Impact of vegetation control and annual fertilization on properties of loblolly pine wood at age 12

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Abstract

Loblolly pine (*Pinus taeda* L.) stands in the Coastal Plain and Piedmont of Georgia were subjected to four intensive silvicultural regimes to monitor and record relative tree growth. Treatments included: intensive mechanical site preparation, complete vegetation control with multiple applications of herbicides, annual high rates of nitrogen fertilization, and complete vegetation control plus annual high rates of nitrogen fertilization. In response to the intense cultural practices, growth increased 270 percent in the Coastal Plain and 158 percent in the Piedmont compared to the intensive mechanical site preparation treatment. Increment cores were collected from trees at age 12 to determine the effect of treatments on earlywood and latewood specific gravity (SG) and duration of juvenility. Trees were also felled to determine the impact of intensive cultural practices on wood stiffness, strength, and toughness. Annual vegetation control plus annual high rates of nitrogen fertilization increased the diameter of the juvenile wood core 62 percent and thus, the proportion of stem basal area in juvenile wood. Annual ring earlywood SG was not affected by treatments, but annual ring latewood SG was significantly reduced in fertilized and herbicide plus fertilized trees. Vegetation control did not significantly affect SG, strength, stiffness, or toughness but did significantly increase the juvenile core-wood diameter. Annual fertilization alone or in combination with vegetation control reduced weighted stem SG 6 to 10 percent compared to that of the trees receiving only the mechanical site preparation treatment. Annual heavy fertilization alone or in combination with vegetation control significantly reduced toughness, as well as strength and stiffness of juvenile wood. Thus, wood harvested from stands that since planting received annual vegetation control plus annual high rates of nitrogen fertilization would be less desirable for structural lumber production compared to wood from conventionally managed and planted loblolly pine stands.

The wood products industry is using herbicides to control competing vegetation, as well as fertilizers to increase growth in southern pine. In 1987, a long-term monitoring study was established to determine the growth potential of loblolly pine (*Pinus taeda* L.) in the southeastern United States (Borders and Bailey 2001). Very intensive cultural practices were applied including intensive mechanical site preparation, complete vegetation control with multiple applications of herbicides, annual high rates of nitrogen fertilization, and complete vegetation control plus annual fertilization. Borders and Bailey (2001) report that growth increased up to 270 percent in response to the intensive cultural treatments. Volume mean annual increment at age 12 for the trees receiving complete vegetation control plus annual fertilization was 325 to 490 $ft.^3$ of wood per acre per year, growth rates which are comparable to the best loblolly pine growth anywhere. It was concluded that growth rates in loblolly pine plantations under conventional management in the southeastern United States (100 to

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Forest Prod. J. 54(12):90-96.

150 ft.^{3}/acre) fall short of their potential and that intensive cultural practices would be economically beneficial.

If the wood products industry were to apply such intensive cultural practices, officials in the private sector would want to understand how these treatments affect juvenile and mature wood formation and wood properties. The use of herbicides to reduce competing vegetation in a pine plantation will increase soil moisture and the amount of nutrients available for pine growth. Thus, competition control may significantly influence the proportion of earlywood and latewood tracheids produced. Fertilization at planting or during the first few years of growth, especially if combined with vegetation control, has been shown to decrease specific gravity (SG) and percent latewood (Larson et al. 2001). If fertilization treatments are heavy or frequently repeated, SG and percent latewood may be reduced significantly (Posey 1964). The Borders and Bailey (2001) study was sampled to determine the effects of intensive mechanical site preparation, complete vegetation control with multiple applications of herbicides, annual high rates of nitrogen fertilization, and complete vegetation control plus annual heavy fertilization treatments on SG of earlywood and latewood, proportion of latewood, and length of juvenility. The impact of these intensive practices on stemwood SG, moisture content (MC), stiffness, strength, and toughness were also investigated.

