# AGROFORESTRY PLANTING DESIGN AFFECTS LOBLOLLY PINE GROWTH

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**Abstract**—The effect of plantation design on resource utilization has not been adequately investigated in agroforestry plantations. An experiment was conducted near Booneville, AR, on a silt loam soil with a fragipan. Loblolly pine (*Pinus taeda* L.) trees were planted in 1994 in three designs: two rows (1.2 by 2.4 m) with a 7.3-m alley, four rows (1.2 by 2.4 m) with a 12.2-m alley, and a rectangular 1.2- by 2.4-m configuration. Each 0.4-ha design was replicated three times. Height and d.b.h. were measured for 6 consecutive years (2002 to 2007) in 0.047-ha plots. Tree height increased annually from 7.30 m (2002) to 13.27 m (2007). For any given year, d.b.h. was greatest in the two-row design, and the four-row design had greater d.b.h. than the rectangular design in 2004 to 2007. Exterior rows in the four-row design had greater d.b.h. than interior rows. Depending on design, plantations might be useful for alley cropping, silvopasture, or pine straw.

## INTRODUCTION

Agroforestry systems can help decrease financial risk and increase farm receipts through commodity diversification and the simultaneous production of food and fiber (Clason and Sharrow 2000, Pearson and others 1995). Pines, pastures, and cattle can be intentionally coproduced in an agroforestry system known as silvopasture. About 9 million ha in the South, much of it marginal crop and pastureland, could yield a greater economic return if planted to pine silvopastures (Haynes 1990).

Relatively few landowners in the United States employ silvopastoral practices, perhaps because there is poor understanding of the economics, marketing, and cost efficiencies involved with the production and sale of agroforestry products such as wood and pine straw (Pearson and others 1995). Further, the complex design and management of silvopastoral systems, compared to row crop, pine, or livestock monoculture, might constrain adoption of this technology. Pine straw production could be a financial incentive to landowners, especially if it occurred relatively early in the tree rotation (Moore and others 1996).

Information is needed on the appropriate design of conifer tree stands for agroforestry applications. Recommended densities for pine silvopastures are only broadly defined, ranging from 250 to 980 tree seedlings/ha, and are determined by tree crop and companion crop requirements, management objectives, and equipment constraints (Robinson and Clason 2000). The rapidity with which trees shade and impact herbage yield depends on tree species, initial row width, row orientation, site productivity, and subsequent thinning.

Loblolly pine (*Pinus taeda* L.) grows well when soil pH is between 4.5 and 6.0 (Schultz 1997), and silvopastures often are established on unfertilized sites with low herbage productivity (Pearson and others 1995). Fertilization usually enhances herbage and wood production in silvopastures (Clason 1999, Schultz 1997), even though many producers do not routinely fertilize their silvopastures (Morris and Clason 1997).

Pine spacing and silvopasture management are objective driven and site specific. The knowledge database needs to be expanded to enable growers to match silvopasture design and management to specific growing conditions, objectives, and budget. The objective of this study was to determine if plantation design affected loblolly pine height and d.b.h. growth.

## METHODS

The experiment was conducted near Booneville, AR, on a Leadvale silt loam soil (fine-silty, siliceous, semiactive, thermic Typic Fragiudults). The site has a fragipan at 40 to 60 cm depth (Burner and MacKown 2005). Loblolly pine trees were planted in 1994 in an east-west row orientation in three designs: two rows (1.2 by 2.4 m) with a 7.3-m alley, four rows (1.2 by 2.4 m) with a 12.2-m alley, and a rectangular 1.2- by 2.4-m configuration. These will be subsequently referred to as two-row, four-row, and rectangular designs, respectively. Each 0.4-ha design was replicated three times.

The alley understory in the two- and four-row designs contained mainly tall fescue (*Lolium arundinaceum*) and bermudagrass (*Cynodon dactylon*), but due to a closed canopy there was essentially no understory vegetation in the rectangular design. The 7.3- and 12.2-m alleys in the two- and four-row treatments, respectively, were mowed and/or surface cultivated to 15-cm depth once or twice annually during the study period (2002 to 2007) to emulate a silvopastoral practice. Surface (15-cm depth) tillage was used to establish an annual ryegrass (*L. multiflorum*) cover crop without fertilization. The 2.4-m wide alleys in two- and four-row designs were vegetated with tall fescue and bermudagrass, and this understory was undisturbed throughout the study period. The rectangular design received no tillage or fertilization treatments, but yield of "red" pine straw was

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estimated at 7500 kg/ha from nonreplicated, hand-raked samples collected in 2005 and 2006.

