IMPACT OF INITIAL SPACING ON YIELD PER ACRE AND WOOD QUALITY OF UNTHINNED LOBLOLLY PINE AT AGE 21

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Abstract—The market for southern pine first thinnings is soft. Thus, forest managers are planting at wider spacings, and using weed control and fertilization to grow chipping-saw and sawtimber trees in shorter rotations. A 21-year-old unthinned spacing study was sampled to determine the effect of initial spacing on wood quality and yield per acre of planted loblolly pine (*Pinus taeda* L.). The study area was planted in the Coastal Plain of GA in 1984 with loblolly pine family 7-56 seedlings. Twenty-one trees from each of seven spacings ranging from 6 by 8 feet (908 trees per acre) to 12 by 12 feet (302 trees per acre) were sampled. Total stem green weight per acre of wood and bark to a 3-inch d.o.b top was estimated to be highest in the 6 by 12, 8 by 10 and 8 by 12 foot spacings. Estimated volume of lumber per acre was slightly higher in the 8 by 12 spacing compared to the 12 by 12-feet spacing. Breakeven stumpage price per acre was highest for the trees planted at 8 by 12-feet spacing. Average number of knots, knot diameter, and average maximum knot diameter increased with increased spacing.

INTRODUCTION

The demand for young, small diameter southern pine in the South is soft. Thus, forest managers are planting at wider spacings and using weed control and fertilization to grow chipping-saw and sawtimber sized trees in shorter rotations. Planting at wide spacing stimulates diameter and crown growth, which can result in larger diameter branches (Baldwin and others 2000, Sharma and others 2002). The diameter of knots is an important characteristic which can degrade southern pine dimension lumber and veneer (Clark and others 1994, Clark and McAlister 1998). Amateis and others (2004) examined the effect of spacing rectangularity on stem quality of plantation loblolly pine (*Pinus taeda* L.) and found that rectangularity had no significant effect on survival or number of potential sawtimber trees by age 19. However, they did report that a 1:3 spacing treatment had a significantly larger maximum branch diameter than the 3:4 spacing.

Some land managers are promoting low-density management, where trees are planted at 600 to 700 trees per acre, then thinned at an early age to 100 to 120 trees per acre and pruned to produce sawtimber at a young age (Burton 1982, Huang and Konrad 2004). Nonindustrial private forest landowners (NIPF) will find it difficult to obtain proper stumpage prices for pruned sawtimber grown under low-density management, because to maximize lumber value pruned logs should be sawn into shop lumber (Clark and others 2004). Thus, NIPF landowners need to establish their plantations at initial spacings that will maximize growth of chipping-saw and sawtimber trees with no early thinning or punning. Our study examined the effect of initial spacing on the yield of chipping-saw and sawtimber trees at age 21 in unthinned stands.

METHODS

We sampled a loblolly pine spacing study that was established on the Atlantic Coastal Plain in 1984 near Rincon, GA. The spacing study contained 11 spacings and each was replicated three times. The study was planted with loblolly pine family 7-56 seedlings on commercially prepared beds with 8 rows and 8 trees per row. At the time of planting each spacing plot was fertilized with 125 pounds of diammonium phosphate and herbaceous weeds were controlled with a broadcast application of herbicide. All plots were re-treated during the first and second years for herbaceous weed control and fertilized with 300 pounds of urea at ages 5 and 10.