Procedures

The Borders and Bailey (2001) long-term growth study sampled was conducted in 1987 in the Lower Coastal Plain at two locations on the Dixon State Forest near Waycross, Georgia, and in 1988 in the Piedmont at two locations on the B.F. Grant Experimental Forest near Eatonton, Georgia. The study is a randomized complete-block design with four treatments randomly assigned to two blocks at each location in each physiographic region. The following treatments were applied to 3/8-acre plots:

H Herbicide used to control all woody and herbaceous competing vegetation throughout the life of the study

F Fertilize as follows:
First two growing seasons—250 lb./acre DAP plus 100 lb./acre KCL in the spring and 50 lb./acre of ammonium nitrate midsummer.
During each subsequent growing season—150 lb./acre ammonium nitrate early to late spring

HF Herbicide plus annual fertilizer treatment

C Control: intensive mechanical site preparation only.

The study was installed on recently cutover forestland and hand planted with 1-0 improved loblolly seedlings at about 680 trees per acre. Seedlings planted in the Coastal Plain were from the genetically improved half-sib family 7-56, and seedlings planted in the Piedmont were from the half-sib family 10-25.

Coastal Plain locations for wood properties in the winter of 1999 at age 12, and the Piedmont locations in the winter of 2000 at age 12 were sampled. Increment cores (12-mm diameter) were collected at breast height (4.5 ft. above the ground) from 20 trees in each treatment plot within each block for a total of 40 trees per treatment per location or 80 trees per treatment per physiographic region. Trees were selected for boring in proportion to diameter at breast height (DBH) distribution in each plot. Four of the trees bored in each plot were destructively sampled based on the DBH distribution for physical and mechanical wood properties analysis (**Table 1**). Cross-sectional disks 1-1.5 inches thick were cut at 3 feet and 8 feet and at 8-foot intervals to a 1-inch diameter outside bark top for stemwood and bark SG, MC, and green weight of wood and bark per cubic foot determination. SG was determined on a green volume and ovendry weight basis. MC was determined on a green weight and ovendry basis. Weighted stem SG, MC, and green weight per cubic foot were calculated by weighting disk values in proportion to the cross-sectional area of the disk.

Two 2-foot bolts were cut at 3-, 8-, 16-, and 24-foot heights, and the wood in each bolt was sampled for toughness, strength (modulus of rupture [MOR]) and stiffness (modulus of elasticity [MOE]). A 1.5-inch-thick slab was cut from bark to bark through the pith for processing into static bending samples; and one radii slab was cut from each bolt for processing into toughness samples. The static bending and toughness slabs were kiln-dried to 12 percent equilibrium moisture content (EMC). After drying the slab, two clear static bending samples, 1 by 1 by 16 inches, were cut from juvenile wood, and two samples were cut from mature wood. Juvenile wood samples were cut from rings 2 through 4, and mature wood samples were cut next to the bark at height levels containing mature wood. Toughness samples 5/8 by 5/8 by 10 inches were cut in consecutive order from the pith to the bark from one radii.

The increment cores were dried, glued to core holders, and sawn into 0.078-inch strips. SG of earlywood and latewood from each annual ring for each radial strip was determined at 0.0024-inch intervals using an x-ray densitometer with a resolution of 0.00001. A SG value of 0.480 was used to distinguish earlywood from latewood. The densitometer was calibrated to express SG on a green volume and ovendry weight basis. The age of demarcation between ju-

Table 1. — Average characteristics of loblolly pine trees destructively sampled for wood properties by physiographic region and treatment.

	Characteristics				
Treatment	Sample trees	Average DBH	Range of DBH	Average total height	Range of height
	(no.)	- - - - - - - - (in.) - - - - - - - -		- - - - - - - - (ft.) - - - - - - - -	
			Coastal Plain region		
Control	16	6.1	4.1 to 8.4	47	37 to 62
Herbicide	16	7.1	6.4 to 8.3	53	47 to 61
Fertilize	16	8.4	6.6 to 10.5	62	54 to 69
Herb/Fert	16	7.9	6.5 to 9.0	62	52 to 69
			Piedmont region		
Control	16	5.9	5.3 to 6.5	44	38 to 56
Herbicide	16	6.8	5.4 to 8.2	49	43 to 55
Fertilize	16	7.0	6.1 to 8.4	50	37 to 56
Herb/Fert	16	7.9	7.0 to 9.0	55	48 to 62

venile and mature wood was determined using the fixed-species definition method. The transition from juvenile to mature was defined as the year in which ring SG was ≥ 0.48 and percent latewood was greater than 40 percent for two consecutive annual rings.