Four contiguous tree rows were randomly selected within each plot (avoiding exterior rows in the rectangular design). Selected rows were randomly partitioned into two subplots (east and west one-half of the plot). The entire subplot received one of two pruning treatments in 2002: pruning to a height of 2 m (about 25 percent of the total tree height), or not pruned. Pruning debris was left onsite. Twenty dominant or codominant trees (about every other tree) within a row were marked with a numbered tag. Plots represented a 0.047-ha sample size. Height of every second tagged tree was measured with a clinometer, and d.b.h. of every tagged tree was measured with a d-tape. Data were collected for 6 years (2002 to 2007). Climatic data (minimum, maximum, and mean air temperatures, and rainfall) for 2002 to 2007 were obtained from National Oceanic and Atmospheric Administration (NOAA) (2002b, 2003) and from a nonofficial weather station (Model 900, Spectrum Technologies Inc., Plainfield, IL) located 1 km west of the study location, and data were compared to long-term (1971 to 2000) means (National Oceanic and Atmospheric Administration 2002a).

Analysis of variance of d.b.h. and height data used a mixed linear model, PROC MIXED (SAS Institute 2002). Fixed effects were year, design, pruning, row location (north, middle, or south, depending on the design), and interactions. Pruning was not a significant effect ($P > 0.07$) presumably because few live branches were removed, so this treatment was not included in the full model. Replication was the random effect. Tree within year, replication, and design was the repeated measure with a Toeplitz covariance structure and restricted maximum likelihood estimation method (SAS Institute 2002). Degrees of freedom were calculated by the Satterthwaite approximation method. Means were considered different at $P < 0.05$ using the Tukey honestly significant difference test.

## RESULTS AND DISCUSSION

Tree counts at planting were estimated at 1,540 trees/ha (two- and four-row designs), and 3,340 trees/ha (rectangular design), at least twice the conservative rate (850 trees/ha) recommended for forestry plantations (South 2003). An estimated 75 to 90 percent of trees (40 to 46 trees per row) were alive in 2007 with no apparent difference in survival between designs. Survival was consistent with predicted estimates (Schultz 1997).

Mean annual air temperatures during the study period (table 1) tended to be cooler than the long-term mean (National Oceanic and Atmospheric Administration 2002a) but were within the suitable range for loblolly pine in the Southeastern United States. There were large annual fluctuations in total rainfall during the study period, and the mean (1063 mm) was 12 percent less than the long-term mean (National Oceanic and Atmospheric Administration 2002a). Rainfall during some years of the study was less than adequate (1020 mm) (Schultz 1997). An adjacent stand on the same soil with 995 trees/ha had more soil water during the growing season of 2002 (wetter year) than 2003 (drier year), and the rate of soil water depletion in 2003 was more rapid than that of a meadow (Burner and MacKown 2005). Tree growth of all plantations probably was constrained with respect to soil water availability, due to the fragipan, especially in years with below average rainfall. Further, annual cultivation of the 7.3- and 12.2-m wide alleys of agroforestry plantations also could have differentially impacted tree roots, water uptake, and growth compared to the rectangular configuration.

**Table 1—Mean annual air temperature and total rainfall for Booneville, AR, for 2002 through 2007**

| Year[a] | Air temperature Minimum | Air temperature Maximum | Air temperature Mean | Rainfall |
|---|---|---|---|---|
| | °C | | | *mm* |
| 2002 | n/a[b] | n/a | 15.8 | 1393 |
| 2003 | n/a | n/a | 15.9 | 737[c] |
| 2004 | 8.3 | 22.8 | 15.4 | 1279 |
| 2005 | 7.9 | 23.9 | 15.6 | 764 |
| 2006 | 8.0 | 24.1 | 15.9 | 1213 |
| 2007 | 8.4 | 23.2 | 15.5 | 994 |
| Mean[d] | 9.9 | 23.0 | 16.5 | 1214 |

[a] Data for 2002 and 2003 were from National Oceanic and Atmospheric Administration (2002b, 2003). Data for 2004 to 2007 were from a nonofficial weather station located 1 km west of the study location.

[b] Data not reported due to missing values.

[c] Some data were missing.

[d] Long-term (1971 to 2000) mean air temperature or total rainfall (National Oceanic and Atmospheric Administration 2002a).

### Height

There was a year × design effect for height ($P < 0.001$) (table 2), but designs did not differ ($P > 0.28$) in height within any given year. Tree height increased annually ($P = 0.001$) from 7.30 m in 2002 to 13.27 m in 2007 (fig. 1). Tree height was not affected by the row location × design interaction ($P = 0.51$).

