EFFECT OF INTENSIVE FOREST MANAGEMENT PRACTICES ON WOOD PROPERTIES AND PULP YIELD OF YOUNG, FAST GROWING SOUTHERN PINE

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ABSTRACT

The demand for southern pine fiber is increasing. However, the land resources to produce wood fiber are decreasing. The wood industry is now using intensive cultural treatments, such as competition control, fertilization, and short rotations, to increase fiber production. The impact of these intensive environmental treatments on increased growth is positive and significant, but their effects on wood properties, pulp yields, and paper properties is not well known. This paper presents research on the effect of planting density and herbaceous competition control of 14 year loblolly pine in the Piedmont and herbaceous competition control and fertilization of 17 year slash pine in the Coastal Plain on wood properties and pulp yield. Thirty-two trees of small sawlog size were harvested from each treatment and processed into lumber and residual chips using a chipping saw (CNS). Trees were also harvested from a 24 year operational loblolly plantation in the Piedmont and 24 year slash pine plantation in the Coastal Plain as controls. Specific gravity, moisture content, percent latewood, chip size and fiber length were analyzed for each treatment. The CNS chips were processed into pulp at 90 Kappa for linerboard and 60 Kappa for sack paper, and pulp yields are reported.

INTRODUCTION

The wood industry faces many challenges in the coming decade. Reduced acreage for production of wood fiber and changing environmental policies will require more fiber production from fewer acres. The pressure to produce more wood fiber is leading to intensively managed plantations, which generally accelerate the early growth of the trees and reduce rotation length to maximize return on investments. The wood industry is now using intensive cultural treatments such as competition control, fertilization, and planting of genetically improved seedlings to increase fiber production, The impact of these intensive environmental treatments on increased growth is positive and significant, but their effects on wood properties, pulp yields, and paper properties is not well known.

This study is part of a comprehensive effort to examine the effects of planting density, competition control and fertilization on wood properties, chip characteristics, and pulp and paper yields for 14 to 17 year old southern pines. Chip characteristics and pulp yields were determined for chips representing the whole stem (butt to 5 cm top), chips from topwood (15 cm to 5 cm top) and sawmill residue chips. This paper presents research results on the effect of planting density (988, 1,483, 1,977 trees per hectare) (TPH) and herbaceous competition control of 14 year loblolly pine (*Pinus teada* L.) in the Piedmont, and herbaceous competition control and fertilization of 17 year slash pine (*P. elliottii* Engelm. *var.elliottii*) in the Coastal Plain on wood properties, chip characteristics, and pulp properties of the CNS chips. Specific gravity, moisture content, chip size and fiber length are presented. The CNS chips were processed into pulp with the total yields reported at a target kappa no. of 90 for linerboard and 60 for sack paper.

LITERATURE REVIEW

Typical loblolly pine plantations in Southeast United States produce 4.9 to 8.0 m^3/hectare/year of wood. However, research (5) has shown that with intensive management practices, such as complete competition control, multiple fertilizations, and genetically improved stock, these growth rates can be increased to 15 to 25 m^3 of wood/hectare/year. These growth rates compare well with the fastest growing loblolly pine anywhere in the world (5).

The definition of southern pine wood quality depends on the type of product for which the wood is used. High specific gravity is almost universally considered a desirable wood quality trait. High specific gravity is positively correlated with wood strength and stiffness. Wood from young, fast-growing pine plantations often has physical and mechanical properties that make it less desirable than older, slower grown wood for structural lumber because of large volumes of low specific gravity juvenile wood (1, 2, 3, 4, 11, 14). Wood and fiber properties that affect paper-making include specific gravity, cellulose percent and other chemical constituents, fiber length and microfibril angle (9, 12, 17, 20). For pulp and paper, higher specific gravity results in higher pulp yield and is generally associated with longer fibers with increased strength for packaging papers (linerboard, kraft sack). Paper from juvenile wood pulp will have good tensile, burst, fold and sheet smoothness but lower tear and opacity than paper made from mature wood pulp (20). Wood quality and specific gravity variations associated with earlywood and latewood can significantly affect paper quality (20, 21, 22).