The 1- by 1- by 16-inch clear static bending samples were tested at 12 percent EMC over a 14-inch span with center loading and pith up on a Tinius Olsen Test Machine following the procedures for alternate sample size under ASTM D-143 (ASTM 1980). A continuous load was applied at a head speed of 0.07 inches per minute, rather than 0.05 inches per minute to reduce test time. Preliminary tests showed specimens failed primarily in compression with no defined break or tension failure. After testing, each sample was ovendried at 103°C, and SG was calculated based on specimen dimensions at 12 percent EMC and ovendry weight. MOE and MOR were calculated using procedures outlined in ASTM D-143 (ASTM 1980).

The 5/8- by 5/8- by 10-inch clear toughness samples were tested at 12 percent EMC over an 8-inch span in a radial direction on a Wiedemann Baldwin Toughness Machine®. Toughness was calculated using the following equation (USDA 1941):

$$T = W \times D\,(\cos A2 - \cos A1) \quad [1]$$

where:

T = toughness of specimen (in.-lb.),
W = weight of pendulum (lb.),
D = distance from the center of the supporting axis to the center of gravity of the pendulum (in.),
A1 = initial angle pendulum, and
A2 = final angle the pendulum makes with the vertical after specimen failure.

After testing, each sample was ovendried at 103°C and SG was calculated based on specimen dimensions at 12 percent EMC and ovendry weight.

An analysis of variance (ANOVA) was run on the data to determine the effect of physiographic region and treatment on weighted stem SG, MC, weight per cubic foot, MOE, MOR, and toughness. The ANOVA was run on juvenile and mature wood property annual ring and specimen averages for each tree.

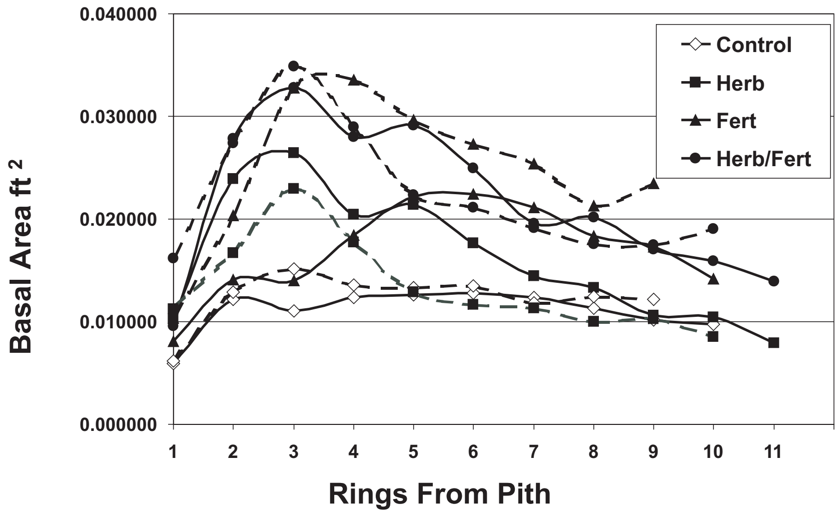

Figure 1. — Average ring basal area growth over rings from pith by treatment for 12-year-old loblolly pine sampled in the Piedmont (solid line) and Coastal Plain (dash line) regions.

MOE and MOR of juvenile and mature wood were analyzed separately because it was assumed that there was a significant difference between the two. An ANOVA showed no significant difference in wood properties between locations within a region, thus the two blocks or repetitions at each location were pooled and treated as four blocks within a region. Treatment and region effects were assumed to be fixed and block effects assumed to be random. The statistical design included:

a = Regions: Coastal Plain versus Piedmont
r = Blocks: four blocks per region
b = Treatments: C, H, F, HF
s = Trees: four trees per treatment per block

The general form of the ANOVA was:

Source	Degree of freedom	df
Regions	$a - 1$	1
Blocks (regions)	$a(r - 1)$	6
Treatments	$b - 1$	3
Region × Treatments	$(a - 1)(b - 1)$	3
Blocks × Treatments (region)	$a(r - 1)(b - 1)$	18
Trees (Region × Block × Treatment)	$abr(s - 1)$	93

Statistical differences between regions was tested using Blocks(Regions) as the error term and differences among Treatments and Region × Treatment were tested using Blocks × Treatments (Region) as the error term.

