USE OF MINIATURE PLANTATIONS TO EXAMINE ACCELERATED STAND DEVELOPMENT IN LOBLOLLY PINE PLANTATIONS: SECOND YEAR RESULTS

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Abstract—A miniature loblolly pine plantation was established in southeastern Arkansas in 2001. Two-month-old seedlings were planted in the spring of 2001 in a factorial arrangement of plots consisting of four within row spacings (10.2, 20.3, 30.5, and 50.8 cm) and four between row spacings (10.2, 20.3, 30.5, and 50.8 cm). Three replicates were installed. Half of the study was fertilized in February 2002 to incorporate fertilization into the experiment. To date vigor, root collar diameter, total height, and crown diameters in four directions have been measured five times. Fertilization has not had a significant effect on any of the attributes. Spacing did not have a significant effect on any attribute until the September 2002 measurement period, when the effect on root collar diameter and crown diameter was significant. By the January 2003 measurement, total height was also significantly affected by spacing.

INTRODUCTION

Loblolly pine (*Pinus taeda* L.) is the most commercially important tree species in Arkansas as well as the southern United States. As a result, much research has been devoted to measuring, quantifying, and modeling the growth and yield of such plantations (Baldwin and Cao 1999). Demand for forest products is increasing. Therefore, various management or silvicultural techniques are being studied and implemented in order to quantify any positive or negative effects on loblolly pine productivity. Two such techniques affecting productivity are fertilization (at planting or midrotation) and altered spacings at time of planting (planting density).

Over 600,000 ha of loblolly pine plantations in the southern United States were fertilized during the period 1976-1996. The number of ha given midrotation fertilization increased from 6,000 ha per year in 1988 to 81,000 ha per year in 1994 and to 162,000 ha per year in 1996 (NCSFNC 1995, NCSFNC 1997). Fertilization has an associated financial cost. Therefore, a multitude of fertilization studies have been implemented in the southeastern United States to quantify fertilization effects in those areas. Such information is crucial in order to make sound (biologically and economically) management decisions.

Plantation productivity can also be altered by employing different planting densities. Many studies are in place to examine these effects as well (Amateis and others 1988, Harms and Lloyd 1981, Haywood 1994, Liu and Burkhart 1994, Pienaar and Rheney 1996, Radtke and Burkhart 1999, Sterba and Amateis 1998). Ideally, an optimum density can be found to achieve optimal productivity for a given objective.

As with all avenues of scientific experimentation, new management or silvicultural techniques, as well as combinations of new techniques, will continually be proposed and examined. However, there exists one substantial drawback to performing such experiments with respect to loblolly pine plantation productivity: time to results. Almost all of the loblolly pine plantation research performed to date has been installed in full scale, or operational, plantations. Plantation development is determined by the combination of plant size and density. As a result, many of these studies can take 10 to 15 years before results are obtained, using typical plantation tree sizes and plantation densities.

Researchers have used scaled versions of experiments (Groninger and others 1995, Qiu and others 1992) in greenhouse environments to obtain research results in a more timely fashion. Such experiments typically last just one or two growing seasons. Amateis and others (2003) expanded the use of scaled experiments by using scaled loblolly pine plantations (hereafter referred to as miniature plantations) to examine spacing effects over a number of growing seasons and compared the results to more traditional, full scale plantation research. They chose to replicate through time instead of space. This project expands the groundbreaking work of Amateis and others (2003) by using miniature loblolly pine plantations replicated in space (and not over time) and by adding fertilization, in addition to spacing, as a factor in the experiment. Two-year results from the experiment are reported herein.

METHODS

The study site used in this project is located just outside of Monticello Arkansas, and is part of University of Arkansas-Monticello School of Forest Resources' university forest. The study area, dominated by juvenile loblolly pine and sweetgum (*Liquidambar styraciflua* L.) was cleared and tilled prior to planting. The soils in the area are mapped as a Calloway series with a Fine-silty, mixed, thermic Glossaquic Fragiudalf taxonomic classification. A hardpan is present at a depth of about 35 cm. Ditches were installed around the study area to allow drainage during the wet winters common to this area.