A radial cross-section of a pine stem contains three zones of wood (Fig. 1): (1) core or crown-formed wood, which is produced by immature cambium in the vigorous crown and has anatomical, chemical, and physical properties substantially different from mature wood; (2) transition wood, in a zone where wood properties are changing rapidly before wood reaches maturity; and (3) mature wood. In the spring, radial growth begins at the apex of the bole in the vigorous crown (18, 19) and progresses with time to the base of the tree. Thus, more thin-walled earlywood tissues and wider rings of earlywood are produced in the upper bole in the crown than in the lower bole. The transition to thick-walled latewood tracheids occurs first near the base of the bole, farthest from the source of auxins, and proceeds upward as moisture stress increases and translocation of auxins down the bole decreases (10, 18). As trees grow older and taller and stands close, lower branches cease to be vigorous, and the lower boundary of the active crown moves up the stem. Therefore, there is a core of crown-formed wood around the pith surrounded by a band of transition wood from the butt to the merchantable top of the tree and a wide outer band of mature wood (2). Both crown-formed and transition wood are commonly referred to as juvenile wood.

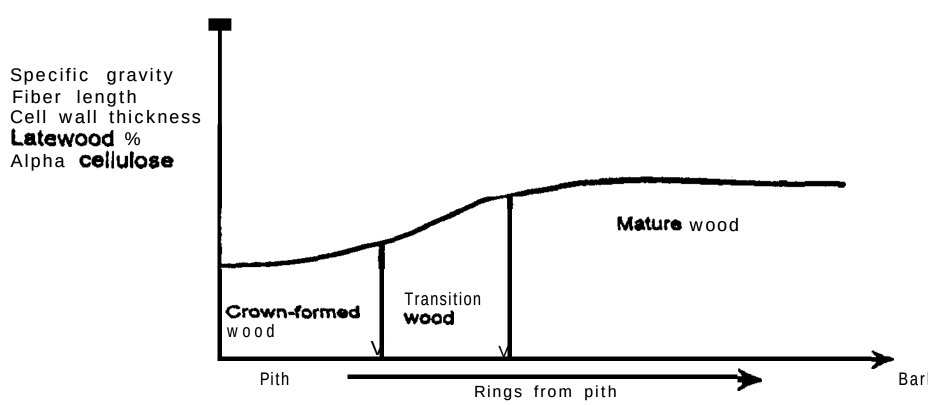

Figure 1. Schematic diagram of radial change in wood properties with age from pith and the pattern of maturation.

Planting density or spacing significantly influences the proportion of stem basal area in juvenile wood but not the age of transition from juvenile to mature wood (6). It has also been shown that the juvenile period does not differ between slash and loblolly pine when the species are planted at the same location, but does vary with geographic location. The length of the juvenile period of slash and loblolly pine in the Southeast decreases geographically from north to south. In loblolly and slash pine, the period of juvenile wood formation decreases from 10 to 14 years in the Piedmont to 6 to 8 years in the Gulf Coastal Plain (6). In a study by Cregg and others (7) it was observed that the transition from earlywood to latewood occurred one month earlier in a year of low rainfall and high spring evaporate demand than in a year of low evaporate demand and high rainfall. Whether an early transition to latewood leads to an annual ring with a high percentage of latewood, and thus high specific gravity, depends on the growing conditions that occur after the transition to latewood production. Based on Moehring and Ralston's work (13) it appears the moisture supply and pan evaporation in the months of July, August, September, and October control the amount of latewood that is produced. The use of herbicides to reduce competing vegetation in a pine plantation will increase soil moisture and nutrients available for pine growth. Thus, competition control could significantly influence the proportion of earlywood and latewood tracheids produced.

PROCEDURES

Raw-Material Resources

The raw materials for this study were obtained from two accelerated pine growth studies. The slash pine trees came from a study managed by the Plantation Management Research Cooperative (PMRC) administered by the University of Georgia (16). The PMRC initiated the site preparation and soil type study in 1979 in the Coastal Plain. originally 20 sites were established ranging from Savannah, Georgia to Apalachicola, Florida. Currently 16 of the original sites are maintained. When the trees for this study were sampled the slash pine plantations were 17 years of age. Four trees growing under each of two treatments were sampled at 8 of the sites for a total 32 trees per treatment. The following treaments were sampled at each location: 1. Chop, bum, bed, competition control (HERB) 2. Chop, bum, bed, competition control, and fertilization (HERB/FERT). All sites were within an 80 kilometer radius of Jacksonville, Florida. An operational 24-year-old slash pine plantation was selected as a control. The slash control plantation was planted at 1,347 TPH on a site similar to the treatment sites in the same geographic area, was unthinned and received no competition control or fertilization.

