

Effect of initial planting spacing on wood properties of unthinned loblolly pine at age 21

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Abstract

Young, fast growing, intensively managed plantation loblolly pine (*Pinus taeda* L.) contains a large proportion of juvenile wood that may not have the stiffness required to meet the design requirements for southern pine dimension lumber. An unthinned loblolly pine spacing study was sampled to determine the effect of initial spacing on wood stiffness, strength and specific gravity (SG) at 8, 24, and 40 feet up the stem of chipping-saw loblolly pine grown using competition control and fertilization at planting plus fertilization at midrotation. Seven spacings ranging from 6 by 8 feet to 12 by 12 feet were sampled. Analysis of the effect of spacing at each height level showed significant differences in stiffness, strength, and SG among spacings at 8 feet, but did not vary significantly with spacing at 24 or 40 feet. Stiffness at 8 feet of trees planted at 12 by 12 feet was 12 to 14 percent lower than that of trees planted at 6 by 8, 6 by 10 and 6 by 12 feet because the 12 by 12 trees were growing rapidly in response to fertilization and less competition and thus contain a larger diameter of juvenile wood characterized by wide microfibril angles and lower stiffness. Average weighted whole stem wood stiffness and strength decreased only 6 to 7 percent when spacing increased from 6 by 8 feet and 12 by 12 feet, and was not significantly different at the 0.05 level. Estimated stiffness, strength and SG at 8, 24, and 40 feet decreased significantly with increasing tree height because of increased juvenile wood in the upper stem.

Timberland owners and forest managers in the southeastern United States need information on the effect that initial spacing or number of trees planted per acre (TPA) has on the wood properties of intensively managed plantation grown loblolly pine (*Pinus taeda* L.). Traditionally, land managers planted 600 to 900 TPA and thinned the stands to 250 to 400 TPA by harvesting pulpwood at age 12 to 16. However, with the planting of superior seedlings and weed control and fertilization, foresters can now grow pulpwood size southern pine by age 8 to 10, but there is little demand for young, fast growing pulpwood trees. Thus, landowners are now using low-density management (planting fewer TPA) (Huang and Kronrad 2004) and using chemical competition control and fertilization to grow chipping-saw and sawtimber trees in 16 to 22 years without thinning.

In order for the southern pine industry to maintain its competitive position in the global market, it must produce wood from intensively managed plantations with the strength and stiffness required to meet lumber standards. Lumber produced from young fast growing pines that contain large volumes of

juvenile wood may not have the stiffness required to meet the design requirements for southern pine dimension lumber (MacPeak et al. 1990). Biblis and others (1993) examined the effect of stand age on the strength and stiffness of dimension lumber sawn from 25-, 30-, and 35- year-old plantation loblolly pine. They found that a significant percentage of the

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tested lumber could not meet the required stiffness values for the assigned visual grade. They found that only 13 percent of the No. 2 dimension lumber produced from the 25 year-old trees meet SPIB stiffness requirements for stiffness compared to 66 percent that was in compliance for strength.

Planting at wide spacings stimulates rapid stem diameter growth early in the rotation (Baldwin et al. 2000, Sharma et al. 2002) which results in larger volumes of juvenile wood than occur in slower growing trees (Martin 1984, Clark and Saucier 1989). Juvenile wood is characterized as having low specific gravity (SG), short tracheids, and large microfibril angles (MFA), resulting in lower strength and stiffness compared to mature wood (Megraw 1985, Larson et al. 2001).

The effect of initial planting density on wood strength and stiffness of loblolly pine was investigated by Biblis and Mel-dahl (2006). In this study conventionally managed plantations that did not receive chemical competition control at planting or midrotation fertilization were sampled. They determined the modulus of elasticity (MOE) and modulus of rupture (MOR) of small, clearwood specimens (2 by 2 by 30 in) cut from along the length of lumber cut from the bottom 8 feet of 20-year-old loblolly pines planted at 6 by 6 ft (1210 TPA) and 12 by 12 ft (302 TPA). The results showed that the average MOE and MOR from the two stands did not differ significantly at the 0.05 level.