Seven of the 11 spacings in the study were selected for sampling to represent a range of trees per acre. The spacings sampled include: 6 by 8 feet or 908 trees per acre, 6 by 10 feet or 726 trees per acre, 6 by 12-feet or 605 trees per acre, 8 by 10-feet or 544 trees per acre, 8 by 12-feet or trees per acre TPA, 10 by 12-feet or 363 trees per acre and 12 by 12-feet or 302 trees per acre. The diameter at breast height (d.b.h.) and total height (THT) were measured on all trees in each plot in the fall of 2004 (table 1). Seven trees were selected for destructive sampling from each plot in proportion to the d.b.h. distribution in the plot. The trees were felled in June 2005 and the height above ground and diameter of all live, dead, and overgrown knots to a 4-inch diameter outside bark (d.o.b.) top were recorded. If the knot was on the face of the stem within the row or between rows also was recorded. Stem height to a 5.5-, 4-, 3- and 2- inch d.o.b. was recorded and the d.o.b. at 17.3 feet also was recorded. Cross-sectional disks 1.5-inches thick were cut at stump, 4.5 feet and at 5 feet intervals up the stem to a 2-inch d.o.b. top. Stem diameter outside and inside bark (d.i.b.) were determined from the disks.

The Girard form class (FC) of each tree ≥ 8.0 inches d.b.h. was calculated based on d.i.b. at 17.3 feet and d.b.h. Stem green weight of wood and bark from stump to a 3-inch d.o.b. and stem weight from stump to a 5.5 inch d.o.b. top were estimated based on d.b.h. and THT using plantation loblolly pine weight equations (Clark and Saucier 1990). Estimated sawmill lumber tally by lumber grade was based on log small-end d.i.b., log length and log grade using unpublished cut log lumber yield equations developed by Clark (Alexander

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Table 1—Average tree characteristics and surviving tree count by initial spacing at age 21

	Initial	d.b.h.		Total Height		Trees < 8.0 inch	Trees ≥ 8.0 inch	Total trees	Proportion trees
Spacing	TPA	Average	Range	Average	Range	d.b.h.	d.b.h.	surviving	surviving
feet	*No.*	*inch*		*feet*		*No./acre*	*No./acre*	*No./acre*	*%*
6X8	908	7.7	2.8-13.8	72	25-89	321	265	586	65
6X10	726	8.4	4.6-12.8	76	52-91	221	278	499	69
6X12	605	8.7	4.1-13.1	75	42-91	165	340	505	83
8X10	544	9.3	5.3-15.5	77	52-90	119	318	437	80
8X12	454	9.7	4.0-14.4	80	36-94	54	333	387	85
10X12	363	10.2	5.7-13.6	81	55-94	31	295	326	90
12X12	302	11.0	3.2-16.4	81	29-92	19	254	273	90

Clark III, Southern Research Station, 320 Green St, Athens GA). Sawlog grade was based on small-end d.i.b. and maximum knot diameter in the log. Log lengths were assumed to be 16.3 feet starting at the base of the stem and 8.3 feet for the top log when log length for the top log was less than 16.3 feet to a 5.0-inch d.i.b. top. Small-end d.i.b. at the top of each log was estimated by interpolation based on disk d.i.b. measurements. Lumber widths cut from a log were calculated assuming the maximum width cant would be cut from a log based on the following log scaling diameter requirements to produce dimension lumber of a specific width:

Dimension lumber size (inches)	Minimum log scaling diameter (inches)
2 by 4	5.0
2 by 6	6.1
2 by 8	8.0
2 by10	10.0

Average lumber grade yields per log were estimated based on log scaling diameter, log length, and log grade of the felled trees, then expanded to per acre yield based on measurement plot tree tallies. Standing tree stumpage price per acre was estimated using the following stumpage values based on Timber-Mart South (2006):

Pulpwood: 5.0 to 7.9 inches d.b.h. at $6.00 per green ton
Chipping-saw: > 7.9 and < 12.0 inches d.b.h. at $22.00 per green ton
Sawtimber: ≥ 12.0 d.b.h. at $38.00 per green ton.

Wholesale lumber value (WLV) based on mill tally was calculated using estimated lumber volume by grade, width and length and Random Length prices for January 17, 2007 (Random Length, 2007).