The loblolly pine chips were obtained from trees growing in a planting density, competition control study established in 1983 on an old soybean field on the University of Georgia's B.F. Grant Memorial Forest in the Piedmont of Georgia in Putnam County (15). When the loblolly plantation was 14 years old the study plots were marked for thinning. A total of 32 trees from those marked for thinning were selected from each of the following treatments: 988 TPH with, competition control; 1,483 TPH with competition control; 1,977 TPH with competition control. A 24-year loblolly pine plantation in Hancock County, in the Georgia Piedmont was selected as an operational control. The stand was planted in 1973 at 1,495 TPH on an old field and received no herbicides or fertilizer treatments and was thinned to 618 TPH in 1990.

A stratified random sample of trees from 20 to 28 cm DBH (diameter at breast height) was selected from each treatment (Table1). The trees were felled and bucked into 2.6 to 5.2 m sawlogs to a 14 cm dii top. The 130 loblolly trees produced 276 sawlogs and the 96 slash trees produced 195 sawlogs. Three 2.5 cm thick cross sections and a 7.6 cm cross section were removed at the butt and each bucking point to a 5 cm tip, sealed in polyethylene bags, and stored in a freezer. Disk 1 of the 2.5 cm disks was analyzed to determine bark content, wood and bark specific gravity (SG), moisture content (MC), and wood and bark weight per cubic foot. MC was determined on an ovendry weight basis and SG was determined based on a green volume and ovendry weight. Disk 2 of the 2.5 cm disks was used to measure earlywood and latewood of each ring using image analysis. Total annual ring area growth was calculated by summing the ring area for each year of each disk in a tree. The percent latewood of each ring was scanned from pith to bark and a boundary between juvenile and mature wood was marked. A threshold of 40% latewood in a ring was used to determine the boundary between juvenile and mature wood. Disk 3 of the 2.4 cm disks was used for microfibril analysis which is currently being conducted. The 7.6 cm thick cross sections were used to examine chips, pulp and paper properties of the total stem which will be reported in a separate paper.

CHARACTERISTIC	Loblolly Pine				Slash Pine		
	988 TPH	1,483 TPH	1,977 TPH	Control	HERB	HERB/ FERT	Control
TREES SAMPLED (no)	29	35	33	34	32	32	32
AVG DBH (cm)	23.6	23.4	21.8	24.1	21.8	22.1	23.0
RANGE IN DBH (cm)	19.3-28.2	19.3-28.2	19.3-25.1	20.3-29.0	20.1-28.7	19.3-30.0	19.3-27.7
AVG TOTAL HT (m)	18	19	17	22	18	19	19
RANGE IN TOTAL HT (m)	17-19	17-21	1619	17-24	16-21	16-21	16-22

Table 1. Means and Range of sample tree measurement by species **and** treatment

The 471 **sawlogs** were sawn into 2.5 cm boards and 5 by **10** cm and **5** by 15 cm dimension lumber in a sawmill equipped with a chipping **headrig** and horizontal gang resaw. The logs were processed through the mill in batches baaed on silvicultural treatment. The CNS chips produced while sawing each batch of logs were collected and weighed. A random sample of 227 kg of CNS chips was selected **from** each batch of chips. The green chips from each of the 7 treatments were mixed and classified using a chip classifier at the Rayonier Research Center in Jesup, GA. **Only** chips **from** the accept class were used for the pulping studies.

The chips were pulped in a 10 liter digester with liquor circulation and indirect electric heating. The chip charge was 1.5 oven-dry kg. Liquor-to-wood ratio was 4: 1 with a **sulfidity** of 25%. The active alkali charge was typical for the pulp grade being produced.

Two pulp grades were produced from each chip sample. These were nominally 90 kappa no. (linerboard) and 60 kappa no. (sack paper). For each grade, an appropriate H-factor (time and temperature) was determined and used. After each cook, the chips were **defibered,** washed, then screened on a 0.010 inch slotted **flat** screen. The total yield, percent rejects, screened yield, and kappa number **(TAPPI** method T236) were determined. The fiber length distribution for each unbeaten sample were determined by a Kajaani FS-100 analyzer **(T271).**

Data analysis was done to determine differences in pulping response and pulping yield.