### Diameter at Breast Height

There was a year × design effect for d.b.h. ($P < 0.001$). For any given year (fig. 2), tree d.b.h. was greater in the two-row than the four-row design ($P < 0.05$), and the four-row design had greater d,b,h, than the rectangular design in 2004 to 2007 ($P < 0.05$). Row location did not have an effect on d.b.h. in two-row and rectangular designs ($P > 0.98$), but exterior rows in the four-row design had larger d.b.h. than interior rows ($P < 0.01$, data not shown).

**Table 2—Analysis of variance of height and d.b.h. for loblolly pine in three planting designs at Booneville, AR**

| | | Height | | D.b.h. | |
|---|---|---|---|---|---|
| Source of variation | *DF* | *F*-value | *Pr* > *F* | *F*-value | *Pr* > *F* |
| Year (Y) | 5 | 3429.30 | <0.001 | 8704.83 | <0.001 |
| Design (D) | 2 | 0.29 | 0.761 | 32.13 | 0.001 |
| Y × D | 10 | 22.34 | <0.001 | 47.46 | <0.001 |
| Row (R) | 3 | 5.00 | 0.002 | 2.79 | 0.040 |
| Y × R | 15 | 2.73 | <0.001 | 7.17 | <0.001 |
| D × R | 6 | 0.88 | 0.510 | 5.05 | <0.001 |
| Y × D × R | 30 | 1.53 | 0.033 | 9.89 | <0.001 |

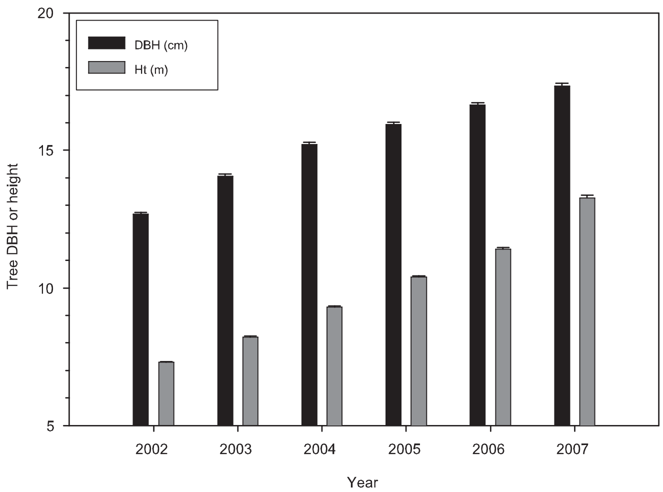


Figure 1—Mean height and d.b.h. of loblolly pine in three agroforestry designs at Booneville, AR. Small vertical bars which exceed the line width indicate standard errors ($n$ = 360 and 720 for height and d.b.h., respectively). Years differ in d.b.h. and height ($P < 0.05$).

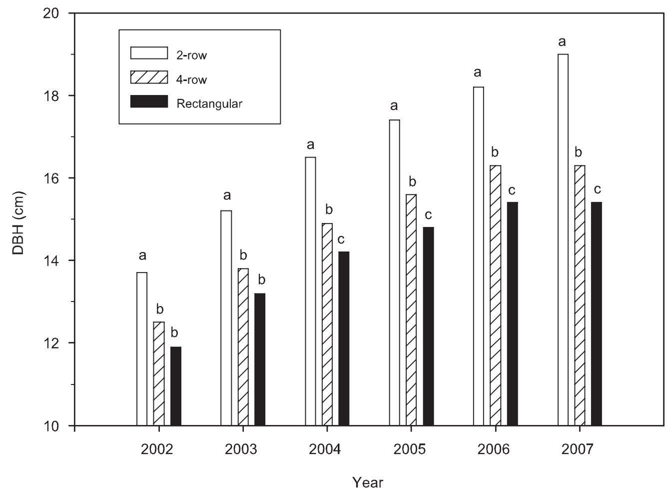


Figure 2—Effect of the year × design interaction on mean d.b.h. of loblolly pine grown in agroforestry plantations at Booneville, AR. Bars within a year having a common letter do not differ ($P > 0.05$).

## CONCLUSIONS

Tree d.b.h. growth was greater in the two-row than four-row agroforestry design, and d.b.h. growth in either agroforestry design usually surpassed that of the rectangular design. This growth difference occurred even though tree roots in the 7.3- and 12.2-m wide alleys of agroforestry plantations might have been disturbed by cultivation. Each of these plantation designs has potential application for fiber, alley crop, or cattle production. While d.b.h. in the rectangular design was constrained by overstocking, this design could be used for pine straw production. The 7.3- and 12.2-m wide alleys in two- and four-row designs might be useful for alley cropping or silvopasture. Selection of the "best" design would depend on production objectives.


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