CULTURE AND GENETIC VARIATION INFLUENCES ON JUVENILE WOOD PROPERTIES OF SLASH AND LOBLOLLY PINES IN FLORIDA

D. L. Rockwood[1], J. R. Saucier[1], and A. Clark III[2]

Abstract. The effects of four cultural levels (conventional site preparation and bedding, maximal fertilization, complete vegetation control, and combined fertilization and vegetation control) on latewood percent, age of transition from juvenile to mature wood, and wood specific gravity of young slash and loblolly pines were first evaluated by extracting lower stem cores from 200 10-year-old trees on a flatwoods site near Gainesville, Florida. Latewood percent, which increased from ring ages 4 to 10 years, tended to increase with intensive culture, particularly in slash pine. Under the intensive cultures, slash pine formed mature wood starting at age seven, whereas loblolly pine did not typically form >50% latewood until nine years. No slash pine progeny formed mature wood before age seven, but two progenies tended to deposit more latewood at all ages. Findings on transition age generally confirm previous indications that slash and loblolly pines form mature wood earlier with decreasing latitude. Specific gravity in rings 6-10 was not related to tree DBH, total height, or height to live crown. A second sampling of 80 13-year-old trees using stem disks at 1.5m indicated a trend toward insignificantly lower specific gravity with intensive culture. Previous latewood and transition age patterns persisted. In both samples, slash pine had insignificantly higher specific gravity than loblolly pine in three cultures and overall. Variability between species and within slash pine for important wood properties may offset some undesirable wood quality changes resulting from culturally induced faster growth.

Keywords: *Pinus elliottii, Pinus taeda,* latewood, mature wood, specific gravity.

INTRODUCTION

Southern pine plantations are projected to provide 2.7 billion and 4 billion cubic feet, 50% and 67%, respectively, of harvested softwood in the Southeast in the years 2000 and 2030 (Knight 1986). This increasing reliance on plantation-grown trees with less desirable wood properties, such as the proportion of juvenile wood and the size and frequency of knots (Clark and Saucier 1991a), will have dramatic impacts on wood-using industries. As intensive culture and genetic improvement lead to more rapid tree growth in plantations, the consequences of this management intensity on the quality of an increasingly important wood resource become more important.

'School of Forest Resources and Conservation, University of Florida, Gainesville, FL 32611.
[2]Disturbance and the Management of Southern Pine Ecosystems Research Work Unit, Southern Research Station, Athens, GA 30602.
Journal Series Paper No. N-01413 of the Florida Agricultural Experiment Station.

This investigation had three objectives: 1) evaluate the effects of intensive culture, 2) assess the potential for genetic variability in slash pine to mediate culture-induced changes, and 3) extend previous indications of latitudinal influences for latewood percent (LWP), age of transition from juvenile to mature wood, and wood specific gravity of young slash and loblolly pines.

MATERIALS AND METHODS

The study, established in January 1983 at a spacing of 6' between trees along beds and approximately 12' between beds, is a split-plot design with three replications of the two species in main plots and four cultural treatments in subplots: conventional site preparation and bedding (C), maximal fertilization (F), complete vegetation control (H), and combined fertilization and vegetation control (F+H). Four progenies representing faster growing and more rust resistant clones were systematically located as 10 single-tree plots within slash pine subplots. The loblolly is a bulklot from an unrogued orchard of 30 clones (primarily Marion and Nassau Counties, Florida, selections), several of which were relatively rust-susceptible and slow-growing. The cultural treatments were maintained at least annually through 10 years.

For the first wood evaluation, two 12-mm bark-to-bark cores were taken in November 1992 at approximately 4.5' above ground from each of 200 10-year-old trees free of wood impacting stem diseases: 10 trees of each of four slash pine progenies and one loblolly bulklot per measurement subplot, for a total of 160 slash pine and 40 loblolly pine (Table 1 a). Stratified random sampling was used to select two trees from the lower- through upper-1/5 of the DBH range in two replications of each culture of each of the five genetic entries. Cores were segmented into annual rings. Physical and anatomical measurements taken by the methods of Clark and Saucier (1989) were completed in June 1993. Each sample tree's DBH and some trees' total heights were measured after the wood sampling at age 10 years . Height to live crown, total height, and DBH at 11 and 13 years were also determined.

A second wood sampling in October 1995 used stem disks taken at 1.5m from 80 13-year-old trees (Table lb) in gross plots surrounding the measurement subplots. The slash pine were taken without knowledge of specific pedigree from a mix of progenies 1-56 (33%), 6-56 (2%), 106-56 (32%), and 183-58 (33%), and the loblolly were the same orchard bulklot as in the measurement plots. Wood analyses again followed Clark and Saucier (1989). Latewood measurements utilized strips cut from disks.