RESULTS

Increasing the amount of water and nutrients available for tree growth by eliminating competition **from** herbaceous weeds and **wildlings** increased the mean annual increment **(MAI)** of the 14 year loblolly pine by 61 to 71% compared to that of the 24 year control (Table 2). At the time of harvest the 24 year loblolly control stand contained only 2 to 11% more stem pulpwood biomass than that of the 14 year loblolly stands. The loblolly pine plots planted at 1,977 TPH contained 10% more stem pulpwood biomass at age 14 compared to the plots planted at 988 TPH. The average DBH of the trees on the 988 TPH plots was however 23.1 cm compared to 18.3 cm for the 1,977 TPH plots.

Herbaceous weed control in the slash pine plots in the Coastal Plain also increased growth significantly. The **MAI** of the herbicide treatment was 106% higher than that of the 24 year control **(Table** 2). The MA1 of the herbicide/fertilize plots was 124% higher than that of the control but only 9% higher than that of the herbicide only plots. On average the **MAI** of the 14 year loblolly pine in the Piedmont was 68 to 100% higher than that of the **17** year slash pine in the Coastal Plain. The MA1 of the 24 year thinned loblolly stand in the Piedmont was 140% higher than that of the 24 year unthinned slash pine stand in the Coastal Plain.

TREATMENT	TREES PER HECTARE	DBH	PULPWOOD STEM WEIGHT	MEAN ANNUAL INCREMENT
	No.	cm	MTN/Ha	m^3/Ha
			LOBLOLLY PINE	
988 TPH, AGE 14	976	23.1	269	18.5
1,483 TPH, AGE 14	1,322	20.1	280	19.2
1,977 TPH, AGE 14	1,730	18.3	298	20.2
CONTROL, AGE 24	509	28.2	303	11.8
			SLASH PINE	
HERBICIDE, AGE 17	1,139	17.8	198	10.1
HERB/FERT, AGE 17	1,189	18.3	215	11.0
CONTROL, AGE 24	927	16.8	137	4.9

Table 2. Average number of trees, dbh, stem weight per hectare, and mean annual increment by treatment for loblolly and slash plantations sampled at harvest.

Graphic plots of annual ring percent latewood over rings from the pith show the wood formation pattern at the stump, and top of the first and second sawlog for each species and treatment (figure 2.) Ring percent latewood is highly correlated with ring specific gravity (R=0.90). The plots show that the Coastal Plain slash pine produced a higher proportion of annual ring growth in latewood than the Piedmont loblolly pine. The slash pine were producing annual rings with 40% or more latewood (mature wood) by four rings form the pith at the stump, and by five rings from the pith at the top of the first and second sawlogs. The treatment and control loblolly pine were producing 40% latewood by five rings at the stump and the treatment trees were producing 40% latewood by ring nine at the top of the first sawlog. However, the control trees did not produce 40% latewood till about 15 rings from the pith at the top of the first sawlog. On average, none of the loblolly pine were producing mature wood (40% latewood) at the top of the second sawlog.

Planting density had little or no effect on the wood formation pattern of the 14 year loblolly pine (figure 2). Competition control appears to have influenced the formation of latewood in both the slash and loblolly pine. The trees under competition control produced annual rings with a higher proportion of latewood in rings five to seven ring for the slash and in rings five to ten for the loblolly compared that of the controls (figure 2). Competition control increases soil moisture and thus stimulates earlywood growth and delays the transition to latewood. After soil moisture decreases in early to mid summer and latewood production starts, competition control stimulates and prolongs production of latewood because of increased soil moisture in the late summer.

Controlling competing vegetation dramatically accelerated the annual growth of the loblolly pine in the Piedmont planted at 988, 1,483 and 1,977 TPH during the first IO-years compared to that of the control trees (figure 3). On average, the trees planted at 988 TPH put on more annual radial growth than those planted at 1,483 or 1,977 TPH. The rate of growth peaks at about 7 years and then declines due to crown closure and competition between trees.

