IMPACTS OF FOUR DECADES OF STAND DENSITY MANAGEMENT TREATMENTS ON WOOD PROPERTIES OF LOBLOLLY PINE

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Abstract—Stand density management is a powerful silvicultural tool for manipulating stand volumes, but it has the potential to alter key wood properties. At a site in northcentral Louisiana, five density management regimes were conducted over a 45-year period. At age 49, a stratified sample of trees was destructively harvested for crown length, taper, and specific gravity determination. No differences among these tree and wood characteristics were found, suggesting that forest managers have great flexibility in density management options for such a site from a wood quality perspective.

INTRODUCTION

Manipulation of stand density is integral to the management of loblolly pine (*Pinus taeda* L.) plantations. Silvicultural tools for manipulating stand density consist of initial stocking density and thinning. Initial stocking density strongly influences the timing of crown closure, the rate at which stand-level yield accrues, mean tree size at rotation, and the timing and intensity of midrotation treatments such as thinning (Harms and others 2000, Sharma and others 2002, Zhang and others 1996). Thinning similarly affects tree- and stand-level growth rates and mean tree size at rotation (Brix 1982, Visser and Stampfer 2003, Zahner and Whitmore 1960). Due to these profound effects on tree- and stand-level growth and development, Clason (1994) asserted that biological, financial, and ecological performance of pine plantation management is determined by combinations of initial stocking densities and thinning schedules.

In addition to their influences on tree- and stand-level growth and yield, initial stocking density and thinning schedules can influence wood properties and the resulting quality of timber produced (Clark and others 1994). As such, stand density regulation is the most profound silvicultural practice for controlling wood formation and quality (Larson and others 2001). Low initial stocking densities tend to increase branch retention and the size of the live crown as suppression of branches is delayed, which can degrade log quality via the presence of larger and more frequent knots (Macdonald and Hubert 2002). Poor stem straightness has also been observed in response to relatively low initial stocking densities (Brazier 1986, Macdonald and Hubert 2002). The relatively fast stem diameter growth promoted by low initial densities can result in larger volumes of juvenile wood characterized by low specific gravity (Clark and others 2008, Larson and others 2001). Low specific gravity is of particular merit due to its close correlation with structural properties of dry wood and importance as a component of grading rules for southern pine lumber and timber (Larson and others 2001). Similar to low initial stockings, heavy and/or frequent early thinnings promote greater retention of lower branches, increase stem taper, and increase the proportion of juvenile wood within stems. However, the effect of thinning on wood properties is variable depending on initial planting densities, tree age, time of year, and site conditions (Larson and others 2001, Macdonald and Hubert 2002).

While the effects of initial stocking density and thinning on loblolly pine wood properties have been studied, rotation-length information on the effects of combinations of these practices on wood properties is lacking. Such study is vital for determining the quality of wood that can be generated by a wide range of rotation-length density management regimes. The objective of this study was to determine the effects of initial stocking density and thinning regimes on key wood properties of loblolly pine.

METHODS

In 1958, a loblolly pine plantation was planted with 1,200 trees per acre at the Louisiana State University AgCenter Hill Farm Research Station in northwest Louisiana (32°44' N, 93°03' W) on a gravelly, fine sandy loam Darley-Sacul soil (an association of a fine, kaolinitic, thermic Hapludult and a fine, mixed, active, thermic Aquic Hapludult). This well-drained soil type is common in upland forests of northwestern Louisiana, southwestern Arkansas, and eastern Texas (Kilpatrick and Henry 1989). Site index for loblolly pine on a 25-year basis for this site was 65 feet. Prior to planting, the area had reverted from an agricultural field to a 40-year-old mixed pine-hardwood stand. When the previous stand was harvested, merchantable trees were harvested and remaining vegetation was piled and burned 2 years prior to planting.

In 1962, the stand was precommercially thinned to approximate initial stocking densities. Five stocking density treatments, each replicated four times, were conducted: 1,000, 600, 300, 200, and 100 trees per acre. Treatments were arranged in a randomized complete block design, with slope as the blocking factor, and applied to 0.5-acre plots. At age 21, thinning regimes were superimposed on the initial stocking density treatments (table 1). Thinning regimes followed correlated curve trend study protocol (Craib 1947, O'Conner 1935), in which thinning occurred when annual d.b.h. growth of a thinning regime declined relative to that of a thinning regime with lower stand density. The goal of the

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Table 1—Stand density throughout a series of five density management regimes conducted in a loblolly pine plantation in northcentral Louisiana

	Density management regime				
Thinning age	1	2	3	4	5
year	*trees per acre*				
4	1,000	600	300	200	100
21	300	300	200	100	50
26	200	200	100	50	—
31	100	100	50	—	—
36	50	50	—	—	—
41	25	25	25	25	25

thinning regimes was to sequentially reduce initial stocking densities to 25 trees per acre via the correlated curve trend approach.

