WESTERN GULF CULTURE-DENSITY STUDY—EARLY RESULTS

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Abstract—The Western Gulf Culture-Density Study is a collaborative research effort between Texas A&M University and five forest products companies to examine the effects of early silvicultural treatment intensity and a wide range of both densities and soil types on performance of loblolly pine. The study tests 2 silvicultural intensities, 5 planting densities (200 to 1,200 trees per acre), and 4 soil types classified by drainage class and depth to a restrictive layer. Eighteen sites were established between 2001 and 2003 in four states. The final product of this research will be an estimate of the best combination of early silvicultural practices for a given soil type and location and the production of data for growth and yield modeling of loblolly pine stands in the West Gulf. This paper presents current survival and growth data for the study sites and discusses trends in response to density, culture, and soil type.

INTRODUCTION

Planting density is one of the most important factors regulating every stage of forest stand development. Productivity in a forest ecosystem is normally limited by resource availability; therefore, stand density management is vital to sustaining maximum productivity. In fact, forestry has been described as the ‘science of density optimization’ (Zeide 2004). Stand density determines such ecosystem processes as time to canopy closure, suppression of understory vegetation through overstory shading, inter- and intra-specific competition, crown recession, lateral growth, mortality (Nyland 2002), faunal diversity associated with snags, litter production (Ferguson and Archibald 2002), and carbon sequestration (Zhou 2001). Natural stand characteristics, such as wood quality at final harvest and risks from pathogens, are also heavily influenced by stand density (Nyland 2002). Stand density impacts forest management decisions such as the objectives of planting, frequency of thinning, planting methods including equipment choice, and degree of likely mechanization of future operations (Nyland 2002). Intensive forest management is currently practiced on more than 34.5 million acres in the southern United States. The application of intensive management has sometimes tripled aboveground biomass accumulation when compared to lower inputs, although results have varied widely among soil-site conditions. Due to its ability to reproduce and grow rapidly on a wide range of site conditions (Schultz 1997), loblolly pine (*Pinus taeda* L.) has become ‘the’ southern pine species for nearly a century. Several spacing trials with loblolly pine (Burkes and others 2003, Harms and others 2000, Lin and Morse 1975) have been implemented in the last few decades. Some studies (Harms and others 2000, Lin and Morse 1975) did not include intensive forest management in their design whereas others include one level of intensive management (Burkes and others 2003). Therefore, the need is obvious for a study involving planting densities and levels of intensive forest management. In addition, such a study should be replicated on a range of soil-site conditions to cover a wide region. Therefore, the objective of the Western Gulf Culture-Density Study (WGCDS) is to test the effect of planting density and cultural treatments on loblolly pine growth and survival on a wide range of soil-site conditions.

MATERIALS AND METHODS

A soil classification based on drainage and depth to a restrictive layer (fragipan or argillic horizon) was developed (table 1). On each of these soil types, a study involving planting density and cultural treatments was established with several replications. Five levels of planting density (table 2) and two levels of silvicultural intensity (table 3) were used. At each study site location, only one soil type was present, and hence the replications were across locations; i.e., each site location had 1 replication of 16 plots, 10 of which represented the core study (5 densities x 2 cultural intensities) and 6 which were designated for a thinning study (3 thinning regimes x 2 cultural treatments). The thinning regimes are: (1) initial planting density of 700 trees per acre (TPA) thinned to 450 TPA; (2) 700 TPA thinned to 200 TPA; and (3) 450 TPA thinned to 200 TPA. The thinning trigger chosen for the WGCDS is 55 percent of the maximum Reineke’s stand density index for loblolly pine,

Table 1—Western Gulf Culture-Density Study soil groups based on site drainage and depth to subsurface restrictive layer

WGCDS soil group	Drainage class	Depth to subsurface restrictive layer
		inches
A	Poorly - somewhat poorly	< 20
B	Poorly - somewhat poorly	> 20
C	Moderately well – well	< 20
D	Moderately well – well	> 20

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Table 2—Five planting densities, associated tree spacings, and plot sizes in the Western Gulf Culture-Density Study