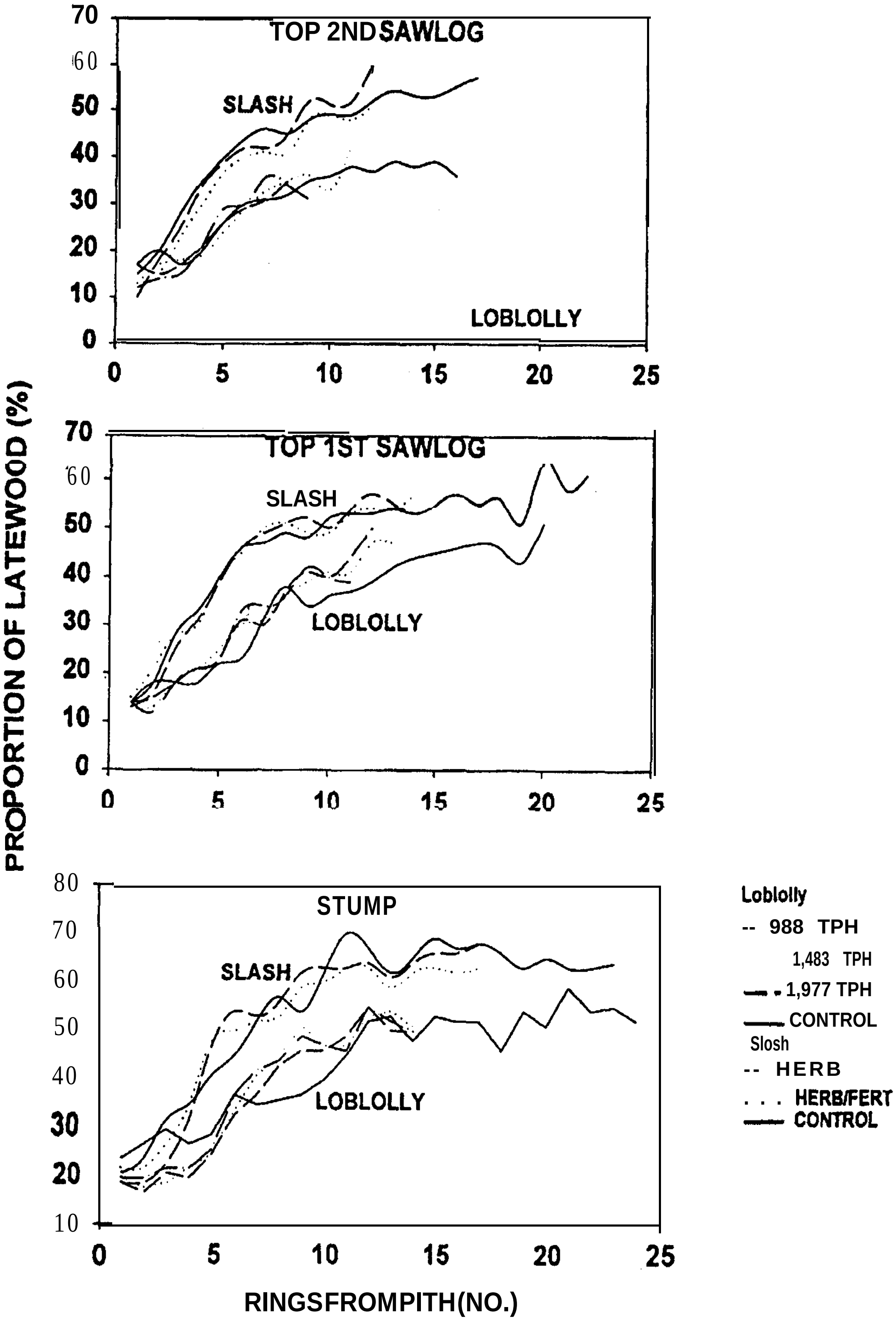

Figure 2. Wood formation pattern based on proportion of annual ring latewood at stump, top of first sawlog and top of 2nd sawlog for loblolly and slash pine by treatment.