Breakeven stumpage, the maximum a manufacturer can pay for standing stumpage when considering costs and revenue, was estimated using the following equation:

$$BESTUM = (WLV + CHIPS + BKRES) - (CUTHALL + MANFACT + IRR) \quad (1)$$

where:

BESTUM = break-even stumpage, dollars per ton
WLV = wholesale lumber value, dollars per thousand board feet
CHIPS = wood chips, assume worth $22.00 per ton
BKRES = bark residue, assume worth $14.00 per ton
CUTHAUL = cut and haul costs, assume $16.50 per ton
MANFACT = manufacturing costs, assume $110 per thousand board feet
IRR = internal rate of return, assume 18 percent

RESULTS

Initial spacing at planting had a profound effect on average d.b.h., THT and number of surviving trees per acre at age 21 (table 1). Average d.b.h. and THT increased with increased spacing or decreasing number of trees per acre. The trees planted at 6 by 8-feet spacing averaged 7.7-inches d.b.h. and a 72-foot height, compared to trees planted at 12 by 12 spacing, which averaged 11.0-inches d.b.h. and an 81-foot height at age 21. The distribution of trees by d.b.h. class was influenced by spacing (fig.1). Increased spacing shifted the distribution of trees to the right into larger diameter classes. The closest spacing (6 by 8-feet) resulted in a large proportion of pulpwood size trees and few chipping-saw trees compared to the widest spacing (12 by 12-feet), which resulted in few pulpwood trees and nearly all chipping-saw and sawtimber trees at age 21. The number of chipping-saw and sawtimber trees increased from 265 trees per acre for the 6 by 8-feet spacing to 340 trees per acre for the 6 by 12-feet spacing and decreased to 254 trees per acre for the 12 by 12-feet spacing (table 1). The proportion of trees surviving at age 21 ranged from 65 percent for the 6 by 8-feet spacing to 90 percent for the 10 by 12- and by 12-feet spacing.

The average number of knots on the stem to a 4-inch d.o.b. top increased with increase in spacing and averaged 60 for the 6 by 8-feet spacing compared to 81 for the 12 by 12-feet spacing (table 2). Average knot diameter increased only slightly with increased spacing, ranging from 1.3 inches for the 6 by 8-feet spacing to 1.5 inches for the by 12 by 12-feet spacing. However, average maximum knot diameter increased from 2.7 and 2.6 inches for the 6 by 8- and 6 by 10-feet spacing, respectively, to 3.1 inches for the 12 by 12-feet spacing. Knot diameter within the row and between the rows did not appear to differ. For example, average knot diameter for the rectangular spacing of 6 by 12-feet was 1.3 inches within the row compared to 1.4 inches between the rows.

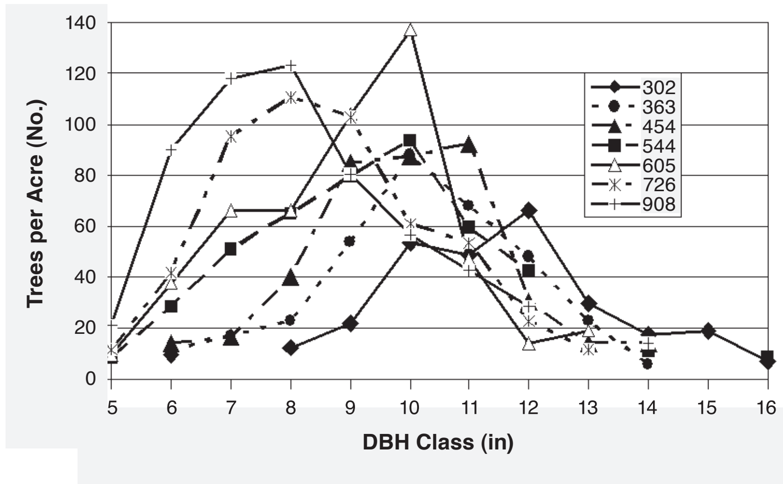

Figure 1—Effect of initial spacing on average diameter distribution of loblolly pine trees at age 21.