Results and discussion

Total competition control and annual high rates of nitrogen fertilization significantly increased ring basal area growth in the Coastal Plain and Piedmont compared to that of trees receiving intensive site preparation only, based on breast-height increment core annual ring measurements (**Fig. 1**). Trees receiving the F treatment in the Coastal Plain and HF treatments in the Piedmont produced the largest annual basal area growth. Plots of cumulative basal area growth (**Fig. 2**) show that the increase in growth in response to the intensive cultural treatments continued through age 12. The F and HF trees in the Coastal Plain and HF trees in the Piedmont were growing fastest and the C trees in both regions were growing the slowest.

In both regions, intensive cultural treatments significantly increased annual radial growth in the first four years after planting (**Fig. 1**), thus increasing the juvenile wood-core diameter and proportion of basal area in juvenile wood (**Table 2**). In the Coastal Plain, F and HF treatments both increased the juvenile wood-core diameter by 62 percent. In the Piedmont, the increase was not as great for the F treatment (31%), but HF treatment increased the juvenile wood-core diameter by 62 percent over the C treatment.

Plots of ring SG over rings from pith show the normal juvenile/mature wood formation pattern for all treatments with low SG, core-formed wood formed in the first few rings, followed by a rapid

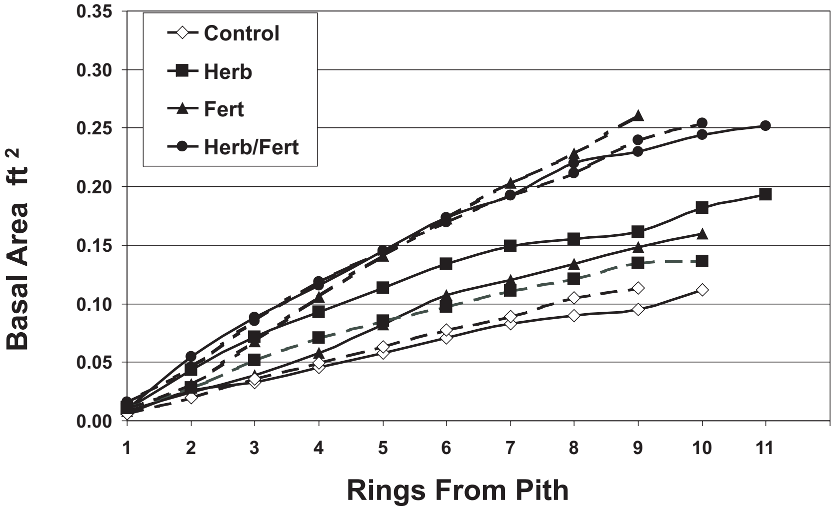

Figure 2. — Average cumulative basal area growth over rings from pith by treatment for 12-year-old loblolly pine sampled in the Piedmont (solid line) and Coastal Plain (dash line) regions.

Table 2. — Effect of intensive silvicultural treatment on diameter of juvenile wood at DBH, proportion of tree wood basal area in juvenile wood, and average juvenile and mature wood ring SG by treatment and physiographic region for 12-year-old loblolly pine.[a]

Treatment	Length of juvenility	Juvenile wood core diameter	Proportion of basal area in juvenile wood	Juvenile wood ring specific gravity	Mature wood ring specific gravity
	(years)	(in.)	(%)		
			Coastal Plain region		
Control	4	2.9	33	0.41a	0.56ac
Herbicide	4	3.5	33	0.40a	0.57a
Fertilize	5	4.7	43	0.41a	0.53b
Herb/Fert	5	4.7	50	0.40a	0.54bc
			Piedmont region		
Control	6	3.9	64	0.41a	0.53ab
Herbicide	6	4.6	65	0.41a	0.55a
Fertilize	7	5.1	74	0.41a	0.48c
Herb/Fert	7	6.3	89	0.40a	0.49bc

[a] Within a property and region, values with a different letter are statistically different at the 0.05 level.