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Genetically improved loblolly pine seeds were stratified and germinated in Jiffy® peat pellets during the 2000-2001 dormant season. At approximately 2 months of age, the seedlings (in the pellets) were planted at the research site. Seedlings were planted in plots (experimental units) consisting of a factorial arrangement of 4 within row spacings (10.2, 20.3, 30.5, and 50.8 cm) and 4 between row spacings (10.2, 20.3, 30.5, and 50.8 cm) resulting in 16 spacing combinations (or plot sizes). Each plot consisted of nine rows of nine seedlings, with the outer two rows in all directions serving as buffer trees. Therefore, just the interior 25 trees were used as observational units and averaged by plot for subsequent analysis.

Two fertilization levels (fertilized and non-fertilized) were also present within the experiment. Therefore, a complete replicate consisted of 16 spacing combinations and 2 fertilization levels, totaling 32 plots. Three replicates were installed, so a total of 96 plots were installed, and a total 7,776 seedlings were planted in the spring of 2001.

All plots were irrigated during the 2001 growing season and periodically treated with herbicide (sulfometuron methyl, 140 g ha^{-1}, and metsulfuron methyl, 35 g ha^{-1}) to control competition during the 2001 and 2002 growing seasons. Additionally, the plots were periodically treated with permethrin (290 ml ha^{-1}) to control Nantucket tip moth [*Rhyacionia frustrana* (Comstock)] during the 2002 growing season.

The study was first measured in January 2002, one growing season into the experiment and prior to fertilization (one time application of 200 kg ha^{-1} of a 11-40-6 fertilizer in late February 2002) and has been measured four times after fertilization, in April, June, and September of 2002 and January 2003 (two growing seasons into the experiment). At each measurement period, the following attributes were recorded for each observational unit: vigor (alive or dead) total height (to the nearest cm), root collar diameter (to the nearest 0.1 mm), and four crown diameters: within row, between row, and along the two diagonals (to the nearest cm). While other measures were taken, the aforementioned list is limited to those analyzed herein.

RESULTS AND DISCUSSION

Though the experiment allows examining all spacings formed by the factorial arrangement of 4 within row and 4 between row spacings (16 spacing combinations in all), the results from just the square spacings (10.2 x 10.2, 15.3 x 15.3, 30.5 x 30.5, and 50.8 x 50.8 cm) are reported herein. Since just the square spacings were analyzed, the four measured crown diameters for each seedling were averaged, and the average crown diameter was used in the analysis. Furthermore, only two replicates were used in the analysis herein as part of the third replicate was lost. All statistical tests were performed at $\alpha = 0.05$, and an arcsine transformation was applied to the survival percentages for all analyses.

Table 1 contains the p-values for the fertilization x spacing interaction for the respective factorial ANOVAs (one for each response: survival, root collar diameter, total height, and crown diameter). In all cases, the interaction term was insignificant. No p-value was reported for the January 2002 measurement as the study has yet to be fertilized.

In the absence of a significant fertilization x spacing interaction effect, each of the main effects: spacing [4 levels: (10.2 x 10.2, 15.3 x 15.3, 30.5 x 30.5, and 50.8 x 50.8 cm) and fertilization (two levels: fertilized and non-fertilized)] were examined. Table 2 contains the p-values for the respective spacing main effect tests by response and measurement date. Spacing began to significantly affect some of the measured responses by the summer of 2002, or about 1.5 years into the experiment. The spacing effect took longer to appear in this study when compared to that reported by Amateis and others (2003), though their spacings were slightly different.