At age 21 average total heights of the felled trees ≥ 8 inches d.b.h. varied only slightly with increased spacing, averaging 82 feet for the 6 by 8-feet spacing compared to 85 feet for the 8 by 12- and 10 by 12-feet spacing (table 2). Average sawlog merchantable height to a 5.5-inch d.o.b. top, however, increased with increased spacing and averaged 2.5 logs for the 6 by 8-, 6 by 10-, 6 by 12-, and 8 by 10-feet spacing compared to 3.0 logs for the spacings of 8 by 12-, 10 by 12- and 12 by 12-feet. The primary reason for the change in sawlog merchantable height is that the rate of stem taper decreased with an increased spacing. Average form class was 75 for spacings of 6 by 8-, 6 by 10-, and 8 by 10-feet spacing, increasing to 77 for the 8 by 12-feet spacing, and decreased to 76 for the10 by 12- and 12 by 12-feet spacing (table 2).

Average total stem green weight per acre with bark to a 3-inch d.o.b. was estimated to be 190 tons for the 6 by 8-feet spacing and increased to 215 tons for the 8 by 10-feet spacing and then decreased to 195 tons for the 12 by 12-feet spacing (table 3). Green weight per acre of chipping-saw and sawtimber to a 5.5-inch d.o.b. top was estimated to increase from 114 tons for the 6 by 8-feet spacing to 180 tons for the 8 by12-feet spacing and then decreased to 178 tons for the 12 by 12-feet spacing (table 3). The weight per acre of pulpwood trees to a 3-inch top and the weight of pulpwood in the tops of chipping-saw and sawtimber per acre decreased as spacing increased. When pulpwood and pulp tops are priced at $6 per ton, and all trees ≥ 8-inches d.b.h. are priced as chipping-saw at $21/ton, total standing tree stumpage was highest for the 8 by 12-feet spacing ($3,979 per acre) and lowest for the 6 by 8-feet spacing ($2,763 per acre) (table 3). When chipping-saw was defined as trees 8.0 to 11.9 inches and priced at $21/ton, and sawtimber was defined as trees ≥ 12.0 inches and priced at $38/ton (Timber Mart-South 2006), the 12 by 12-feet spacing had the highest stumpage at age 21 while the lowest stumpage occurred at the 6 by 8-feet spacing (table 3).

When marketing southern pine dimension lumber, width, length, and grade all are important in determining wholesale lumber value. Figure 2 shows the number of sawlogs per acre based on scaling diameter that would be harvested from each spacing, assuming all trees ≥ 8-inches d.b.h. were

Table 2—Average tree[1] and knot characteristics for sample trees by initial spacing

	Spacing (feet) / TPA (no.)						
Variable	6X8 908	6X10 726	6X12 605	8X10 544	8X12 454	10-X12 363	12X12 302
Number of trees sampled (no)	20	21	14	19	20	14	21
d.b.h. (inches)	9.7	9.7	9.7	10.1	10.3	10.8	11.7
Total height (feet)	82	83	83	83	85	85	84
Sawlog merchantable height to 5.5-in d.o.b. (feet)	42	43	42	44	48	49	51
Stem form class	75	75	75	75	77	76	76
Average height to base live crown (feet)	57	59	56	58	59	58	56
Avg number of knots in stem to 4.0 inch d.o.b. top (No.)	60	64	65	72	76	69	81
Average diameter of knots (inch)	1.3	1.4	1.4	1.5	1.4	1.5	1.5
Average maximum diameter of knots (inch)	2.7	2.6	2.8	3.0	3.0	3.0	3.1

[1] Trees ≥ 8.0 inches d.b.h.