RESULTS AND DISCUSSION

After 10 years, growth responses to cultural treatment were large, and species comparisons differed with treatment (Table 2). For slash pine, F or H increased volume/ha some two times over C. F+H resulted in as much as a four-fold increase in stand volume over C, depending on species. Slash pine progenies had approximately twice the volume/ha of the loblolly bulklot under C and were similar to loblolly with F or H. Slash progeny 6-56 had the greatest volume/ha under F+H. F+H produced trees of a size not typically achieved with conventional culture on flatwoods sites for **at least another four years.**

Table 1. Wood sampling conducted at a) 10 years of age for four slash pine progenies and a loblolly pine seed orchard bulklot and b) 13 years of age for slash pine and loblolly pine bulklots grown at four cultural levels..

Species: Progeny	Culture C	F	H	F + H	Total
	(number of sample trees)				
a) Sampling at Age 10 from Measurement Plots					
Slash:					
1-56	10	10	10	10	40
6-56	10	10	10	10	40
106-56	10	10	10	10	40
183-58	10	10	10	10	40
Loblolly	10	10	10	10	40
Total	50	50	50	50	200
b) Sampling at Age 13 from Gross Plots					
Slash	10	10	10	10	40
Loblolly	10	10	10	10	40
Total	20	20	20	20	80

LWP generally increased with ring age, but the pattern of increase differed with species, progeny, and culture (Table 3). For slash pine, LWP averaged as low as 20% in C in the fourth year to as high as 59% in the ninth year with F. F, H, and/or F+H cultures significantly increased LWP at each age except five years, by as much as 10% at four years to just over 1% at 10 years. Differences among the intensive cultures varied with ring age but were usually small in slash pine. In loblolly pine, F, H, and F+H cultures had somewhat similar but inconsistent influences on LWP. The three intensive cultures usually resulted in nonsignificantly higher LWPs at all ages except age 5. H alone, though, tended to have more latewood in rings six through nine years. Increases in LWP in both species with more intensive culture may be due to F, H, and F+H cultures extending the growing season, as evidenced through additional growth flushes (Neary et al. 1990).

Intensive culture typically increased LWP at each age for each slash pine progeny (Table 3). However, the F, H, and F+H cultures had varying influence on the LWP of the four progenies. While progenies 106-56 and 183-58 tended toward higher amounts of latewood than progenies 1-56 and 6-56 at ring ages six through eight, progeny differences were nonsignificant. Progenies

Table 2. Tenth-year mean height, DBH, survival, basal area/ha, volume/ha, and rust and pitch canker incidences for slash pine progenies 1-56, 6-56, 106-56, and 183-58 and a loblolly pine seed orchard bulklot (S.O.Lob.) grown at four cultural levels.

Genetic Entry	Height (m)	DBH (cm)	Survival (%)	BA/ha (sq.m)	Vol/ha (cu.m)	Rust (%)	Pitch Canker (%)
				C - - -			
1-56	8.9	10.2	90.0	11.7	46.1	25.0	0.0
6-56	10.3	12.4	96.7	17.7	103.3	23.3	0.0
106-56	10.2	10.8	83.3	12.0	83.0	18.5	0.0
183-58	9.4	11.1	83.3	12.3	76.3	24.0	4.0
S.O.Lob.	8.1	9.0	92.5	9.8	43.8	40.5	0.0
				F - - -			
1-56	12.1	14.7	86.7	22.8	111.2	42.9	0.0
6-56	13.6	15.0	93.3	25.2	201.2	17.9	0.0
106-56	12.3	15.6	83.3	24.3	151.1	15.4	0.0
183-58	11.1	15.0	76.7	21.0	127.9	41.7	8.3
S.O.Lob.	13.7	15.7	92.5	28.2	168.5	61.9	0.9
				H - - -			
1-56	10.9	14.2	83.3	20.4	123.5	23.1	3.8
6-56	13.0	15.0	83.3	22.8	151.7	29.6	0.0
106-56	12.7	14.7	96.7	25.2	166.5	40.0	3.3
183-58	12.9	15.0	90.0	26.4	186.7	37.9	0.0
S.O.Lob.	12.7	15.7	92.5	24.6	158.4	65.2	0.0
				F + H			
1-56	13.3	16.4	70.0	22.4	131.5	28.0	16.0
6-56	13.3	18.8	96.7	40.4	270.7	23.3	20.0
106-56	11.1	16.7	70.0	23.8	153.4	35.7	22.2
183-58	11.9	17.7	90.0	33.5	183.0	41.4	31.0
S.O.Lob.	14.4	17.0	93.3	32.4	195.6	53.5	0.9

106-56 and 183-58 formed as much as 63% latewood in the ninth annual ring when grown in F or H culture. Differences among progenies in LWP are moderately heritable, but latewood density is more heritable than LWP (Hodge and Purnell 1993).