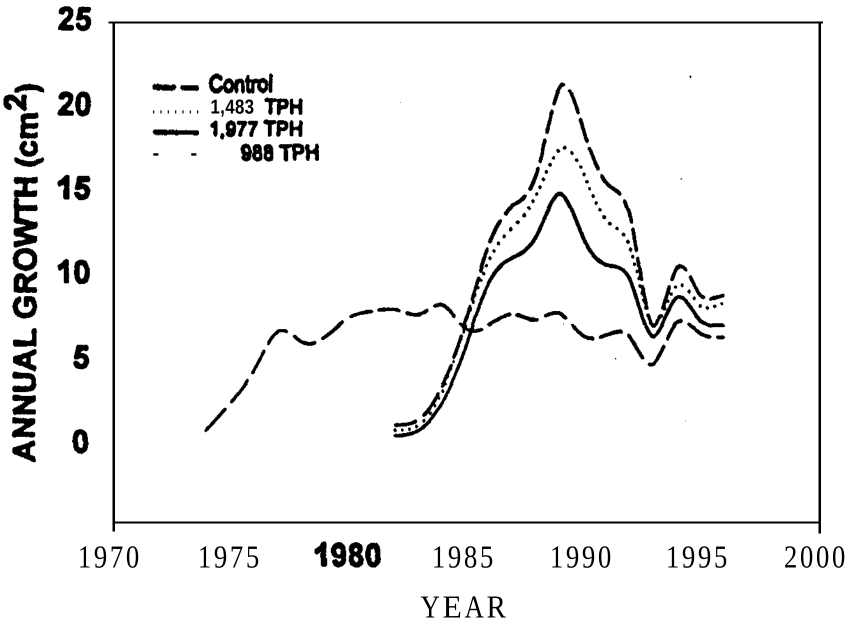

Figure 3. Total annual growth per tree for loblolly pine in the Piedmont by treatment.

The competition control and competition control plus fertilization had less of an effect on initial annual growth for the slash pine in the Coastal Plain compared to the controls (figure 4). The effect of fertilization is minimal since application was limited to year 1 and I 1 and nutrient deficiencies were minimal in the stands sampled.

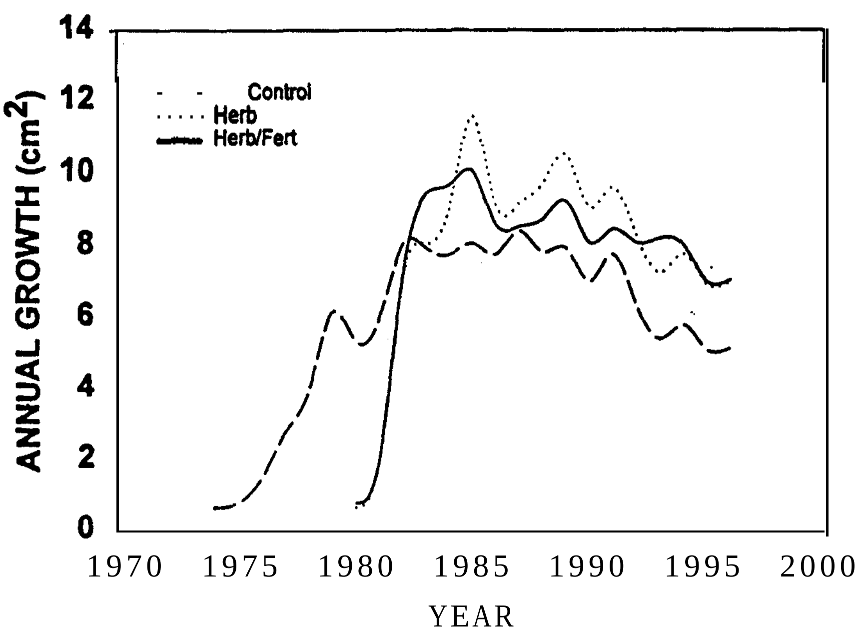

Figure 4. Total annual growth per tree for slash pine in the Coastal Plain by treatment.

Accelerated growth in the early stages of stand development improved volume production but increased the volume of juvenile wood (figure 5). The proportion of juvenile wood in the sawlog stem was affected by treatment, tree age, and species or geographic location. The proportion of juvenile wood in the sawlog stem was highest in the loblolly planted at 988 and 1,483 TPH because the trees with the least competition put on the largest radial growth during their early years when juvenile wood is produced. The trees planted at 1,977 TPH had less juvenile wood than the 988 or 1,483 TPH because these trees grew at a slower rate during the early years of the rotation because of increased competition between trees.