Density	Spacing	Trees per measurement plot	Measurement plot	Gross plot
trees/acre	*ft x ft*		- - - - - - - - - - - - *acres*	- - - - - - - - - - - - -
1,200	4.5 x 8	120	0.1 15 trees x 8 rows	0.23 23 trees x 12 rows
950	5.7 x 8	96	0.1 12 trees x 8 rows	0.25 20 trees x 12 rows
700	6.2 x 10	72	0.1 9 trees x 8 rows	0.26 15 trees x 12 rows
450	9.7 x 10	48	0.1 6 trees x 8 rows	0.27 10 trees x 12 rows
200	15.6 x 14	42	0.2 7 trees x 6 rows	0.55 11 trees x 10 rows

Table 3—Silvicultural treatments (LO and HI) for the Western Gulf Culture-Density Study

Treatment	LO	HI
Site preparation	No difference between LO and HI, but differs among soil types: soil type 'A': bedding and ripping; soil type 'B': bedding only; soil type 'C': ripping only; soil type 'D': none	
Fertilization	250 lb DAP/ac in year 1 only	Year 1: 250 lb DAP/ac Year 2: N/P/K/B mix Year 4+: as per biennial foliar analyses
Herbicide	Year 1 only	Until canopy closure
Insecticide	First 2 years for tip moth; no difference between LO and HI	

assumed to be 450 TPA at quadratic mean diameter of 10 inches (Reineke 1933). Currently, no plot across the entire WGCDS has reached the thinning trigger and, as such, data from thinning plots are reported with data from core plots.

The study sites were established during 3 years on 19 locations in Texas, Arkansas, Louisiana, and Mississippi (table 4). The oldest sites were established in early 2001 and completed their fourth growing season in the summer of 2004. The youngest sites were 2 years old at the end of 2004.

Table 4—Western Gulf Culture-Density Study site matrix by soil type and establishment year

Establishment year	Soil type A	B	C	D	Total
2001	3	3	1	3	10
2002	—	3	—	1	4
2003	1	—	4	—	5
Total	4	6	5	4	19

Site Establishment

Sites were mechanically prepared according to the soil type (table 3). Since there was only one soil type at any location, mechanical site preparation did not vary within sites regardless of planting density or cultural intensity. All sites were planted with loblolly pine. No genetic control was maintained across site locations; i.e., each site was planted with the best open-pollinated genetic family for that location. Each planting spot was double planted to ensure good survival, with one of the seedlings clipped off in the first September or October where two survived.

Post-Planting Treatments

All sites were fertilized according to the two levels of cultural treatments (table 3). The entire study was fertilized with 250 pounds of diammonium phosphate (DAP) per acre in year 1.

In year 2, the HI plots were treated with 100 pounds of elemental N, 10 pounds of elemental P, 40 pounds of elemental K, and 0.5 pound of elemental B per acre. On the sites planted in 2001, foliar samples were collected from the HI plots in the winter of 2003-2004 and analyzed for fertilizer recommendation. Following analyses, HI plots on these sites were fertilized with 120 pounds of elemental N (using DAP and urea), 10 pounds of elemental P (using DAP), and 50 pounds of elemental Mg (using SulPoMag) per acre in year 4.

All study sites were sprayed for herbaceous competition in year 1, regardless of the level of cultural treatments (HI and LO). Beginning in year 2 and continuing until year 4, only HI plots were treated for undesirable vegetation control. The choice of chemical was not uniform across sites as the objective was to suppress competition to <20 percent ground cover.

On soil types ‘A’ and ‘B’, chemicals were broadcast for complete control, whereas on soil types ‘C’ and ‘D’, a 2-foot radius around each tree was spot sprayed to minimize erosion.

The entire study site was treated for Nantucket pine tip moth (*Rhyacionia frustrana*) for the first 2 years using MIMIC® (tebufenozide) and Pounce® (permethrine) either by spraying one of the two or alternating between them, spraying monthly between March and October.

Height and Diameter Measurements

Height and diameter were measured at the end of each growing season between the months of December and January. Height was measured for each tree in the measurement plot (table 2). Diameter was measured at the groundline (GLD) following year 1 on a subsample of trees (frequency varied among densities with 33+ percent of all trees measured on any plot). After the trees developed a diameter at breast height (d.b.h.), they were measured for GLD and d.b.h. for that year and then only d.b.h. on all trees in the following years. Height was measured to the nearest 0.1 foot and diameter to the nearest 0.1 inch.