Cregg et al. (1988) noted that low rainfall and/or high evaporation may delay a tree's transition from earlywood to latewood in a particular year by up to a month. The differences from year to year in LWP, particularly from ring 9 to 10 (Table 3), may reflect a dry summer in 1992. Cregg speculated that summer rains may extend latewood formation in the Coastal Plain.

Using 50% latewood as the transition from juvenile wood to mature wood (McAlister and Powers 1992), intensive culture influences the length of the juvenility period in both species (Table 3). Under conventional culture, slash pine did not average 50% latewood at any age

Table 3. Fourth- to 10th-year latewood percentages for four slash pine progenies, slash pine overall, and a loblolly pine seed orchard bulklot grown at four cultural levels.

Genetic Entry	Latewood Percentage by Annual Ring Age (years)						
	4	5	6	7	8	9	10
				C - - - -			
1-56	15.7	22.0	28.3	41.6	43.0	51.5	49.1
6-56	20.9	22.3	27.7	42.3	34.6	46.8	41.9
106-56	17.1	25.1	36.0	47.6	45.9	49.8	51.6
183-58	25.2	26.8	34.3	47.8	46.2	50.7	46.9
Slash	19.9b1	24.0a	31.6b	44.8b	42.4b	49.7c	47.4c
Loblolly	13.4a	18.0a	21.8b	34.6a	42.5a	44.0a	38.2a
				F - - - -			
1-56	28.1	28.2	39.8	56.3	49.0	58.4	47.6
6-56	34.0	28.4	30.1	47.9	46.0	55.1	46.3
106-56	31.4	28.5	40.6	56.6	58.1	63.2	54.9
183-58	27.9	27.8	39.5	51.6	55.7	60.5	47.0
Slash	30.4a	28.2a	37.5ab	53.1a	52.2a	59.3a	48.9bc
Loblolly	15.4a	18.4a	27.9ab	38.8a	42.8a	53.2a	50.2a
				H - - - -			
1-56	26.4	24.5	42.3	49.0	45.7	57.9	49.0
6-56	27.8	22.8	34.4	49.0	47.6	52.8	41.2
106-56	32.0	26.3	41.4	59.3	52.6	62.0	51.0
183-58	34.5	33.8	44.9	54.9	55.0	62.6	55.1
Slash	30.2a	26.9a	40.8a	53.1a	50.2a	58.8a	49.1ab
Loblolly	18.7a	18.1a	34.7a	50.7a	51.4a	57.7a	49.1a
				F + H - - -			
1-56	24.2	22.8	37.1	52.4	48.1	54.2	47.1
6-56	28.3	27.4	36.2	56.5	45.4	55.7	51.4
106-56	25.3	24.4	39.8	55.9	52.1	60.2	50.7
183-58	34.6	29.4	41.9	57.8	55.0	61.3	53.4
Slash	28.2a	26.0a	38.7ab	55.6a	50.2a	57.9b	50.6a
Loblolly	25.7a	14.8a	26.6ab	42.8a	44.9a	52.9a	47.9a
				Overall			
Slash	27.2a;E2	26.3a;E	37.2a;D	51.7a;B	48.7a;C	56.4a;A	49.0a;C
Loblolly	18.9a;D	17.3b;D	27.8a;C	41.7b;B	45.4a;AB	52.0a;A	46.4a;AB

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except nine years. However, F, H, and F+H each formed mature wood at age seven years. This agrees with the Clark and Saucier (1991a) expectation that slash pine produces juvenile wood for six years in Florida. Intensive culture did not cause any of the slash pine progenies to exceed 50% latewood before seven years, but progenies 106-56 and 183-58 tended to have high LWPages, even over 60%, beginning in the seventh year when grown intensively. Mature wood classified by Clark et al. (1990) had approximately 53% latewood. Intensive site preparation increased the duration of juvenility of slash pine by two years on moderately drained Coastal Plain sites (Clark et al. 1990).

The juvenile period for loblolly pine in Florida is at least six years, which is the age reported by Clark and Saucier (1991a) for slash in Florida. With complete vegetation control, loblolly began to form mature wood in the seventh year. With complete fertilization, the transition to mature wood may have begun in the ninth year. Thus, unlike the observation of Clark and Saucier (1991a), intensive culture may influence the duration of juvenility in loblolly pine. Clark and Saucier (1991b) suggested that the duration of juvenility in loblolly pine may be related to the length of the growing season and seasonal rainfall pattern. These findings on transition age generally confirm previous indications that slash and loblolly pines form mature wood earlier with decreasing latitude.