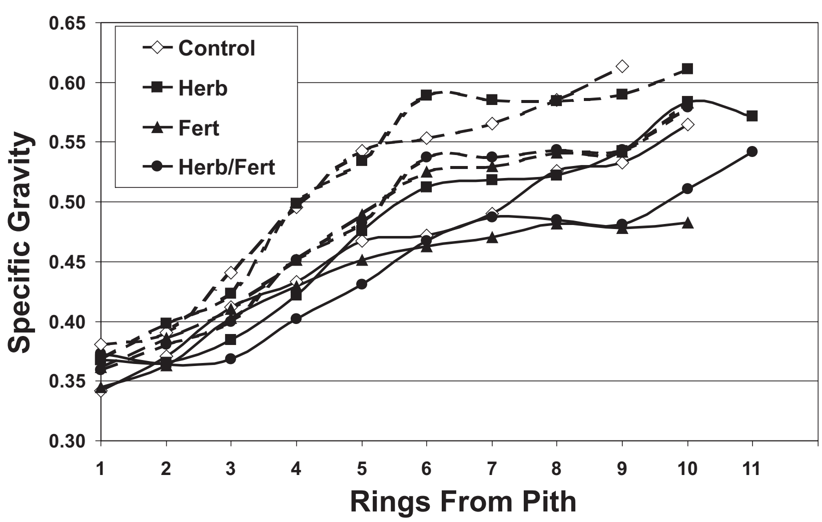

Figure 3. — Average ring SG over rings from pith by treatment for 12-year-old loblolly pine sampled in the Piedmont (solid line) and Coastal Plain (dash line) regions.

increase in SG in the transition zone, followed by high SG in mature wood (**Fig. 3**) (Bendtsen and Senft 1986, Zobel et al. 1959). Based on the criteria used in this study to define the transition from juvenile to mature wood, H and C trees in the Coastal Plain were on average producing mature wood by ring 5, and the F and HF trees by ring 6 (**Table 2**). In the Piedmont, C and H trees were producing mature wood by ring 8, and F and HF trees started producing mature wood in ring 9. On average, annual ring SG was higher for all treatments in the Coastal Plain (**Fig. 3**). In both the Coastal Plain and Piedmont, F and HF trees had a lower ring SG than the H and C trees.

Annual ring mature wood SG for the F trees was significantly lower than that of the H or C trees in the Coastal Plain and Piedmont (**Table 2**). Average ring latewood SG varied significantly among treatments ($p = 0.0001$) (**Fig. 4**) but did not vary significantly between physiographic regions ($p = 0.2955$). The lower SG of latewood in the F trees (**Fig. 4**) apparently is caused by reduced secondary wall thickening of latewood tracheids in the fast-growing F trees, not a reduction in percent latewood in the annual ring within a region (**Fig. 5**). The primary reason for geographic variation in loblolly pine wood SG is the proportion of the annual ring that is in late wood (Clark and Daniels 2003). The proportion of late wood is moderately correlated with seed source and highly correlated with climatic conditions (Cregg et al. 1988). Percent latewood was significantly higher for all treatments in Coastal Plain trees than in Piedmont trees (**Fig. 5**). Coastal Plain loblolly pine has a higher proportion of latewood because of the higher summer precipitation and longer growing season compared to the Piedmont (Clark and Daniels 2003). The slightly higher proportion of latewood in the H trees probably is due to the increased soil moisture resulting from reduced vegetation competition. Plots of increment core annual ring earlywood SG over rings from pith showed earlywood ring SG did not vary significantly between physiographic regions ($p = 0.0908$) or among treatments ($p = 0.4273$), and that earlywood SG does not change with ring number from pith.