Table 3— Average stand characteristics by initial spacing for unthinned loblolly pine at age 21

	Spacing (feet) / Trees per acre (no.)						
Variable	6X8 908	6X10 726	6X12 605	8X10 544	8X12 454	10X12 363	12X12 302
Basal area (square feet per acre)	199	202	218	216	207	189	187
Total stem weight to 3-inch d.o.b. (tons per acre)	190	195	213	215	214	196	195
Weight pulpwood trees < 8.0-inch d.b.h. (tons per acre)	56	48	31	26	11	7	5
Chip-Saw weight to 5.5-inch d.o.b. (tons per acre)	114	126	158	168	180	170	178
Weight of topwood 5.5- to 3.0-inch d.o.b. (tons per acre)	20	21	24	21	23	19	14
Stumpage[1] pulpwood trees and tops ($ per acre)	652	661	627	536	474	383	272
Stumpage pulp + trees ≥ 8.0 inch ($ per acre)	2,763	3,069	3,652	3,809	3,979	3,737	3,838
Stumpage pulp + chip-saw + sawtimber ($ per acre)	3,107	3,243	3,952	4,444	4,411	4,445	5,294
Breakeven stumpage trees ≥ 8.0 inch ($ per acre)	2,667	2,946	3,482	3,572	3,724	3,466	3,486
Lumber volume (mill tally) (1000 boardfeet per acre)	28.7	28.8	35.3	34.8	41.7	34.6	39.1
Wholesale lumber value ($ per acre)	8,628	8,648	10,658	10,745	12,995	10,676	12,763

[1] Stumpage prices

Pulp = $6 per ton

Chip-saw (trees 8.0- to 11.9-inch d.b.h.) = $21 per ton

Sawtimber Trees ≥ 12.0-inch d.b.h. = $38 per ton

Breakeven stumpage is maximum price per ton buyer can pay and covers costs and internal rates of return as shown in figure 3.

harvested and processed into a maximum number of 16 foot sawlogs plus 8-foot top logs when needed to a 5.0-inch d.i.b. top. The number of sawlogs with a scaling diameter sufficient to make 2 by 4 and 2 by 6 lumber, but not large enough to make 2 by 8-lumber, was highest in the closer spacings and lowest in the wider spacings. The number of sawlogs of sufficient diameter to produce 2 by 8-lumber was lowest for the closer spacings and increased with increased spacing (table 2). Only at the widest spacings (10 by 12- and 12 by 12-feet) would more than 20 sawlogs be harvested at age 21 that are large enough to produce 2 by 10 lumber and 2 by 12 lumber (figure 2).

The 8 by 12-feet spacing produced the highest lumber volume per acre mill tally, based on sawlog scaling diameter, length and log grade, followed by the 12 by 12-feet spacing, while the lowest lumber volume per acre occurred for the 6 by 8-feet spacing (table 3). Based on lumber prices for January 2007 (Random Length, 2007) the 8 by 12-feet spacing also yielded the highest wholesale lumber value per acre followed closely by the 12 by 12-feet spacing. Sawlogs from the 12 by 12-feet spacing were, on average, larger in scaling diameter (7.3 inches) than those from the 8 by 12-feet spacing (6.8-inches). However, the 8 by 12-feet spacing produced 231 more sawlogs per acre than the 12 by 12-feet spacing. The 6 by 8-feet spacing had the lowest lumber value per acre and the smallest average log scaling diameter (6.2 inches).

Figure 3 shows the average breakeven stumpage price per ton by d.b.h. class for a simulated harvest of this spacing study

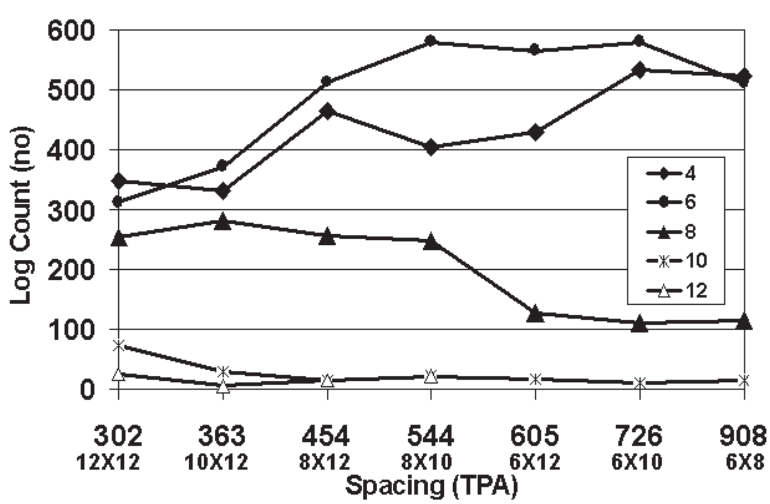

Figure 2—Effect of initial spacing on average number of sawlogs by lumber cant width for loblolly pine at age 21.