Clark et al. (2008) sampled an unthinned loblolly pine spacing study in the Coastal Plain of Georgia to determine the effect of initial spacing, competition control, and fertilization on yield per acre. Seven spacings ranging from 6 by 8 ft (908 TPA) to 12 by 12 ft (302 TPA) were sampled. The proportion of trees surviving at age 21 ranged from 65 percent in the 6- by 8-ft spacing to 90 percent in the 10- by 12- and 12- by 12-ft spacings. Total stem wood and bark green weight per acre was estimated to be 190 tons for the 6- by 8-ft (908 TPA) spacing, increased to 215 tons for the 8- by 10-ft (544 TPA) spacing and decreased to 195 tons for the 12- by 12-ft (302 TPA) spacing. Estimated volume of lumber per acre at age 21 was lowest for the 6- by 8-ft spacing and highest in the 8- by 12-ft spacing, which was slightly higher than the 12- by 12-ft spacing. Breakeven stumpage price per acre was highest for the trees planted at 8- by 12-ft spacing.

Planting at wide spacings also stimulates crown growth resulting in larger diameter branches (Baldwin et al. 2000, Sharma et al. 2002). The diameter of knots is an important characteristic that degrades southern pine dimension lumber and veneer (Schroeder and Clark 1970, Clark et al. 1994, Clark and McAlister 1998). Clark et al. 2007 also investigated the effect of initial spacing, competition control, and fertilization on both the number of knots and knot size. Results showed that the average number of knots, knot diameter and average maximum knot diameter increased with increased spacing. Lumber cut from trees planted at wide spacings could contain larger knots that result in lower lumber grade and lower stiffness and strength.

The same spacing study sampled by Clark et al. (2008) was sampled for wood properties and the results are presented in this paper. The objectives of this paper are to determine the effect of initial planting spacing on clearwood stiffness (MOE), strength (MOR), and SG up the stem of chipping-saw loblolly pine trees at age 21, grown using competition control and fertilization at planting plus fertilization at midrotation.

Material and methods

The trees selected for sampling were from a loblolly pine spacing study that was established on the Atlantic Coastal Plain in 1984 near Rincon, Georgia, in the United States. The experimental design of the study was a randomized complete block, replicated three times, with seven spacings: 12 by 12 (302 TPA), 10 by 12 (363 TPA), 8 by 12 (454 TPA), 8 by 10 (544 TPA), 6 by 12 (605 TPA), 6 by 10 (726 TPA), and 6 by 8 feet (908 TPA). The study was planted with loblolly pine family 7-56 seedlings on commercially prepared beds with the sample plot consisting of 8 rows and 8 trees per row. At the time of planting each spacing plot was fertilized with 125 lbs of diammonium phosphate, and herbaceous weeds were controlled with a broadcast application of herbicide. All plots were retreated during the first and second years for herbaceous weed control and fertilized with 300 lbs of urea at age 5 and 10.

In the summer of 2005, seven trees ≥ 8 inches in diameter at 4.5 feet aboveground (DBH) were selected in proportion to the diameter distribution of the trees in each plot, were felled and destructively sampled for wood properties. Cross-sectional disks 1.5 inches thick were cut at stump, 4.5, 10, and then at 5 feet intervals up the stem to a 2-inch d.o.b. top for processing into radial strips for annual ring growth analysis. Bolts 2 feet in length were cut at 8, 24, and 40 feet up the stem, representing the center of the butt, second and third 16 foot logs, for processing into static bending samples.

A 1.5-inch-thick slab was cut from bark to bark through the pith of each 2-foot bolt for processing into static bending samples. The static bending slabs were kiln-dried to 12 percent equilibrium moisture content (EMC). After drying, the slab was split in half through the pith, and clear static bending samples, sized 1 by 1 by 16 inches, were cut consecutively from each half, starting at the bark. The number and age of the annual rings in each static bending sample were recorded. Any static bending samples containing pith were deleted from the study.