Weighted stem wood SG and wood MC based on cross-sectional disks were significantly different between regions and between treatments (**Tables 3 and 4**). Average stem wood SG was 5 percent higher and average stem MC was 6 percent lower in the Coastal Plain compared to the Piedmont. The F and HF treatments significantly reduced weighted stem wood SG compared to that of the H and C treatments of trees sampled in both regions (**Table 4**). This 6 to 10 percent reduction in weighted stem SG is due to the significant increase in volume of low SG juvenile wood and lower mature wood latewood SG in the F and HF trees. Trees in the Coastal Plain receiving F and HF treatments also had significantly higher stem wood MC than H and C treated trees. The intensive cultural practices did not significantly influence MC of trees in the Piedmont. Green weight per cubic foot of wood did not vary significantly between regions or treatments, because the high MC of the Piedmont trees compensated for low SG. The ANOVA showed no significant difference in green weight of wood and bark per cubic foot of wood between regions, but it did show a significant difference between treatments (**Table 3**). The F and HF trees had a significantly lower green weight of wood and bark (**Table 4**) than the C trees, because the F and HF trees were larger in diameter (**Table 1**) and therefore had a smaller proportion of their weight in bark (10% versus 13% bark, respectively).

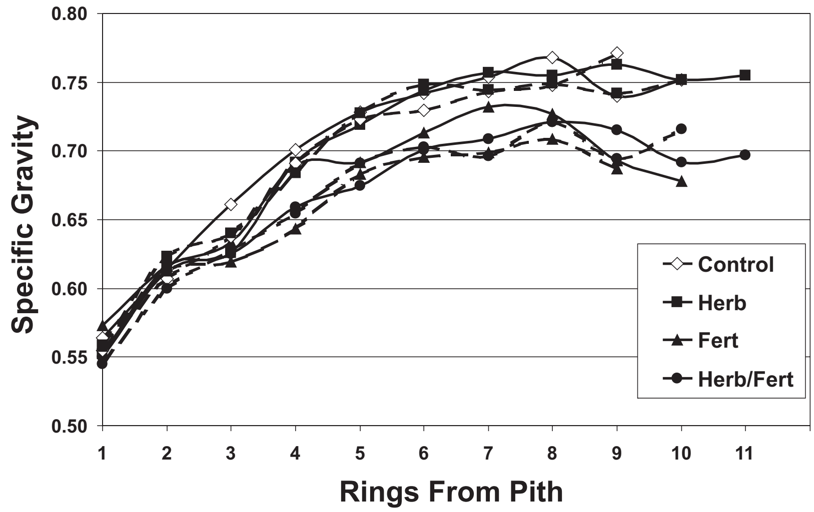

Figure 4. — Average ring latewood SG over rings from pith by treatment for 12-year-old loblolly pine sampled in the Piedmont (solid line) and Coastal Plain (dash line) regions.

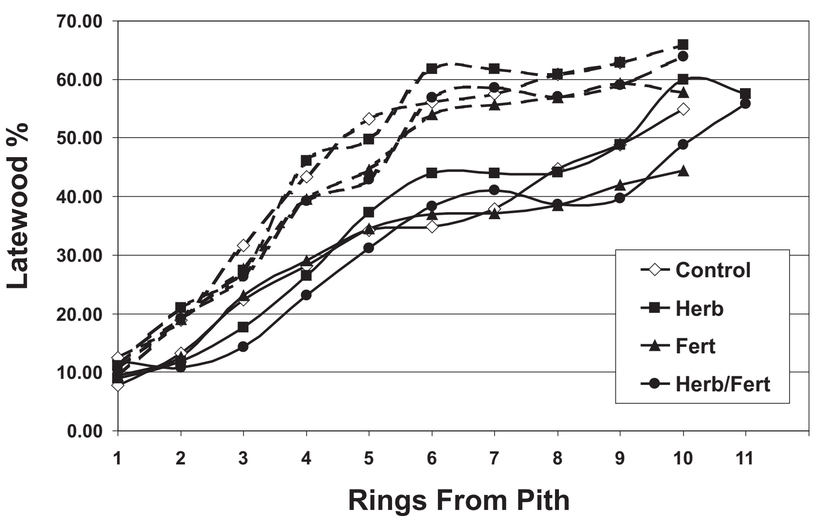

Figure 5. — Average proportion of ring in latewood over rings from pith by treatment for 12-year-old loblolly pine sampled in the Piedmont (solid line) and Coastal Plain (dash line) regions.