In July and September 2007, a destructive harvest of trees was conducted. Sampling was stratified by stem d.b.h. distributions in each plot, based on stem d.b.h. measurements collected in June 2007. In each plot, d.b.h. distributions were divided into three classes (upper, middle, lower), and one tree from each d.b.h. class was felled using a feller buncher. Upon felling, total stem length and length of the stem to the lowest live whorl of branches were measured, and crown length was calculated as the difference between these measurements. Inside-bark diameter was measured at the base of the stem and 16, 32, and 48 feet along the stem. Taper was calculated for each 16-foot length of stem from the inside-bark diameter measurements as the change in height per change in radius (Bohannan and others 1974) to provide taper for three logs of each tree. A disk of 1.5-inch thickness was cut from the stem at 4.5 feet for specific gravity determination. A 0.006-inch thick strip was cut through the center of each disk and dried at 50 °C. Specific gravity of each annual ring was determined at 0.0002-inch intervals using an x ray densitometer (Quintek Measurement Systems, Inc., Knoxville, TN) with a resolution of 0.00001 (Clark and others 2006). Specific gravity for each ring was weighted by its basal area. Weighted ring specific gravities of each tree were averaged for the 1962 through 1978 period to isolate the effects of the initial stocking densities, averaged for the 1978 through 2007 period to isolate the effects of thinning regimes, and averaged for the entire life of each tree to determine the effects of the density management regimes on specific gravity.

Analyses of all variables were conducted by analysis of variance (ANOVA) using the MIXED procedure of the SAS system (SAS Institute Inc., Cary, NC). When an ANOVA indicated significant ($P < 0.05$) treatment effects, treatment means were calculated and separated by the DIFF option of the LSMEANS procedure. The models for all analyses consisted of density regime as a fixed effect and block and the block × treatment interaction as random effects.

RESULTS AND DISCUSSION

Among all variables measured, only d.b.h. was significantly affected by the density management regimes (table 2). The lowest density (regime 5) had greater d.b.h. than all other treatments, and d.b.h. of regime 4 exceeded that of regimes 1, 2, and 3. Clason (1994) found that d.b.h. growth of regimes 4 and 5 exceeded that of the other regimes as early as age 7 at this site. These final d.b.h. measurements indicate that diameter growth differentials were very persistent in response to these regimes, so much so that d.b.h. differences among regimes remained even though all regimes were at the same density from 1999 through 2007. This indicates that at this site diameter growth of trees managed at relatively higher densities could not reach growth trajectories of stands managed at relatively low densities, even when thinned to comparable levels.

Larger crowns are associated with low-density management regimes (Larson and others 2001, Macdonald and Hubert 2002), and persistently larger crown areas would likely induce the long-term differences in d.b.h. seen among regimes at this site. However, although crown lengths of regimes 4 and 5 were 7 to 21 percent greater than those of the higher density regimes, they did not significantly differ among regimes (table 2). It is probable that crown damage sustained in an ice storm in 2001 mediated differences in crown area among treatments.

Taper was unaffected by the density management regimes (table 3). In accordance with the uniform stress theory, trees taper to equalize bending stress from wind drag acting on the crown; as such, there is a close linkage between crown dimensions and taper (Dean and Long 1986, Metzger 1893). The lack of differences in crown lengths among regimes in this study may have thus contributed to the lack of taper

Table 2—Crown length, d.b.h., weighted average specific gravity of the entire stem at d.b.h., weighted average specific gravity of wood formed prior to the first commercial thinning, weighted average specific gravity of wood formed during commercial thinnings, and taper in response to five density management regimes conducted in a loblolly pine plantation in northcentral Louisiana

Regime	Crown	D.b.h.	SG	SG-PRE	SG-THIN
	feet	*inches*			
1	37.4 a	19.1 c	0.456 a	0.456 a	0.468 a
2	34.4 a	18.7 c	0.480 a	0.478 a	0.495 a
3	35.0 a	20.2 c	0.465 a	0.472 a	0.466 a
4	40.3 a	23.1 b	0.454 a	0.447 a	0.468 a
5	43.6 a	25.6 a	0.451 a	0.449 a	0.447 a

Means within a column followed by a different letter differ significantly at $P < 0.05$.

Crown = crown length; D.b.h. = diameter at breast height; SG = weighted average specific gravity of the entire stem at d.b.h.; SG-PRE = weighted average specific gravity of wood formed prior to the first commercial thinning; SG-THIN = weighted average specific gravity of wood formed during commercial thinnings.

Table 3—Taper of the lowest, middle, and uppermost logs (defined as 16 feet of stem length) in response to five density management regimes conducted in a loblolly pine plantation in northcentral Louisiana

Regime	LOW	MID	UPPER
	-------	*feet per inch*	-------
1	7.9 a	24.3 a	17.2 a
2	7.4 a	27.1 a	18.3 a
3	8.3 a	22.4 a	17.7 a
4	5.9 a	24.6 a	20.5 a
5	6.0 a	20.0 a	12.9 a

Means within a column followed by a different letter differ significantly at $P < 0.05$.

LOW = taper of the lowest logs; MID = taper of the middle logs; UPPER = taper of the uppermost logs.

differences among density regimes. Given the correlation between stem taper and characteristics such as strength, stiffness, and dimensional stability, it is possible that these regimes produced wood with similar key characteristics.

Specific gravity values were within average values for loblolly pine in previous studies (Zobel 1972, Zobel and McElwee 1958), and no differences in specific gravity were observed among treatments (table 2). Larson and others (2001) noted that specific gravity of loblolly pines planted at close spacings seldom differ from that of wider spacings because summerwood formation is greatly restricted by close spacings. Such an effect would likely be pronounced at this site because summer precipitation of the region is typically substantially below potential evapotranspiration of the same period (Blazier and Clason 2006).

CONCLUSIONS

The lack of differences in crown length, taper, and specific gravity among the wide gradient of density management regimes in this study provides evidence that many key wood properties were relatively resistant to change at this site. This may indicate that forest managers have great flexibility in density management from a wood quality perspective at such a site. However, before a broad assertion about density management can be made with greater certainty, more wood quality characteristics should be studied and a greater array of sites must be observed.

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