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-side up on a Tinius Olsen Test Machine following the procedures for alternate sample size under ASTM D143 (ASTM 2003). 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 testing showed specimens failed primarily in compression with no defined break or tension failure. After testing, each sample was oven-dried at 217 °F, and SG was calculated based on specimen dimensions at 12 percent EMC and oven-dry weight. MOE and MOR were calculated using procedures outlined in ASTM D143 (ASTM 2003). Data for each static bending sample cut from each side of the 1.5-inch slab was averaged by position from bark. The average static bending data for each 1-inch static bending position were weighted by the basal area each position represents to estimate the static bending data for a given height level. Weighted whole-stem strength and stiffness were estimated by weighting the height level values in proportion to the basal area of the stem at 8, 24, and 40 feet.

A 1/2- by 1/2-inch radial strip from bark to pith was sawn from each cross-sectional disk, dried, glued to strip holders and sawn into 0.078 inch thick strips. Annual growth of earlywood and latewood from each annual ring for each radial

strip was determined at 0.0024-inch intervals using a scanning x-ray densitometer.

Statistical analysis

We examined the effect of initial spacing on diameter at breast height (DBH), total tree height (THT), sawlog merchantable tree height (MHT), and weighted whole-stem MOE, MOR and SG using an analysis of variance (ANOVA). The experimental design for analyzing these variables constitutes a randomized complete block design with subsampling. The general form of this model can be expressed as:

$$y_{ijk} = \mu + S_i + b_j + (Sb)_{ij} + e_{ijk} \quad [1]$$

$$i = 1, \dots, 7, \quad j = 1, 2, 3, \quad k = 1, \dots, 7,$$

where:

y_{ijk} = the property of interest of the k th tree of the j th block receiving the i th spacing treatment; μ = the population mean; S_i = the i th spacing effect; b_j = the random effect of the j th block, with $b_j \sim NID(0, \sigma_b^2)$, where *NID* is an abbreviation for Normal, Independent, and Identically Distributed. $(Sb)_{ij}$ = the random effect of the i th spacing and j th block (a plot level random effect to account for the subsampling of trees within a particular block receiving a particular treatment) with $(Sb)_{ij} \sim NID(0, \sigma_{Sb}^2)$, and e_{ijk} is residual error with $e_{ijk} \sim NID(0, \sigma^2)$.

For analyzing the effect of initial spacing and height on MOR, MOE and SG, another ANOVA was used. For these data, the trees selected from each plot in this study correspond to a random sample of all trees in each plot falling within a particular block, receiving a particular treatment. Individual tree effects can be represented as random-effects and their contribution to the variance of MOR, MOE and SG can be estimated. In addition, to account for the subsampling of seven trees within each experimental unit (plot), it is necessary to distinguish tree-to-tree variability and within-tree variability from variability across the experimental units. These considerations dictate that a mixed-effects model should be employed to account for the distinct sources of variability in the experiment.

In particular, the full linear mixed model used for the analysis can be written as

$$y_{ijkl} = \mu + S_i + H_l + (HS)_{il} + b_j + (Sb)_{ij} + t_{ijk} + (SbH)_{ijl} + e_{ijkl} \quad [2]$$

$$i = 1, \dots, 7, \quad j = 1, 2, 3, \quad k = 1, \dots, 7, \quad l = 1, 2, 3,$$

where: y_{ijkl} = the property of interest at the l th height, of the k th tree, of the j th block, receiving the i th spacing treatment; μ = the population mean; S_i = the i th spacing effect; H_l = the l th height effect; $(HS)_{il}$ = the interaction of the i th spacing and l th height effect; b_j = the random effect of the j th block with $b_j \sim NID(0, \sigma_b^2)$; $(Sb)_{ij}$ = the random effect of the i th spacing and j th block effects with $(Sb)_{ij} \sim NID(0, \sigma_{Sb}^2)$; t_{ijk} = the random effect of the k th tree of the j th block receiving the i th spacing with $t_{ijk} \sim NID(0, \sigma_t^2)$; $(SbH)_{ijl}$ = the random effect of the i th spacing, j th block and l th height effect with $(SbH)_{ijl} \sim NID(0, \sigma_{SbH}^2)$; and e_{ijkl} = residual error, with $e_{ijkl} \sim NID(0, \sigma^2)$.