Through 14 years, the F, H, and F + H treatments continued to have significant effects (Anon., 1997). The F and H treatments gave similar stand volume increases over C in both slash and loblolly pine, although the F treatment had insignificantly higher volume in loblolly. Compared to C, the F + H treatment increased volume 2.2-fold in slash pine to 2.9 cords/acre/year, while in loblolly pine, stand volume increased 3.6-fold to 3.3 cords/acre/year. As a percentage of total aboveground biomass, slash pine averaged 17.2% bark across treatments in contrast to 12.1% for loblolly. Stemwood growth efficiency was higher for loblolly pine.

Allowing for the potentially different progeny representation for slash pine in the age 13 years wood sample, trends in LWP were generally consistent with the earlier sampling (Table 4). Through 10 years, slash pine had higher LWP than loblolly at virtually every culture and age combination, especially at young ages. After 10 years, LWP tended to increase, and loblolly typically had insignificantly higher LWP than slash. At age 13, culture had no influence on LWP in slash, but more intensive culture resulted in higher LWP in loblolly.

The LWP responses in the two samples were somewhat reflected in the wood specific gravities determined (Table 5). For annual rings 6 to 10, LWP and specific gravity were positively associated. For most cultures and/or species, LWP was a good indicator of wood density. Under the H culture, specific gravities were generally higher and less reflective of LWP.

Based on the first 13 annual rings combined, LWP was less useful in predicting specific gravity. Perhaps due to inconsistent progeny representation across cultures, LWP and specific gravity differences were largely insignificant. For loblolly, the H culture tended toward a higher density.

Table 4. Fourth- to 13th-year latewood percentages for slash pine and loblolly pine bulklots grown at four cultural levels.

Genetic Entry	Annual Ring Age (years) 4	5	6	7	8	9	10	11	12	13
	C									
Slash	10.5b[1]	14.9b	22.4a	41.2a	36.4a	42.6b	46.5a	40.0a	51.3a	47.6a
Loblolly	12.9a	9.3a	15.4b	29.8b	38.6a	41.9a	42.0a	39.9a	59.4a	52.5b
	F									
Slash	25.3a	34.7a	39.3a	46.4a	50.4a	59.3a	51.4a	45.4a	58.3a	54.1a
Loblolly	13.3a	14.5a	25.6a	39.1a	38.8a	46.3a	47.1a	45.9a	56.0a	55.0ab
	H									
Slash	17.8ab	19.5b	31.9a	43.6a	47.3a	56.6a	49.3a	40.5a	53.7a	49.8a
Loblolly	15.3a	13.9a	23.6a	38.5a	43.4a	51.2a	45.1a	44.8a	57.2a	60.4a
	F + H									
Slash.	17.2ab	23.0ab	35.1a	46.5a	48.4a	58.1a	49.0a	43.2a	55.2a	45.9a
Loblolly	15.1a	13.7a	25.5a	37.7a	44.9a	53.8a	47.9a	45.8a	60.3a	56.4ab
	Overall									
Slash	17.9aCD[2]	23.0aCD	32.2aBC	44.4aAB	45.7aAB	54.1aA	49.0aA	42.9aAB	54.6aA	49.3aA
Loblolly	14.2aEF	12.8aF	22.5bE	36.3bD	41.4aCD	48.3aBC	45.5aCD	44.1aCD	58.2aA	56.1aAB

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Specific gravity in the lower stem did not appear to be associated with tree size or crown height. The specific gravity of rings 6-10 was not significantly correlated with tree DBH, total height, or height to live crown (Table 5).

The intensive cultures previously reported not to have significantly changed specific gravity (Clark and Saucier 1991 a) were not as intensive as the treatments applied in this study. F here was a complete fertilizer formulation applied several times a year for eight years beginning at establishment. Similarly, H was complete vegetation control from the beginning using herbicides and mechanical means.

The increased volume and weight yields (wood + bark) from intensive culture may be supplemented by favorable changes in bark volume and weight. In contrast to this study, for 11-year-old loblolly pine in Louisiana of virtually the same size as the F+H cultured loblolly here, Tiarks and Haywood (1993) found that fertilizer and competition control increased wood weight per stem volume by 2.8% and decreased bark volume by 15%.