Average tree toughness was significantly higher in the Coastal Plain compared to the Piedmont and varied significantly among treatments (**Table 3**). Toughness decreased with increasing cultural treatment in both regions, and toughness of the HF trees was 30 to 33 percent lower than that of the C trees (**Table 5**). Wood toughness is highly correlated with SG and average toughness specimen SG was significantly lower in the F and HF trees than in the C trees, because these treatments increased the diameter of the low SG juvenile wood core significantly. For that reason, a higher proportion of the toughness samples were cut from juvenile wood.

Wood strength is highly correlated with SG, and wood stiffness with both SG and microfibril angle (Larson et al. 2001). Thus, MOR and MOE of juvenile wood are consistently lower than that of mature wood (Larson et al. 2001) as is shown in **Table 6**. The significant reduction in stem SG associated with the HF treatment (**Table 4**) resulted in a significant (p = 0.0171) reduction in juvenile wood average strength. Juvenile wood strength of Coastal Plain and Piedmont trees was reduced 9 percent and 10 percent, respectively, in the HF trees compared to the C trees. Mature wood strength in the HF trees was reduced on

Table 3. — Probabilities of a greater F-value for physiographic region, treatment, and region x treatment effects on wood properties.

Source	Df	Stem wood SG	Stem MC	Wood weight per ft.^{3}	Wood and bark weight per ft.^{3}	Toughness	MOE Juvenile	MOE Mature	MOR Juvenile	MOR Mature
Region	1	0.0195	0.0306	0.2468	0.9816	0.0001	0.0089	0.3165	0.0773	0.2268
Treatment	3	0.0002	0.0049	0.0912	0.0002	0.0002	0.0165	0.9097	0.0171	0.7646
Reg × treat	3	0.3188	0.2902	0.6463	0.4421	0.8263	0.1846	0.9093	0.3234	0.8084

Table 4. — Average weighted stem wood SG, MC, and weight per cubic foot for 12-year-old loblolly pine sampled in the Coastal Plain and Piedmont regions by treatment.[a]

Treatment	Stem specific gravity		Stem moisture content		Weight of wood per ft.^{3} wood		Weight of wood and bark per ft.^{3} wood	
	Coastal	Piedmont	Coastal	Piedmont	Coastal	Piedmont	Coastal	Piedmont
			(%)		(lb.)			
Control	0.48a	0.45a	117a	130a	63.7a	63.6a	72.2a	73.5a
Herbicide	0.48a	0.44a	115a	129a	63.8a	62.5a	71.6ac	70.4ab
Fertilize	0.43b	0.42b	139b	137a	63.9a	62.3a	69.9bc	69.9ab
Herb/Fert	0.44b	0.42b	129b	138a	63.1a	61.7a	68.8b	68.7b

[a] Within a property and region, values with a different letter are statistically different at the 0.05 level.

Table 5. — Average stem toughness, specimen SG, and number of annual rings per specimen by treatment for 12-year-old loblolly pine sampled in the Coastal Plain and Piedmont regions.[a]

Treatment	Trees sampled	Stem toughness	Specimen SG[a]	No. rings per specimen
		(in.-lb.)		
		Coastal Plain region		
Control	13	239a	0.54a	2.0
Herbicide	16	198ab	0.51ab	2.0
Fertilize	16	191ab	0.48b	1.5
Herb/Fert	16	166b	0.49b	1.8
		Piedmont region		
Control	16	160a	0.49a	2.6
Herbicide	16	129ab	0.44b	2.0
Fertilize	16	120ab	0.45b	2.0
Herb/Fert	16	107b	0.42b	1.8

[a] Within a property and region, values with a different letter are statistically different at the 0.05 level.