The models in this paper were fit using the SAS® MIXED procedure, with the Kenward-Rogers approximation for computing the denominator degrees of freedom for the fixed effects (SAS Institute Inc. 2004). Tukey's Honestly Significant Difference test was used for pairwise comparisons among treatment means.

Table 1. — Effect of initial spacing on tree size, DBH, total height (THT), and merchantable height (MHT), including the *F*-, *P*-, estimated-values, corresponding standard errors (in parenthesis), and pairwise comparisons.*

Spacing (ft)	TPA no.	Percent chip-saw	DBH	THT	MHT
			$F_{6,10.1} = 15.73,$ $p = 0.0001$	$F_{6,9.35} = 1.28,$ $p = 0.3535$	$F_{6,9.42} = 5.38,$ $p = 0.0115$
			(in)	----- (ft)-----	
6 by 8	908	27	9.6 (0.254) c	82 (1.49) a	41 (2.50) b
6 by 12	605	57	9.8 (0.278) c	84 (1.67) a	44 (2.74) ab
6 by 10	726	41	9.7 (0.246) c	83 (1.47) a	43 (2.43) ab
8 by 10	544	59	9.9 (0.246) c	82 (1.47) a	42 (2.43) ab
8 by 12	454	77	10.2 (0.246) bc	85 (1.47) a	48 (2.43) ab
10 by 12	363	80	11.0 (0.278) ab	86 (1.67) a	51 (2.74) a
12 by 12	302	97	11.6 (0.263) a	84 (1.50) a	51 (2.57) a

*Values down each column with the same letter are not significantly different at the 0.05 level.

Results

Initial spacing had a strong influence on the proportion of trees that grew to chipping saw size by age 21. The proportion of trees 8.0 inches DBH or larger at age 21 increased with increased spacing and ranged from 27 percent of the trees planted at 6 by 8 feet to 97 percent of the trees planted at 12-by 12-ft spacing (Table 1). Initial planting density also had a significant (p -value = 0.0001) effect on the average DBH of the chipping-saw size trees. The largest average DBHs were found in the 12- by 12-ft and 10- by 12-ft spacings with estimated values of 11.6 and 11.0 inches respectively, and were not found to differ from each other (Table 1). The smallest DBHs were found in the 6- by 8-ft, 6- by 10-ft, 6- by 12-ft, and 8- by 10-ft spacings and ranged from 9.6 to 9.9 inches. The DBHs in these spacings were also found to all be significantly smaller than the 12- by 12-ft and 10- by 12-ft spacings.

Spacing was not found to significantly affect tree total height (THT) (p -value = 0.3535) of the chipping-saw trees 8.0 inches DBH and larger. Estimated THT values ranged from 82 feet in the 6 by 8 spacing to 86 feet in the 10 by 12 spacing (Table 1). Sawlog merchantable height (MHT) was found to be significantly effected by spacing (p -value = 0.0115). The tallest MHTs were found in the 12 by 12 and 10 by 12 spacings and the shortest MHTs were found in the 6 by 8 spacing. However, the MHTs in the 12 by 12 and 10 by 12 spacings were not significantly taller than MHTs in the 6 by 10, 6 by 12, 8 by 10, or 8 by 12 spacings which averaged 44 feet (Table 1). The 6 by 8 spacing had the shortest MHT, but did not differ significantly from the 6 by 10, 6 by 12, 8 by 10, or 8 by 12 spacings. Sawlog merchantable height varied significantly, but total height did not because initial spacing influenced stem taper or form class. Average Girard form class was 75 for spacing of 6- by 8-, 6- by 10-, and 8- by 10-ft, 77 for the 8- by 12-ft spacing, and 76 for the 10- by 12- and 12- by 12-ft spacing.