Statistical Analyses

Data for any growing year were combined for all sites, regardless of their establishment year. This provided all 19 sites for height and diameter data after 1 and 2 years of growth, 14 sites (established in 2001 and 2002) for data after 3 years of growth, and 10 sites (established in 2001) for data after 4 years. Data were analyzed using a split-split plot design where soil type was considered as the main plot, planting density as the subplot, and cultural treatment as the sub-subplot. Treatment means were separated using Tukey’s procedure. All statistical significance was tested at $\alpha = 0.05$. To avoid redundancy throughout the text, statistical significance level has been omitted to reflect values at 0.05 unless otherwise mentioned. Single degree-of-freedom linear contrasts were used to compare soil groups. All data were analyzed using SAS version 8.0 (SAS Institute Inc., Cary, NC, USA 2000).

RESULTS AND DISCUSSION

Survival

Survival at the end of year 4 was not affected by soil type, cultural treatment, or planting density. Average survival for all trees across all study site locations was 94.3 percent. The high survival is likely due to the double planting. Survival for all seedlings at the end of year 1, following clipping of additional seedlings from each planting spot, was 96.9 percent. The fact that survival has not been affected by density suggests that density-dependent mortality had not yet occurred after 4 years of growth.

Height and Diameter

Height and GLD were not affected by cultural treatment in year 1, but beginning in year 2, height and d.b.h. were consistently higher for seedlings in the HI treatments than in the LO treatments (table 5). At the end of year 4, height and d.b.h. for HI trees were 9 and 22 percent greater, respectively, than those for LO trees. Cultural treatments for HI and LO treatments were the same in year 1, and the difference between these two treatments began in year 2. Therefore, the pattern of delayed differences in height and diameter for these two cultural treatments is expected.

Height was not affected by planting density for any measurement except for year 3, when tree height for the 700-TPA was greatest and that for the 200-TPA was lowest (table 6). Planting density significantly affected d.b.h. beginning in year 3 and continuing to year 4. D.b.h. started to show a density response

Table 5—Average loblolly pine height and dbh by cultural treatment at the end of each of four growing seasons in the WGCDS

Cultural treatment	Year 1 Height	Year 1 GLD	Year 2 Height	Year 2 dbh	Year 3 Height	Year 3 dbh	Year 4 Height	Year 4 dbh
	ft	*in*	*ft*	*in*	*ft*	*in*	*ft*	*in*
LO	2.2 a	0.7 a	5.8 b	0.7 b	10.5 b	1.5 b	15.4 b	2.7 b
HI	2.2 a	0.7 a	6.2 a	0.8 a	11.3 a	1.8 a	16.8 a	3.3 a

Table 6—Average loblolly pine height and dbh by planting density at the end of each of four growing seasons in the WGCDS

Density (TPA)	Year 1 Height	Year 1 GLD	Year 2 Height	Year 2 dbh	Year 3 Height	Year 3 dbh	Year 4 Height	Year 4 dbh
	ft	*in*	*ft*	*in*	*ft*	*in*	*ft*	*in*
200	2.1 a	0.7 a	5.7 a	0.7 a	10.4 b	1.7 a	15.5 a	3.4 a
450	2.2 a	0.7 a	5.8 a	0.7 a	10.7 ab	1.7 a	16.0 a	3.2 a
700	2.3 a	0.7 a	6.1 a	0.8 a	11.1 a	1.7 a	16.4 a	3.0 ab
950	2.2 a	0.7 a	6.0 a	0.8 a	10.9 ab	1.6 b	16.1 a	2.9 b
1,200	2.2 a	0.7 a	6.0 a	0.8 a	10.8 ab	1.6 b	15.8 a	2.6 c

in year 3, when it decreased with increasing density. The decrease in diameter with increasing density was consistent across densities at the end of year 4 (table 6), when trees of the 200-TPA had 31 percent greater d.b.h. than those of the 1,200-TPA.

