerized stock in late April/early May 2008.

A 2x2x3 factorial split plot design was used. Main-effects treatments included two genetic varieties of loblolly pine and two levels of management intensity. Main-effects treatment plots were randomly applied and were split by three randomly applied planting spacings with trees within the spacing subplots planted in 64 tree blocks (8 by 8 tree spacing). The inner 36 trees constituted the measurement plots. Each combination of genotype, management intensity, and spacing was replicated four times.

Two varietal genotypes (i.e., clones) of loblolly pine were included in the study based on their putative divergent crown architectures. Produced by ArborGen, LLC, the varieties included one competitor ideotype (comp) characterized by a relatively wide crown form and a crop-tree ideotype (crop) with a more narrow, compact crown form. The management-intensity treatments included a standard intensity (low) and a high intensity (high). Along with the chemical site preparation and subsoiling, both high- and low-intensity plots received a broadcast application of Oustar® (10 ounces per acre) in year 1 for herbaceous competition control. The high-management-intensity plots also received tipmoth control in the form of a single SilvaShieldTM tablet (Bayer Environmental Science) in the planting hole at time of planting, herbaceous competition control in year 2 (1 ounce per acre of Escort®, 16 ounces per acre of Arrow®, 32 ounces per acre of Goal®), PTM™ insecticide (BASF Corp.) injected 3 to 6 inches deep in the soil adjacent to each tree (0.05 ounces active ingredient per tree) in years 2 and 3 for additional tipmoth control, and mowing between rows in year 3. The three initial tree spacings were 6 by 14 feet [519 trees per acre (tpa)], 9 by 14 feet (346 tpa), and 16 by 14 feet (194 tpa).

Seedling heights were measured immediately following planting. Survival has been assessed and heights measured annually through the first five growing seasons (2008-2012). Diameter at breast height (d.b.h.) has been measured on each tree starting in year 4. Reineke's Stand Density Index (SDI; Reineke 1933) was calculated for each plot at year 5 and expressed as a percentage of 450, the maximum SDI for loblolly pine (Dean and Baldwin 1993, Reineke 1933). A simple volume index was calculated for each stem from d.b.h. and total height using the formula for a cone. Plot volume was expressed as cubic feet per acre. We tested for treatment differences in mean tree size, relative density, and early volume production following five growing seasons. All reported treatment differences are based on a critical value of $\alpha = 0.05$.

RESULTS AND DISCUSSION

First-year survival was high across all treatments (table 1), with overall seedling survival over 94 percent. There were no differences in survival associated with the spacing treatment. Surprisingly, the low-intensity

Table 1--Survival at years 1 and 3, and height at years 1, 3, and 5 for two genetic varieties of loblolly pine planted at three different spacings and managed at two different management intensities on a site previously managed for agricultural production in central Mississippi

	Survival[a]		Mean height[a]		
	Year 1	Year 3	Year 1	Year 3	Year 5
	percent		*feet*		
Overall average	94.1	92.2	1.69	7.89	14.8
Initial spacing					
6 x 14 feet	94.8	93.6	1.69	8.07	15.1
9 x 14 feet	95.7	94.8	1.71	8.07	14.9
16 x 14 feet	91.8	88.2	1.66	7.52	14.5
Management intensity					
Low	96.3*	92.7	1.66	6.53	12.1
High	91.9	91.7	1.71	9.25*	17.5*
Genetic variety					
Crop	98.5*	98.0*	1.68	8.39*	15.9*
Competitor	89.7	86.3	1.69	7.38	13.7

[a]Values followed by an asterisk are significantly different from other values in the group at $\alpha = 0.05$.

management treatment had slightly greater survival than the high-intensity treatment. The crop-tree ideotype had better survival that the competitor ideotype. Little additional mortality was observed by year 3, with overall survival still exceeding 92 percent. The differences in survival associated with the management-intensity treatments that had been observed in year 1 had disappeared by year 3. However, the survival differences observed between genotypes remained and increased to nearly 12 percent. Initial spacing was still having no effect on survival through age 3, although one plot at the 16-foot spacing did experience excessive mortality due primarily to sawfly damage.