Average weighted whole-stem MOR, MOE and SG increased as spacing at planting decreased (Table 2). Average whole-stem MOR increased from 11,985 pounds per square inch (psi) in the 12- by 12-ft spacing to 12,836 psi for the 6- by 8-ft spacing, or by 7 percent. The effect of spacing on whole-stem MOR was not statistically significant (p -value = 0.2296). MOE increased from 1.23 million pounds per square

inch (mil psi) for the 12- by 12-ft spacing to 1.33 mil psi for the 6- by 8-ft spacing, or by 8 percent. However, the effect of spacing on weighted whole-stem MOE was not statistically significant at the 0.05 level (p -value = 0.0839). Whole-stem SG, based on the SG of the static bending samples, also increased as spacing decreased ranging from 0.477 for the 12 by 12 spacing to 0.502 for the 6- by 8-ft spacing. The SG of the trees planted at the 6- by 8-ft spacing was found to be statistically higher than that of the trees planted at 8 by 12 spacing (p -value = 0.0267) (Table 2).

Results of the ANOVA for testing the effect of spacing and height on MOR, MOE, and SG are presented in Table 3. Spacing was not found to significantly effect MOR (p -value = 0.4280), MOE (p -value = 0.2380), or SG (p -value = 0.0591). Average stem MOR increased slightly as spacing decreased, ranging from 11,906 psi in the 12 by 12 to 12,397 in the 6- by 8-ft spacing (Fig. 1). Average stem MOE was also found to increase slightly as spacing decreased, but was not of sufficient magnitude to be significantly different ranging from 1.24 to 1.31 mil psi in the 12 by 12 and 6 by 8 spacings, respectively (Fig. 2). Average stem SG generally increased with a decrease in spacing and was not found to be statistically significant at the 0.05 level, but was significant at the 0.10 level. Estimated SG increased from 0.470 in the 12 by 12 to 0.488 in the 6- by 8-ft spacing.

MOE, MOR and SG decreased significantly with increasing stem height (p -value = 0.0030 for MOE, p -value = 0.0001 for MOR, and p -value = 0.0001 for SG) because of increased juvenile wood in the upper stem. Pairwise comparisons for MOR indicated that all heights differ significantly from each

other at the 0.05 level (Table 4). The MOR for the 24 feet level was 8 percent lower than that for the 8 feet level and MOR at 40 feet was 12 percent lower than that at 8 feet. Pairwise comparisons indicated no significant difference in MOE between 8 and 24 feet, but MOE at 8 and 24 feet are both significantly higher compared to that at 40 feet. Pairwise comparisons for SG show that all heights differ significantly from each other at the 0.05 level (Table 4).

The spacing by height interaction effect for MOR, MOE, and SG was not significant, with p -values of 0.1499, 0.2307, and 0.4721, respectively and implies that the effect of spacing on MOR, MOE and SG is not dependant on height. Even though the interaction effect of spacing by height was found to be insignificant, it is still of interest to test the simple effect of spacing at each height level. For MOR, these tests indicated that a significant difference exists (p -value = 0.0169) between spacings at a height of 8 feet (Fig. 1). Plots of estimated MOR at 8 feet over initial spacing show that MOR increases with decreased spacing, but at 24 and 40 feet MOR exhibits little change across the spacings. Pairwise comparisons among the spacings at 8 feet indicated that MOR is significantly lower (at the 0.10 level) in the 12 by 12, 10 by 12 and 8 by 12 spacings compared to the 6 by 8 spacing. MOR was found to be 9 to 11 percent lower in the 8 by 12, 10 by 12 and 12 by 12 spacings compared to the 6 by 8.

The tests of simple effects for comparing the effect of height at each level of spacing indicated significant differences in MOR among height levels in the 8 by 12, 8 by 10, 6 by 12, 6 by 10, and 6- by 8-ft spacings (Fig. 1). These results indicated that MOR is significantly larger at 8 feet compared to 24 and 40 feet across all of these spacings, with the exception of comparing MOR at 8 and 24 feet in the 6 by 12 spacing. No significant differences were found when comparing MOR at 24 and 40 feet.