Figure 5. Proportion of **sawlog** stem wood volume classified as juvenile wood.

The **loblolly** and slash pine control trees have a lower proportion of juvenile wood **(10** to 25%) than the younger **accelerated** growth trees. This difference occurs because the controls are older and have been **producing** mature wood along the lower bole for several years. There is little difference in proportion of juvenile wood in the **sawlog** stern between the herbicide and herbicide/fertilize slash pine (Figure 5).

The Coastal Plain slash pine contained significantly less juvenile wood than that of the Piedmont loblolly pine because it converted to mature wood at an earlier age. This difference is related more to differences in summer rainfall and length of growing season due to differences in geographic location than due to species **differences** (Clark and Saucier, 1989).

The proportion of **sawlog** weight in bark was higher for slash pine (1617%) than that of the loblolly pine (1 **1-13%)** (Table 3). The proportion of **sawlog** weight recovered in CNS chips was fairly uniform across treatments for loblolly (39 - 44%) and slash (36 - 44%). There was no significant difference in CNS chip moisture content (MC) among the loblolly treatments or among the slash treatments. However, there was a **significant** difference in MC between Coastal Plain slash and Piedmont loblolly chips. There was a significant difference in chip **specific** gravity (SG) among the loblolly treatments with the 988 TPH chips having the lowest SG. The low SG of the 988 TPH chips is due to the high proportion of juvenile wood in the 988 TPH trees (Figure 2). There was no difference in chip SG between the slash control and herbicide chips but the SG of the **herb/fert** chips was significantly lower than that of the other slash treatments. The loose bulk density and packed bulk density of the chips did not vary significantly among the slash treatments. However, the bulk density values were significantly higher for the slash compared to that of the loblolly.

	Loblolly Pine				Slash Pine		
	Control	1,977 TPH	1,483 TPH	988 TPH	Control	Herb	Herb/ Fert
SAWLOG WEIGHT (Kg)	12,259	6,138	7,841	7,840	8,399	6,420	6,419
BARK WEIGHT (Kg)	1,430	663	839	863	1,302	1,079	1,840
PROPORTION OF BARK (%)	13	11	11	11	16	17	16
CNS CHIP WEIGHT (Kg)	4,218	2,579	3,033	3,437	3,019	2,747	2,847
PROPORTION OF CNS CHIPS (%)	43	42	39	44	36	43	44
MOISTURE CONTENT (%)	57	58	57	58	47	48	48
SPECIFIC GRAVITY	0.40	0.39	0.43	0.37	0.52	0.53	0.47
LOOSE BULK DENSITY (Kg/m^3)	137.0	142.0	144.0	145.4	178.2	178.2	168.5
PACKED BULK DENSITY (Kg/m^3)	153.9	155.9	162.1	162.6	197.2	193.6	189.3

Table 3. Chipping-saw-chip recovery and chip physical properties for loblolly and slash pine by treatment

The 14 year loblolly pine CNC chips yielded an average 4% less acceptable chips tban the 24 year loblolly controls. (Table 4). A high proportion of the lower yield is caused by the high proportion of over-thick chips produced by the 14 year old trees (9.3 - 11 .1%) compared to that produced by the controls (6-7%).

The slash pine produced on average 8% more acceptable CNS chips compared to the loblolly (Table 4). The higher yield for the slash pine is caused by a lower yield of over-length and over-thick chips and less knots. The loblolly pine averaged 3.2% in knots compared to 0.9% for the slash. This difference is due to differences in species branch and self pruning characteristics. Loblolly tends to have larger persistent branches compared to slash pine. Chip size distributions for the herbicide, herbicide/fertilize, and slash control are very similar (Table 4).