At age 1, seedlings averaged 1.7 feet in height with no significant treatment-related differences (table 1). By age 3, overall seedling heights averaged nearly 7.9 feet. Significant differences were observed between the management-intensity treatments, with the high-intensity plots averaging nearly 3 feet taller than the low-intensity plots. In addition to having better survival, the crop-tree ideotype had significantly greater mean heights at age 3, averaging about 1 foot taller than the competitor ideotype. Within each of the genotypes, differences in year-3 mean heights were four times greater on the high-intensity plots (1.6 feet) than on the low-intensity plots (0.4 feet). The spacing treatments were still having no effect on mean heights at age 3. By age 5, mean tree height across all treatments averaged nearly 15 feet. Genotype-related differences in height continued, with the advantage for the crop-tree ideotype increasing to over 2 feet. The biggest treatment-related effect on height continued to be associated with management intensity. Trees in the high-intensity treatment, with an average age 5 height of 17.5 feet, were over 5 feet greater than that of the low-intensity plots.

Average tree diameter across all treatments at age 5 was 3.3 inches, with treatments showing the same trends as observed for heights (table 2). Mean diameters for the crop-tree ideotype was nearly 1 inch greater than that of the competitor ideotype. Management intensity again showed the greatest impact on mean diameter. The high-intensity treatment had mean d.b.h. of 4.0 inches, nearly 1.5 inches greater than the low-intensity plots. Initial spacing has yet to start showing an effect on stem diameters.

Relative density ($\%SDI_{max}$), which takes into account both stem density and mean tree size, showed significant treatment-related differences across all treatments (table 2). The mean relative density across all plots was 14 $\%SDI_{max}$, with individual plots ranging from a low of 3 $\%SDI_{max}$ to a high of 38 $\%SDI_{max}$. While the

Table 2--Mean d.b.h., relative density, and cubic foot volume per acre at year 5 for two genetic varieties of loblolly pine planted at three different spacings and managed at two different management intensities on a site previously managed for agricultural production in central Mississippi[a]

	D.b.h.	Rel. density[b]	Volume
	inches	*%max SD*	*ft³ acre⁻¹*
Overall average	3.3	14	179
Initial spacing			
6 x 14 feet	3.2	20[a]	252[a]
9 x 14 feet	3.3	14[b]	177[b]
16 x 14 feet	3.3	8[c]	102[c]
Management intensity			
Low	2.6	10	89
High	4.0*	19*	264*
Genetic variety			
Crop	3.7*	17*	230*
Competitor	2.9	12	125

[a]Values followed by an asterisk or by different letters are significantly different from other values in the group at $\alpha = 0.05$.
[b]Relative density is expressed as the percentage of maximum SDI for loblolly pine.

spacing treatments did not differ in mean tree size, due to differences in stem density there were large differences in relative density. The average relative density of the 6-foot treatment plots was over 20 $\%SDI_{max}$, while the 16-foot plots averaged only 8 $\%SDI_{max}$. The crop-tree ideotype not only had slightly better survival but also better individual tree growth through 5 years and therefore had higher stocking. Relative density of the crop-tree ideotype plots averaged nearly 17 $\%SDI_{max}$ compared to less than 12 $\%SDI_{max}$ for the competitor ideotype. Once again, management intensity had a noticeable effect on stocking with the high-intensity plots averaging nearly 19 $\%SDI_{max}$ while the low-intensity plots averaged only 10 $\%SDI_{max}$.