The simple effect of testing for differences among spacings at each height level for MOE, indicated a significant difference exists (p -value = 0.0093) between spacings at a height of 8 feet. Plots of estimated MOE over initial spacing showed that MOE at 8 and 24 feet increased with decreasing spacing, but MOE at 40 feet is relatively unchanged. Pairwise comparisons among the spacings at 8 feet indicated that MOE is significantly higher (at the 0.10 level) in the 6 by 8, 6 by 10 and 6 by 12 spacings compared to the 12 by 12 spacing. MOE was found to be 12 to 14 percent lower at 8 feet for the 12 by 12 trees compared to that of the 6 by 8, 6 by 10 or 6 by 12 trees. The tests of simple effects for comparing the effect of height at each level of spacing also indicated significant differences in MOE among height levels for the 6 by 10 spacing (Fig. 2). These results indicated that MOE is significantly higher at 8 and 24 feet compared to 40 feet in the 6 by 10 spacing, with no significant difference between estimated MOE at 8 and 24 feet.

For SG, a significant difference between spacings at a height of 8 and 24 feet was found to exist with p -values of 0.0228 and 0.0194, respectively. Pairwise comparisons indicated that at 8 feet, SG was significantly higher in the 6 by 8 spacing compared to the 10 by 12, 8 by 12, and 8 by 10 feet spacings (Fig. 3). At 24 feet, SG in the 8 by 12 spacing was found to be significantly smaller

Table 2. — Effect of initial spacing on weighted whole-stem MOR, MOE and SG, including the F and p -values, estimated-values, corresponding standard errors (in parenthesis), and pairwise comparisons.*

Spacing (ft)	TPA no.	Whole-stem MOR	Whole-stem MOE	Whole-stem SG
		$F_{6, 10.1} = 1.65,$ $p = 0.2296$	$F_{6, 10.9} = 2.57,$ $p = 0.0839$	$F_{6, 9.54} = 4.09,$ $p = 0.0267$
		(psi)	(1.0×10^6 psi)	
6 by 8	908	12836 (288) a	1.33 (0.026) a	0.502 (0.0059) a
6 by 10	726	12735 (280) a	1.33 (0.026) a	0.495 (0.0057) ab
6 by 12	605	12606 (363) a	1.35 (0.031) a	0.492 (0.0074) ab
8 by 10	544	12036 (280) a	1.26 (0.026) a	0.482 (0.0057) ab
8 by 12	454	11932 (280) a	1.26 (0.026) a	0.468 (0.0057) b
10 by 12	363	12122 (363) a	1.26 (0.031) a	0.474 (0.0074) ab
12 by 12	302	11985 (296) a	1.23 (0.028) a	0.477 (0.0061) ab

*Values down each column with the same letter are not significantly different at the 0.05 level.

Table 3. — Results of the analysis of variance for examining the effect of spacing and height on MOR, MOE, and SG including the probability of a significant difference (p -value) and F -test statistic (F -value).

Source	MOR		MOE		SG	
	F -value	P -value	F -value	P -value	F -value	P -value
Spacing	$F_{6,10.9} = 1.09$	0.4280	$F_{6,11.3} = 1.59$	0.2380	$F_{6,10.9} = 2.5939$	0.0591
Height	$F_{2,25.8} = 47.63$	0.0001	$F_{2,23.4} = 7.55$	0.0030	$F_{2,24.1} = 278.44$	0.0001
Spacing x height	$F_{12,25.5} = 1.62$	0.1499	$F_{12,23.2} = 1.41$	0.2307	$F_{12,23.8} = 1.01$	0.4721

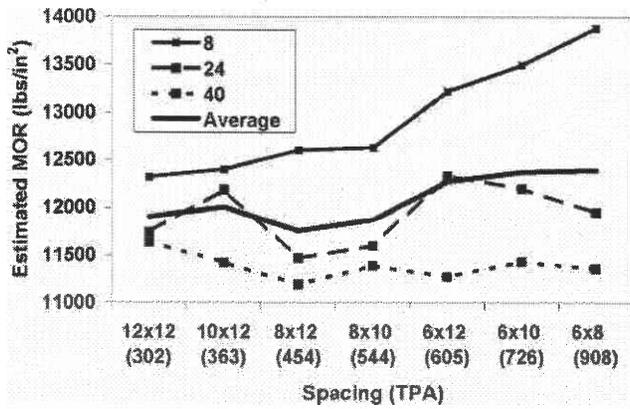


Figure 1. — Estimated modulus of rupture (MOR) at 8, 24, and 40 feet up the stem and average stem MOR plotted over spacing and number of trees per acre (TPA).