at age 21 based on equation (1). Breakeven stumpage was lowest for 8-inch trees ($18 per ton) and ranged from $21 to $23 per ton for trees 9 to 14 inches d.b.h. Breakeven stumpage jumped from a chipping-saw price of about $22 per ton to a sawtimber price of $32 -$36 per ton for trees 15-inches d.b.h. and larger (fig. 3), not 12-inches d.b.h. as indicated by Timber Mart-South (2006) market average prices. The reason for this difference in initial sawtimber pricing is that Timber Mart-South prices are based on the average market price of significantly older trees that have a larger volume of clear wood in the lower bole, resulting in higher log grades and thus a larger volume of high grade lumber. Based on breakeven stumpage prices, the 8 by 12-feet spacing would bring the highest stumpage per acre ($3,724) followed by the 8 by 10-feet spacing ($3,572). The 12 by 12-feet spacing would bring an estimated $ 3,486 per acre at age 21.

CONCLUSIONS

Initial spacing has a large impact on tree survival. Only 65 percent of the trees planted at 6 by 8feet were surviving at age 21 compared to 90 percent survival for the trees planted at 10 by 12 and 12 by 12 feet. Average number of knots, average knot diameter, and average maximum knot diameter increased with increased spacing. The average diameter of knots within the row and between rows did not vary greatly. Average sawlog merchantable height increased with increased spacing and averaged 2.5 logs for the 6 by 8-, 6 by 10-, 6 by 12-, and 8 by 10-spacing compared to 3.0 logs for the 8 by 12-, 10 by 12- and 12 by 12-feet spacing. Wood and bark total stem green weight per acre to a 3-inch d.o.b. top was highest in the 6 by 12-, 8 by 10- and 8 by 12-feet spacings. When chipping-saw is defined as trees 8.0 to 11.9 inches and priced at $21/ton, and sawtimber is defined as trees ≥ 12.0 inches and priced at $38/ton, the spacing with the highest stumpage at age 21 is 12 by 12-feet. However, when break-even stumpage price per acre for a 21-year-old stand are used, the 8 by 12-feet spacing has the highest stumpage. Estimated volume of lumber per acre was slightly higher for trees planted at 8 by 12-feet spacing compared to that for trees planted at the12 by 12-feet spacing, and lowest for trees planted at 6 by 8-feet.

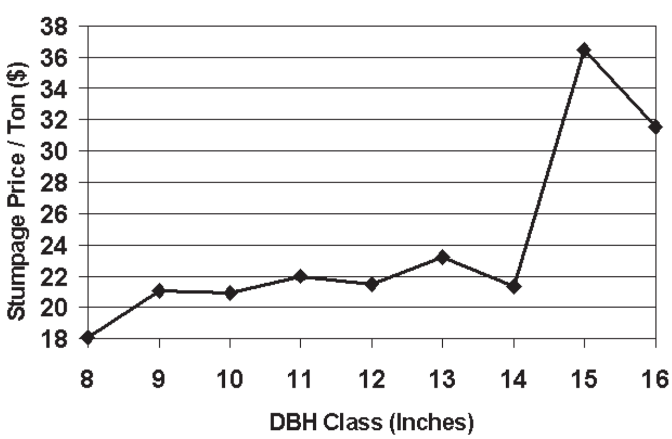

Figure 3—Average break-even stumpage by d.b.h. class for loblolly pine at age 21.

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