CHIP SIZE CATEGORY	LOBLOLLY PINE				SLASHPINE		
	988 TPH	1,483 TPH	1,977 TPH	Control	HERB	HERB/ FERT	Control
	(%)						
FINES	0.8	1.0	0.8	1.2	0.7	0.8	1.0
PINS (3 MM RND)	6.8	7.5	7.2	7.9	4.4	5.5	5.0
KNOTS	4.4	1.2	4.5	2.9	1.2	0.7	0.8
OVER-LENGTH (45MM RND)	2.9	2.2	3.0	2.0	1.1	1.0	0.9
OVER-THICK (8MM BAR)	10.4	11.1	9.3	6.7	8.5	7.7	6.6
LARGE ACCEPTS(15MM RND)	42.9	44.0	43.4	50.3	52.2	48.9	51.9
SMALL ACCEPTS (7MM RND)	30.5	32.0	30.5	27.9	30.6	34.0	32.7
TOTAL ACCEPTS	73.4	76.0	73.9	78.2	82.8	82.9	84.6

Tabk 4. Average chip size distribution by treatment for loblolly pine and slash pine for chipping-saw-chips

Regression analysis of the pulping results showed that there was no significant difference between treatments or species in total yield as a function of kappa no. The total yield determined from the regression results at 90 kappa and 60 kappa is shown in Table 5.

CHARACTERISTIC	LOBLOLLY PINE				SLASHPINE		
	988 TPH	1,483 TPH	1,977 TPH	Control	HERB	HERB/ FERT	Control
	LINERBOARD GRADE PULP						
TOTAL YIELDS **(%)**	54.1	54.1	54.1	54.1	54.1	54.1	54.1
	SACK GRADE PULP						
TOTAL YIELDS **(%)**	49.3	49.3	49.3	49.3	49.3	49.3	49.3

Table 5. Total pulp yields by treatment for linerboard (kappa no. 90) and sack grade (kappa no. 60) pulp made **from** loblolly pine and slash pine chipping-saw-chips.

The weight-weighted average **fiber** lengths for the linerboard and sack grades are shown **in** Table 6. For loblolly **linerboard** grade pulps, t-test analyses showed that there were statistical differences between the control and the pulps derived **from** the loblolly stands at 988 TPH. The fiber length of the control was higher. Overall the 14 year loblolly was 6% lower in fiber length compared to the control. The younger stands have more juvenile wood, with shorter **tracheids** than the controls. There appears to be no difference in the fiber lengths of the slash pine **linerboard** or sack pulp due to treatment. Fiber lengths for the linerboard slash pulps were on average 11 percent longer and slash sack pulp fiber lengths 10 percent longer than that of the loblolly fibers.

LOBLOLLY PINE				SLASH PINE		
988 TPH	1,483 TPH	1,977 TPH	Control	HERB	**HERB/FERT**	Control
mm						
LINERBOARD PULP						
3.55	3.80	3.67	3.88	4.35	4.08	4.10
SACK PULP						
3.38	3.42	3.64	3.63	3.84	3.89	3.97

Table **6—Average** weight-weighted fiber length for loblolly and slash pine linerboard and sack pulps by treatment.

The sack grade pulps appeared to have 4% higher fiber lengths for 1,977 **TPH** and controls (Table 6). The 1,977 **TPH** and control had a higher proportion of mature wood in the **sawlog** which may explain the longer fiber length. The shorter fiber lengths for sack grade versus linerboard pulps are probably due to the greater degree of cooking.

CONCLUSIONS

Controlling competing vegetation dramatically accelerated the growth of 14 year loblolly **pine** on **the Piedmont** and 17 year slash pine in the Coastal Plain. The mean annual increment **(MAI)** of 14 year loblolly pine with **competition** amtrol, planted at 988 TPH, 1,483 TPH or 1,977 TPH was 61 to 71% higher than that of **a 24 year** control. **The MAI** of the 14 year loblolly with competition control was 68 to 100% higher than that of the 17 year slash with competition control or competition control plus fertilization. The largest increase in growth occurred in the **loblolly pine** planted at 988 TPH. **The** effect of competition control on formation of juvenile wood in the 14 year loblolly pine was pronounced since the increased growth occurred during the first 10 years. On average the Piedmont loblolly pine contained twice as much of its **sawlog** volume in low specific gravity juvenile wood as that of the Coastal Plain slash **pine. The slash pine CNS** chips averaged 83% acceptable **chips** compared to 75% for the loblolly CNS chips. **Weighted** average **fiber** lengths for the 14 year loblolly planted at 988 TPH was 6% shorter than that of the 24 year control. There was no **significant difference** in **the** linerboard or sack grade pulp yield between the 14 year loblolly treatments and their 24 year control or between the 17 year slash treatments and their 24 year control.

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