Age 5 is earlier than most studies start assessing volume production, but it does provide another indication of how these stands are developing under these treatment combinations. Again, all treatments had significant impacts on volume production through age 5 (table 2). There was a significant interaction between spacing and management intensity for age 5 volume, ranging from an average of about 47 cubic feet per acre for the low-intensity treatment plots at the 16-foot spacing to as high as 380 cubic feet per acre for the high-intensity plots at the 6-foot spacing (fig. 1). There was also a significant interaction between genotype and management intensity (fig. 2). At low-management intensity, age-5 volume for the crop-tree ideotype average nearly 114 cubic feet per acre, over 50 cubic feet per acre higher than the competitor ideotype. Under the high-intensity treatment, volume averaged 346 cubic feet per acre for the crop-tree ideotype compared to less than 183 cubic feet per acre for the competitor ideotype.

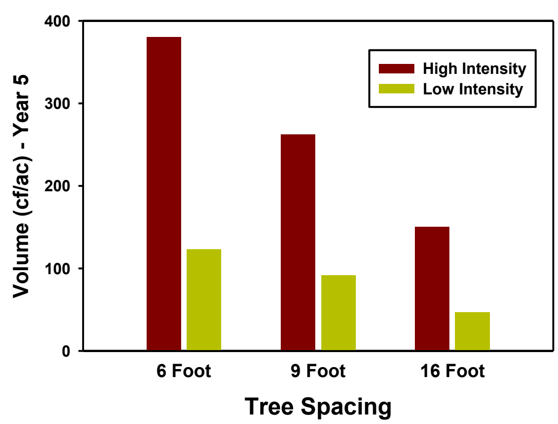

Figure 1--Volume per acre at year 5 for loblolly pine planted at three different spacings and managed at two levels of intensity. All trees were planted in rows 14 feet apart. Tree spacing refers to the distance between trees within rows. Values are means for two different loblolly pine varieties (i.e., clones).

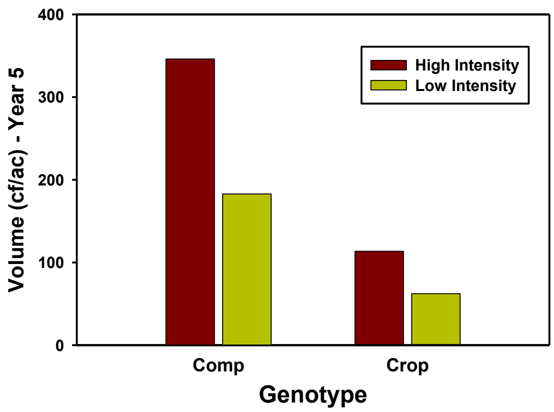

Figure 2--Volume per acre at year 5 for two loblolly pine genotypes managed at two levels of intensity. Values are means across three different initial tree spacing treatments. The 'Comp' genotype refers to a competitor ideotype. The 'Crop' genotype refers to a crop-tree ideotype.

Our results show that, through 5 years, the spacing treatments are not significantly affecting average tree heights or diameters although with initial density only ranging from 194 to 519 trees per acre, it is likely too early to expect much of a density effect on the trees. Significant differences in growth rates have been observed in the genotype treatment, with the crop-tree ideotype demonstrating greater individual tree and stand-level growth. Management intensity has clearly had the biggest impact to date on both tree- and stand-level growth through the first five growing seasons.

Treatment effects on tree growth rates and stem densities have resulted in tremendous variation in average stocking at age 5, ranging from a low of 4 $\%SDI_{max}$ for the competitor ideotype at 16-foot spacing with low-management intensity to a high of 31 $\%SDI_{max}$ for the crop-tree ideotype on 6-foot spacing with high-management intensity. Long (1985) suggests that for many species the onset of competitive interactions between trees begins at around 25 percent of maximum SDI, and that full site occupancy is achieved at about 35 percent of maximum SDI. If these values are accurate for loblolly pine, then a few of our treatment combinations are approaching the onset of inter-tree competition, and one set of treatments has already exceeded that level and is approaching full-site occupancy.

Differences in average tree growth rates and stocking rates have led to a 16-fold difference across treatment combinations in cubic foot volume production through age 5. Current volume approximations range from a low of 30- to a high of 480-cubic feet per acre. However, experience from numerous spacing studies suggests that the observed differences in stocking and volume production will begin to close as tree growth in the high-density stands begins to slow due to increased competition and the earlier onset of density-related mortality.