Table 6. — Average MOE, MOR, and specimen SG for juvenile and mature wood by treatment for 12-year-old loblolly pine sampled in the Coastal Plain and Piedmont regions.[a,b]

Treatment	Trees sampled	MOE	MOR	SG
		(mill psi)	(psi)	
		Coastal Plain juvenile wood		
Control	15	0.80a	9,021a	0.40a
Herbicide	16	0.78a	8,472a	0.39a
Fertilize	16	0.68b	7,776a	0.37b
Herb/Fert	16	0.75ab	8,202a	0.37b
		Piedmont juvenile wood		
Control	16	1.04a	8,506a	0.41a
Herbicide	16	0.78a	8,067a	0.39ab
Fertilize	16	0.76a	8,104a	0.40ab
Herb/Fert	16	0.72a	7,627a	0.38b
		Coastal Plain mature wood		
Control	6	1.04a	12,622a	0.60a
Herbicide	12	1.21a	13,231a	0.60a
Fertilize	16	1.22a	12,809a	0.54b
Herb/Fert	14	1.17a	12,182a	0.54b
		Piedmont mature wood		
Control	3	1.26a	12,288a	0.53ab
Herbicide	8	1.22a	12,534a	0.56b
Fertilize	12	1.25a	11,699a	0.52a
Herb/Fert	16	1.30a	11,398a	0.50a

[a] Values are for 1- by 1-inch clears tested at 12 percent MC.
[b] Within a property and region, values with a different letter are statistically different at the 0.05 level.

average 4 percent in the Coastal Plain and 7 percent in the Piedmont in compared to the C trees (**Table 6**). Average tree juvenile wood MOE varied significantly between regions ($p = 0.0089$) and among treatments ($p = 0.0165$), but mature wood MOE did not vary significantly among regions or treatments. Juvenile wood MOE of the F trees was significantly lower than that of the C trees in the Coastal Plain (**Table 6**). In Piedmont trees, the juvenile wood MOE of F and HF trees was lower than C trees but not significantly lower. MOE of mature wood in both regions did not vary significantly among treatments.

Conclusions

Wood properties of 12-year-old loblolly pine trees responded in the same manner in the Lower Coastal Plain and Piedmont of Georgia to intensive mechanical site preparation, complete vegetation control with multiple applications of herbicides, annual high rates of nitrogen fertilization, and complete vegetation control plus annual fertilization. Trees that received complete vegetation control, annual fertilization and competition control plus fertilization grew faster and were significantly larger than the trees that received only the mechanical site preparation treatment. The intensive cultural treatments significantly increased the diameter of the low SG juvenile wood core and thus increased the proportion of stem basal area in juvenile wood. Annual ring earlywood SG was not affected by the cultural treatments, but annual ring latewood SG was significantly reduced in fertilized and herbicide plus fertilized trees. Vegetation control alone did not significantly affect SG, strength, stiffness, or toughness; but it did increase the diameter of the juvenile core. Annual high rates of nitrogen fertilization alone or in combination with vegetation control reduced weighted stem SG 6 to 10 percent compared to that of the trees that received only the mechanical site preparation treatment. Annual fertilization in combination with vegetation control reduced toughness 30 to 33 percent compared to trees that received only mechanical site preparation. The strength of juvenile wood was reduced 9 to 10 percent and mature wood strength was reduced 4 to 7 percent in trees receiving annual fertilization in combination with vegetation control compared to the trees that received only mechanical site preparation. Annual fertilization in combination with vegetation control significantly reduced stiffness of juvenile wood but not that of mature wood and increased the diameter of the juvenile wood core by 31 percent or more. Coastal Plain trees receiving intensive treatments had a smaller proportion of juvenile wood, higher SG, and higher toughness than did Piedmont trees because of a shorter juvenile period and higher percentage of latewood

Forest managers can significantly increase growth of loblolly pine with annual vegetation control plus annual high rates of nitrogen fertilization started at stand establishment. However, the wood of these intensively managed trees will contain a significantly high proportion of low SG, weaker, less stiff, juvenile wood. Thus, wood harvested from stands receiving annual vegetation control plus annual high rates of nitrogen fertilization since planting will be less desirable for structural lumber production.

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