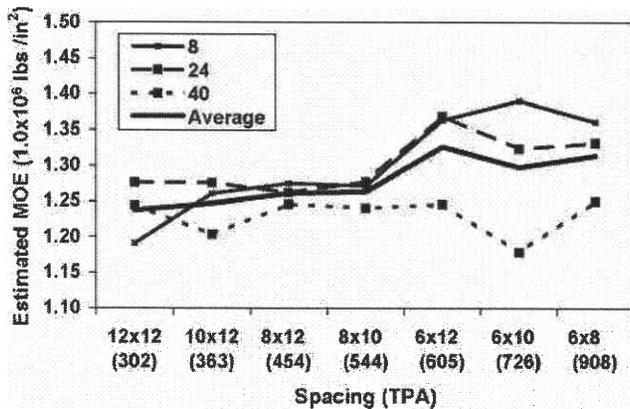


Figure 2. — Estimated modulus of elasticity (MOE) at 8, 24, and 40 feet up the stem and average stem MOE plotted over spacing and number of trees per acre (TPA).

Table 4. — Effect of stem height on weighted MOR, MOE and SG, including estimated values, corresponding standard errors (in parenthesis), and pairwise comparisons.*

Height (ft)	MOR (psi)	MOE (1.0 × 10 ⁶ psi)	SG
8	12940 (103) a	1.30 (0.011) a	0.513 (0.0020) a
24	11928 (104) b	1.30 (0.011) a	0.464 (0.0021) b
40	11386 (126) c	1.23 (0.014) b	0.442 (0.0025) c

*Values down each column with the same letter are not significantly different at the 0.05 level.

at the 0.10 level compared to the 6 by 12, 6 by 10, and 6 by 8 feet spacings (Fig. 3). Comparing the effect of height at each level of spacing also indicated significant differences among height levels across all spacings. For all spacing treatments, SG was found to be larger at 8 feet compared to 24 and 40 feet. Also, SG was found to be significantly larger at 24 feet compared to 40 feet in the 8 by 10, 6 by 12, 6 by 10 and 6 by 8 spacings (Fig. 3).

Discussion and summary

Initial planting density in stands which receive weed control and fertilization had a significant effect on the proportion of loblolly pine trees that grow to chipping-saw size (trees ≥ 8.0 inches DBH) in 21 years. Stands planted at close spacings

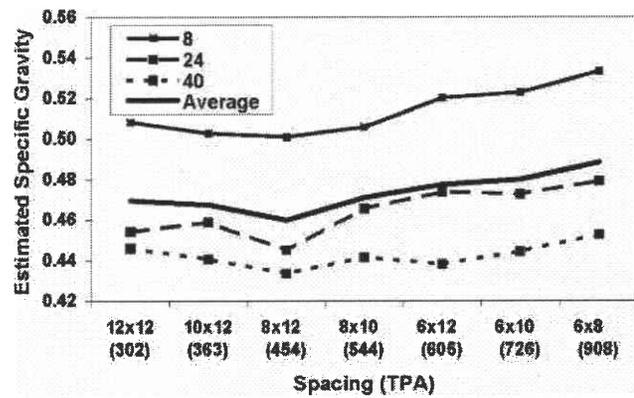


Figure 3. — Estimated SG (ovendry weight/volume at 12 percent MC) at 8, 24, and 40 feet up the stem and average stem SG plotted over spacing and number of trees per acre (TPA).