The results for Tukey's honestly significantly different test of spacing effect for the September 2002 and January 2003 measurement periods are shown in table 3. As expected, pairwise differences of means were found only for effects deemed significant by the respective main effect F-tests (table 2). By January 2003, or two growing seasons into the experiment, separation between the tightest spacing (10.2 x 10.2 cm) and the widest spacing (50.8 x 50.8 cm)

Table 1—P-values of spacing x fertilization interaction tests by measurement date from the factorial ANOVAs

Response	01/2002	04/2002	06/2002	09/2002	01/2003
Survival	N/A	0.0667	0.0722	0.4564	0.4303
Root collar diameter	N/A	0.8320	0.8155	0.9364	0.8294
Total height	N/A	0.6421	0.3272	0.7905	0.6403
Crown diameter	N/A	0.3909	0.1767	0.4209	0.6428

Table 2—P-values of the spacing main effect tests by measurement date from the factorial ANOVAs

Response	01/2002	04/2002	06/2002	09/2002	01/2003
Survival	0.6432	0.1154	0.1638	0.8342	0.3996
Root collar diameter	0.1676	0.4232	0.3512	0.0031	< 0.0001
Total height	0.1789	0.4232	0.2651	0.0706	0.0217
Crown diameter	0.5964	0.2065	0.0596	< 0.0001	< 0.0001

Table 3—Means and Tukey's honestly significantly different test results for the spacing effect from the September 2002 and January 2003 measurement periods by response

Response	Spacing	09/2002	01/2003
	cm x cm		
Survival(%)	10.2x10.2	91a[a]	81a
	20.3x20.3	91a	81a
	30.5x30.5	92a	91a
	50.8x50.8	95a	90a
Root collar diameter (*mm*)	10.2x10.2	5.89a	6.96a
	20.3x20.3	6.79ab	8.45ab
	30.5x30.5	7.04ab	9.16ab
	50.8x50.8	8.67ab	12.15c
Total height (*cm*)	10.2x10.2	30.88a	34.38a
	20.3x20.3	32.20a	35.10a
	30.5x30.5	33.22a	36.53a
	50.8x50.8	40.19a	45.90b
Crown diameter (*cm*)	10.2x10.2	17.04a	18.59a
	20.3x20.3	21.89ab	25.19ab
	30.5x30.5	23.94ab	24.64ab
	50.8x50.8	28.76b	33.71b

[a] Means sharing a common letter within respective response and measurement dates combinations are not significantly different at $\alpha = 0.05$.

was apparent with the tightest spacing resulting in significantly lower responses for all attributes except survival.

Table 4 contains the p-values for the fertilization main effect F-tests from the respective factorial ANOVAs. None of these F-tests was significant. Recall that fertilizer was applied one time at a rate about equal to that of full scale plantations. Perhaps the rate was too low to warrant a significant response given the increased planting density of this study compared to full scale, or operational, plantations.

CONCLUSIONS

This experiment, to date, corroborates the findings of Amateis and others (2003). Scaled, or miniature, loblolly pine plantations can be used to shorten the time necessary to obtain significant spacing effects. Interestingly, a longer length of time was required to obtain significant spacing effects in this experiment than that of Amateis and others (2003). This may be the result of the different spacings used between the studies (slightly wider spacings were used in this study) or the nature of replication used: space in this study versus time in Amateis and others (2003). The slight site to site variation present in this study may be impacting the results herein. Future analysis will include examining the use of site covariates. Interestingly, such variation could be avoided by using the same site repeatedly over time as in Amateis and others (2003). However, this can lend itself to climatic differences from replication to replication, something that is avoided by replicating in space instead of time.

The fertilization effect was not significant two growing seasons into the experiment (or one growing season after application). In retrospect the fertilization rate used might have been too low to warrant a response. Future applications will be at a higher rate.

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Table 4—P-values of the fertilization main effect tests by measurement date from the factorial ANOVAs

Response	01/2002	04/2002	06/2002	09/2002	01/2003
Survival	N/A	0.1197	0.1607	0.2315	0.2408
Root collar diameter	N/A	0.5169	0.7119	0.5278	0.3810
Total height	N/A	0.2542	0.5110	0.5801	0.4222
Crown diameter	N/A	0.4495	0.8024	0.4070	0.3177

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