Table 5. Wood specific gravity and ring diameter and basal area for ring ages six to 10 years and height to live crown at age 11 years for slash pine progenies 1-56, 6-56, 106-56, and 183-58 and a loblolly pine seed orchard bulklot and wood specific gravity, moisture content, and ring basal area for rings one to 13 years for slash and loblolly nine bulklots grown at four cultural levels.

	Ring Ages 6 to 10 Years			Height	Ring Ages 1 to 13 Years		
Genetic Entry	Specific Gravity (g/cm3)	Ring Diameter (cm)	Ring Basal Area (sq. cm)	to Live Crown (m)	Specific Gravity (g/cm3)	Moisture Content (%)	Ring Basal Area (sq. cm)
				C - - - -			
1-56	.534	5.14	8.99	4.84			
6-56	.497	6.34	14.18	5.25			
106-56	.553	5.96	11.81	4.98			
183-58	.545	5.42	10.43	5.28			
Slash	.533'			5.08.	.541a	90.7a	.111c
Loblolly	.503	6.10	8.46	2.45	.538a	89.1a	.069d
				F - - - -			
1-56	.509	5.50	14.97	6.51			
6-56	.508	6.10	18.35	7.18			
106-56	.562	5.50	16.14	6.77			
183-58	.536	6.09	18.39	6.93			
Slash	.529			6.85	.546a	86.9a	.159b
Loblolly	.512	6.86	20.99	7.64	.518a	95.3a	.155c
				H - - - -			
1-56	.544	5.07	14.59	6.78			
6-56	.525	5.48	16.43	7.46			
106-56	.574	5.36	15.79	7.04			
183-58	.580	5.63	17.37	6.99			
Slash	.556			7.07	.532a	92.2a	.160b
Loblolly	.557	5.64	15.92	5.30	.540a	90.2a	.191b
				F + H - -			
1-56	.518	5.13	17.14	7.24			
6-56	.515	6.31	24.40	7.50			
106-56	.541	4.95	17.21	7.11			
183-58	.542	5.85	20.62	7.24			
Slash	.529			7.27	.514a	92.9a	.221a
Loblolly	.508	5.45	17.53	7.72	.503a	102.7a	.256a
				Overall - -			
Slash	.536A2			6.59A	.533A	90.7B	.168A
Loblolly	.520A			5.45A	.525A	94.3A	.163A

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[2]Species means within a trait not sharing an upper case letter are significantly different at the 5% level by Duncan's Multiple Range Test

Genetic variation may provide opportunities for combining desirable wood properties with fast growth and disease resistance. In five- and six-year-old loblolly pine, provenances and families differed in date of height growth cessation and date of latewood transition, and significant correlations were evident for later height growth cessation, later latewood transition, and lower wood specific gravity (Jayawickrama et al. 1995). In a wide sampling of loblolly families and sites, large family differences in wood density were observed, stem volume was slightly negatively correlated with wood density, and sites had a major impact on density (Belonger et al. 1996). Transition age to mature wood is heritable in loblolly pine (Loo et al. 1985). Slash pine progenies such as 106-56 and 183-58 that continue to form dense wood under intensive culture hold such potential, whereas progeny 6-56 demonstrates a very responsive genotype that does not mediate culture-induced change in wood density.

Clark and Saucier (1991a) identified that initial planting density, thinning regime, and rotation length influence wood properties and that length of growing season (latitude or geographic location) affects duration of juvenility. They suggest that plantations need to be managed for No. 2 or better lumber.

Lumber yield is influenced by the formation of clear mature wood (Clark and Saucier 1991b). Initial planting density (to control the diameter of the juvenile wood core and branch diameter and to encourage pruning), thinning regimen (to promote the production of clear wood along the lower stem), and rotation length (to increase the volume of mature wood along the stem) are silvicultural tools to influence the yield of high quality lumber in plantations. When applied to the intensively cultured slash and loblolly pines planted at 1,500 trees/ha in this study, these guidelines would call for a thinning at a relatively young age, perhaps seven years in slash pine and nine years in loblolly pine. Wood accumulation after these ages would be largely mature wood on stems with few branches.

CONCLUSIONS

Latewood percent, which increased from ages 4 to 13 years, tended to increase with intensive culture, particularly in slash pine. Under the intensive cultures, slash pine formed mature wood starting at age seven, whereas intensive culture of loblolly pine did not typically result in >50% latewood until nine years. No slash pine progeny formed mature wood before age seven, but two progenies tended to deposit more latewood at all ages. Variation among slash pine progenies may provide opportunities for combining desirable wood properties with fast growth and rust resistance. Progenies such as 106-56 and 183-58 that continue to form dense wood under intensive culture hold such potential, whereas progeny 6-56 demonstrates a very responsive genotype that does not mediate culture-induced change in wood density.

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