(6 by 8 feet) had only 27 percent of the trees reaching chipping-saw size by age 21 compared to 97 percent of the trees in stands planted at wide spacings (12 by 12 feet). This practice of using low density management regimes to grow trees rapidly to chipping-saw and sawtimber size is becoming common. Much of the wood produced by these wide spaced trees can be considered juvenile owing to rapid early growth which was promoted by weed control and fertilization when young and a relative lack of competition owing to low stocking rates. Weed control, the first few years after planting, has been reported to significantly increase growth but reduce wood SG (Clark et al. 2006). Antony (2006) found that midrotation fertilization with greater than 200 pounds of nitrogen per acre significantly reduces annual ring SG for 2 to 3 years after treatment. This reducing in SG occurs in the latewood proportion of the ring and thus results in a significant reduction in wood stiffness.

Wood strength is highly correlated with SG, and stiffness is highly correlated with both SG and MFA (Megraw 1985). Weighted average bolt SG in this study was significantly correlated with both weighted bolt MOE ($R = 0.60$) and MOR ($R = 0.81$). Figure 1 shows that estimated MOR at 8 feet increased with decreased spacing and follows the same pattern as the plots for weighted bolt SG at 8, 24 and 40 feet (Fig. 3). MOR at 8 feet did not fall below the MOR values for 24 feet and MOR values for 24 feet did not drop below the values for 40 feet. The plots for estimated MOE at 8 feet and 24 feet are similar except that MOE of the 12 by 12 spacing drops below both the 24 and 40 feet MOE values (Fig. 2). The MOE of the bolts at 8 feet from the 12 by 12 feet spacing is lower than that at 24 feet even though the SG of the bolts at 8 feet is significantly higher (Table 3). One possible explanation for this is that MFA at 8 feet for the same ring count from pith is larger than that at 24 feet (Jordan et al. 2005). Another reason the MOE of the bolts at 8 feet is below that for the 24 and 40 feet heights is because the trees planted at 12 by 12 feet were growing rapidly early in the rotation (Fig. 4) and thus contain a larger diameter juvenile wood core with high MFA.

The results of this study demonstrate that when trees are planted at wide enough spacings to produce a significant difference in growth rate, as a result of weed control and fertilization, wood stiffness, strength and SG are reduced. Analysis of the effect of spacing at each height level showed significant differences in stiffness, strength, and SG among spacings at

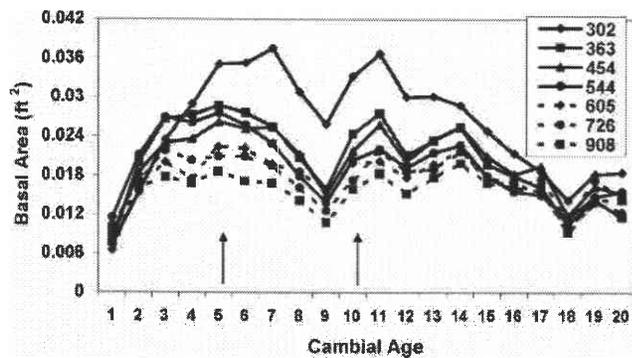


Figure 4. — Effect of initial planting density in trees per acre and fertilization (arrows) on average annual ring basal area growth at 4.5 feet.

8 feet, but did not vary significantly with spacing at 24 or 40 feet. Stiffness at 8 feet of trees planted at 12 by 12 feet was 12 to 14 percent lower than that of trees planted at 6 by 8, 6 by 10 and 6 by 12 feet because the 12 by 12 trees were growing rapidly in response to fertilization and less competition and thus contain a larger diameter of low SG juvenile wood characterized by wide microfibril angles and lower stiffness. A 12 to 14 percent reduction in stiffness at 8 feet, the center of the most valuable sawlog in the tree, is significant since young, fast growing plantation loblolly pines generally contain a large proportion of juvenile wood that may not have the stiffness required to meet the design requirements for No. 2 southern pine dimension lumber (Biblis et al. 1993). The findings of this study emphasizes the importance of considering initial stocking rates to minimize the juvenile core and subsequent good silvicultural management to grow trees that will produce wood that can meet design specifications.

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