Soil type significantly affected height and diameter in all measurement years. Soil type ‘A’, which is poorly- to somewhat poorly-drained with a shallow (<20 inches) subsurface restrictive layer (table 1), had consistently greater height and diameter than the remaining soil types, whereas soil type ‘D’, which is moderately well- to well-drained with a deep (>20 inches) subsurface restrictive layer had the lowest height and diameter (table 7). After year 4, tree height and d.b.h. for soil type ‘C’ were comparable to those of soil type ‘A’. In other words, soils with <20 inches depth to a subsurface restrictive layer (‘A’ and ‘C’) had taller trees and bigger diameters than soils with deep subsurface restrictive layers (‘B’ and ‘D’) at the end of all measurement years (table 8). Tree height and d.b.h. on soils with shallow, restrictive layers averaged 22 and 18 percent, respectively, greater than those on soils with deep restrictive layers. The effect of site drainage on tree height and diameter was also present until year 3, when tree height and d.b.h. were greater on ‘poorly- to somewhat poorly-drained’ sites than on ‘moderately well- to well’-drained sites. However, this response was not present in year 4 (table 8). This is because growth between year 3 and year 4 was lowest for soil type ‘B’ (poorly- to somewhat poorly-drained and >20 inches to the restrictive layer).

There was an interaction between cultural intensity and planting density in year 1; however, this treatment interaction effect was absent in the following years, and the pattern of growth between trees of HI and LO treatments has been very consistent among all densities. There was also an interaction between planting density and soil type for both height and d.b.h. during all measurement years. This was due to poor growth observed for trees on ‘D’ sites (table 7) which responded to density differently from trees on ‘A’ sites wherein the density influence on d.b.h. was strong. We expect that such interactions will be absent in the future years, when slow-growing sites will also begin to show density effects on height and diameter growth.

SUMMARY

Survival has been excellent across the entire study (>94 percent), which is attributed largely to double planting of seedlings and lack of density-dependent mortality over the first four growing seasons. High inputs of silvicultural treatments resulted in taller and larger diameter trees. Planting density affects early diameter growth more than it affects height; trees in 200-TPA plots had 31 percent greater d.b.h. than trees in 1,200-TPA after four growing seasons. There was no interaction of cultural treatment and planting density present in any measurement year, except for height in year 1.

Soil type significantly affected height and diameter across all measurement years for all sites. Both drainage and depth to the restrictive layer significantly affected early growth; however, depth to the restrictive layer had a stronger effect. Soil types with a shallow depth to restrictive layer had greater growth compared to deeper soils. A drainage effect on height and diameter was absent after year 4.

Of all treatments tested in this study (silvicultural intensity, planting density, and soil type), soil type had the greatest effect on growth. The effect of silvicultural treatment intensity on height and d.b.h. was consistent across soil types; however, pattern of density response to tree height and diameter was not consistent among soil types.

Table 7—Average loblolly pine height and dbh by soil type at the end of each of four growing seasons in the WGCDS

	Year							
Soil	1		2		3		4	
type	Height	GLD	Height	dbh	Height	dbh	Height	dbh
	ft	*in*	*ft*	*in*	*ft*	*in*	*ft*	*in*
A	2.8 a	0.9 a	7.6 a	1.0 a	12.5 a	1.9 a	18.6 a	3.2 a
B	2.0 b	0.6 b	5.6 c	0.7 b	10.5 c	1.6 b	14.5 b	2.9 b
C	2.6 a	0.9 a	6.6 b	0.8 b	11.5 b	1.8 b	17.8 a	3.4 a
D	1.8 c	0.6 b	5.2 d	0.6 c	10.1 c	1.5 c	15.3 b	2.7 b

Table 8—Significance value of linear contrasts to compare soil groups by drainage and depth to subsoil restrictive layer

	Year							
	1		2		3		4	
Linear contrast	Height	GLD	Height	dbh	Height	dbh	Height	dbh
Poorly drained (A+B) vs. well drained (C+D)	0.001	0.05	0.0001	< 0.0001	0.001	0.001	0.51	0.45
Shallow subsoil (A+C) vs. deep subsoil (B+D)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

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