Our results show, as have many other studies, the potential growth benefits of improved genetics and intensive forest management. Perhaps just as important, even at this early age our study illustrates the importance, when achieving these benefits, of recognizing that stand development can be greatly accelerated and thus stocking rates and the timing of silvicultural activities need to be adjusted accordingly. Our treatment combinations exhibiting the lowest stocking rates are still several years from reaching the point where competitive interactions between trees will become noticeable. Conversely, stocking rates in our most rapidly developing treatment combinations are approaching, and in some cases have exceeded, levels where we might expect to see competitive effects on tree growth, although we were unable to detect any.

This study also illustrates another seemingly obvious point that is often overlooked. Landowners that are unwilling to invest in high-quality genetic planting stock and intensive management should not expect the same results as landowners that do. Even in our study, where both of the genotypes tested were highly selected, the results show that achieving the highest yields will not be possible if investments are not made in appropriate management intensity. Non-industrial private landowners in particular should not be lulled into believing that they are going to achieve the same yields and rotation lengths attained on intensively managed industrial plantations without a comparable investment in management inputs.

ACKNOWLEDGMENTS

The authors acknowledge the cooperation and assistance of ArborGen, LLC for providing planting stock and other resources to this study, and of Bayer CropScience for contributing the SilvaShield tablets. We also thank Mr. Billy Johnson of the Coastal Plain Branch Experiment Station for his invaluable assistance with this project. This manuscript was approved for publication as Journal Article FO-450 of the Forest and Wildlife Research Center, Mississippi State University.

LITERATURE CITED

Bramlett, D.L. 2007. Genetic gain from mass controlled pollination and topworking. Journal of Forestry. 105: 15-19.

Dean, T.J.; Baldwin, V.C., Jr. 1993. Using a density-management diagram to develop thinning schedules for loblolly pine plantations. Res. Pap. SO-275. New Orleans: U.S. Department of Agriculture Forest Service, Southern Forest Experiment Station. 7 p.

Duzan, H.W., Jr.; Williams, C.G. 1988. Matching loblolly pine families to regeneration sites. Southern Journal of Applied Forestry. 12: 166-169.

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

Jansson, G.; Li, B. 2004. Genetic gains of full-sib families from disconnected diallels in loblolly pine. Sylva Genetica. 53: 60-64.

Li, B.; McKeand, S.E.; Hatcher, A.V.; Weir, R.J. 1997. Genetic gains of second generation selections from the North Carolina State University-Industry Cooperative Tree Improvement Program. In: White, T.; Huber, D.; Powell, G., comps. Proceedings of the 24th biennial southern tree improvement conference. Sponsored publication no. 46: 234-238.

Li, B.; McKeand, S.; Weir, R. 1999. Tree improvement and sustainable forestry - impact of two cycles of loblolly pine breeding in the U.S. Forest Genetics. 6: 229-234.

Li, B.; McKeand, S.; Weir, R. 2000. Tree improvement and sustainable forestry - results from two cycles of loblolly pine breeding in the U.S.A. Journal of Sustainable Forestry. 10: 79-85.

Long, J.N. 1985. A practical approach to density management. Forestry Chronicles. 61: 23-27.

McKeand, S.; Mullin, T.; Byram, T.; White, T. 2003. Deployment of genetically improved loblolly and slash pine in the South. Journal of Forestry. 101: 32-37.

McKeand, S.E.; Abt, R.C.; Allen, H.L. [and others]. 2006a. What are the best loblolly pine genotypes worth to landowners? Journal of Forestry. 104: 352-358.

McKeand, S.E.; Jokela, E.J.; Huber, D.A. [and others]. 2006b. Performance of improved genotypes of loblolly pine across different soils, climates, and silvicultural inputs. Forest Ecology and Management. 227: 178-184.

Reineke, L.H. 1933. Perfecting a stand-density index for even-aged forests. Journal of Agricultural Research. 46: 627-638.