FERTILIZATION AND THINNING EFFECTS ON PLANTATION LOBLOLLY PINE TAPER AND WOOD QUALITY

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Abstract—Loblolly pine (*Pinus taeda* L.) plantation forestry continues to incorporate silvicultural advances that increase individual tree growth. These faster-growing trees may have different stem characteristics than their slower-growing predecessors, with unknown effects on wood quality. We examined fertilizer and thinning effects on individual tree taper and wood properties of loblolly pine in the Piedmont of Virginia, United States. Treatments included two levels of thinning (500 (unthinned) and 200 trees per acre residual density) and two levels of fertilization after thinning (none and 200 pounds of nitrogen + 25 pounds of phosphorus per acre) applied at age 15. Nine years after treatment application, age 24, trees (n = 24) were measured and destructively sampled. Wood disk samples were collected and evaluated for oven-dry specific gravity. Thinning significantly increased diameter at breast height (d.b.h.), with no significant change in total height. Log taper from 4.5 feet to 24 feet and wood specific gravity were not affected by treatment. Wood specific gravity at breast height ranged from 0.52 to 0.56. Overall, fertilizer and thinning increased the diameter of the first log without changing wood quality. Height to live crown significantly increased 9 feet at 500 trees per acre residual density compared to the 200 trees per acre, resulting in the potential for greater log length with live-branch-free mature wood growth, especially on the second log.

INTRODUCTION

Advances in silvicultural practices in Southeastern United States loblolly pine (*Pinus taeda* L.) plantations have more than doubled productivity since the 1960s (Fox and others 2007). Part of that realized productivity increase is due to mid-rotation fertilization and thinning, which are now common silviculture treatments. It is important to understand the effects of fertilization and thinning on wood quality to avoid an unexpected reduction in quality of any additional high-value wood produced (Antony and others 2015, Love-Meyers and others 2009). Quality shifts could occur as changes in wood specific gravity, knot location, and log shape.

Specific gravity, the ratio of the density of a substance to the density of water, is a common metric for evaluating wood quality due to its high correlation with pulp yield, and strength of wood products (Panshin and de Zeeuw 1980). Tasissa and Burkhart (1998) found up to a 50 percent reduction in basal area through thinning did not alter ring specific gravity. A decrease in specific gravity is expected after mid-rotation fertilization at high rates, such as ~300 pounds of nitrogen (N) per acre, due to increased early wood to late wood ratio (Albaugh and others 2004) or a reduction in latewood specific gravity (Antony and others 2009, Borders and others 2004). Mid-rotation fertilization at lower levels, for example, 100-200 pounds N per acre, however, can result in increased radial growth without decreasing specific gravity (Antony and others 2009). Small changes in ring specific gravity are rarely detectable at the whole-disk level (Antony and others 2015, Rodriguez and Tomazello-Filho 2019).

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The most financially valuable part of the tree is the butt log or first log. Lumber grade is affected by stem form and knot size frequency and location, which is a function of branch location in standing timber (Clark and others 1994). Height to live crown (HTLC) is easily measured in the field and gives a general idea of live-branch knot location on the stem before harvest. Fertilization has little to no effect on HTLC (Yu and others 2003). On the other hand, increased stand density has a strong negative influence on branch diameter of the first log (Ballard and Long 1988). If thinning occurs before the crown recedes, the trees will retain their lower branches (Peterson and others 1997). Clark and others (1994) found that stands with a higher initial planting density that were then heavily thinned yielded a higher percentage of stronger lumber due to less juvenile wood and smaller knots in the lower bole, when compared to stands planted at a wider spacing.

Stem taper is a measure of the degree of cylindricity of a stem (Larson 1963). Highly tapered stems produce lower lumber and pole yields by volume because of the diameter difference between the log-ends (Larson and others 2001). In general, greater stem taper results from fast-growing trees with longer live crowns than slower-growing trees with less live crown length (Larson and others 2001). With a balance of stand density and volume growth, however, loblolly pine on a high quality site with good height growth should show minimal taper in the first log pre- and post-thinning (Larson and others 2001). When comparing fertilized and unfertilized trees, Zhang and others (2002) reported that fertilization reduced outside- and inside-bark taper.

In this study, we evaluated mid-rotation fertilization and thinning effects on wood quality of stems in a 24-year-old loblolly pine plantation, 9 years post-treatment. We tested the hypothesis that fertilization and thinning do not affect growth, specific gravity, or taper.

METHODS

Study Design

Our study was part of a larger study (named Regionwide 19) testing the effects of fertilization and thinning on loblolly pine productivity, established in Appomattox-Buckingham State Forest near Appomattox, VA . The site was located in the Piedmont (37.426N, -78.66E) on a silt loam, with slopes between 2 and 7 percent, classified as Littlejoe and Spears Mountain soil series (USDA NRCS 2017). The site was planted at a density of 500 trees per acre in 1994. Treatments were established in spring of 2009 at age 15 as a split-plot design with four replicates. The thinning treatments were the split-plot and fertilization was the main plot. All plots received operational weed control in summer 2010.

A subset of plots from the larger trial was used in this study to examine the effects of fertilization and thinning on wood quality. We evaluated two levels of fertilization, (with 200 pounds of nitrogen + 25 pounds of phosphorus per acre and without) and two levels of residual stand density (unthinned at 500 and thinned to 200 trees per acre) in factorial combination, with two replicates. This subset design yielded four treatments: no fertilizer and unthinned 500 trees per acre (NF 500TPA), no fertilizer and thinned to 200 trees per acre (NF 200TPA), with fertilizer and unthinned 500 trees per acre (F 500TPA), with fertilizer and thinned to 200 trees per acre (F 200TPA).

Sample Collection

In spring 2018, at age 24, we destructively sampled three trees per plot (subsamples) and two plots per treatment for four treatments. In total, 24 trees were felled. Healthy trees were selected that were as close to plot average d.b.h. as possible (within 0.7 inches). After the tree was felled, total height and HTLC were measured. Two-inch-thick wood disks were cut from the main stem at 4.5 feet above the ground (breast height), and then at increments of 10 feet above breast height up to a 2-inch diameter top (14, 24, 34 feet, etc.). The wood disk samples were kiln dried for 1 week (at 221 °F) to approximately 10 percent moisture content. We measured over-bark dimensions, inside-bark dimensions, and dry weight. For the disks cut at breast height, the dimensions and dry weight were also taken with the bark removed. Dry disk volume (cubic inches) was measured by water immersion for the disk cut at breast height without bark.

Data Analysis

Specific gravity was calculated as oven-dry weight/ oven-dry volume/density of water for all over-bark disks and for disks without-bark at breast height (Williamson and Wiemann 2010). Individual tree volume was calculated using thinned (200 TPA) and unthinned (500 TPA) equations by Tasissa and others (1997). HTLC was evaluated using data from the larger study including four replicates over time. Log taper was quantified by taking the slope of the line between the inside-bark diameters of the height of log end points. Taper for two 10-foot log increments was calculated, 4.5-14 feet and 14-24 feet. Analysis of variance (ANOVA) was used to test for differences among treatments for specific gravity, d.b.h., total tree height, individual tree volume, HTLC by year, diameter inside-bark, and taper as linear slope of log end points. If $p < 0.05$, ANOVA was followed by a post-hoc Tukey HSD test. Main effects and interactions were examined using JMP® statistical software.

RESULTS AND DISCUSSION

Productivity

Diameter significantly increased from 9.4 to 10.9 inches with thinning ($p < 0.001$, fig. 1a). There were no significant fertilization effects on d.b.h. ($p = 0.632$). There

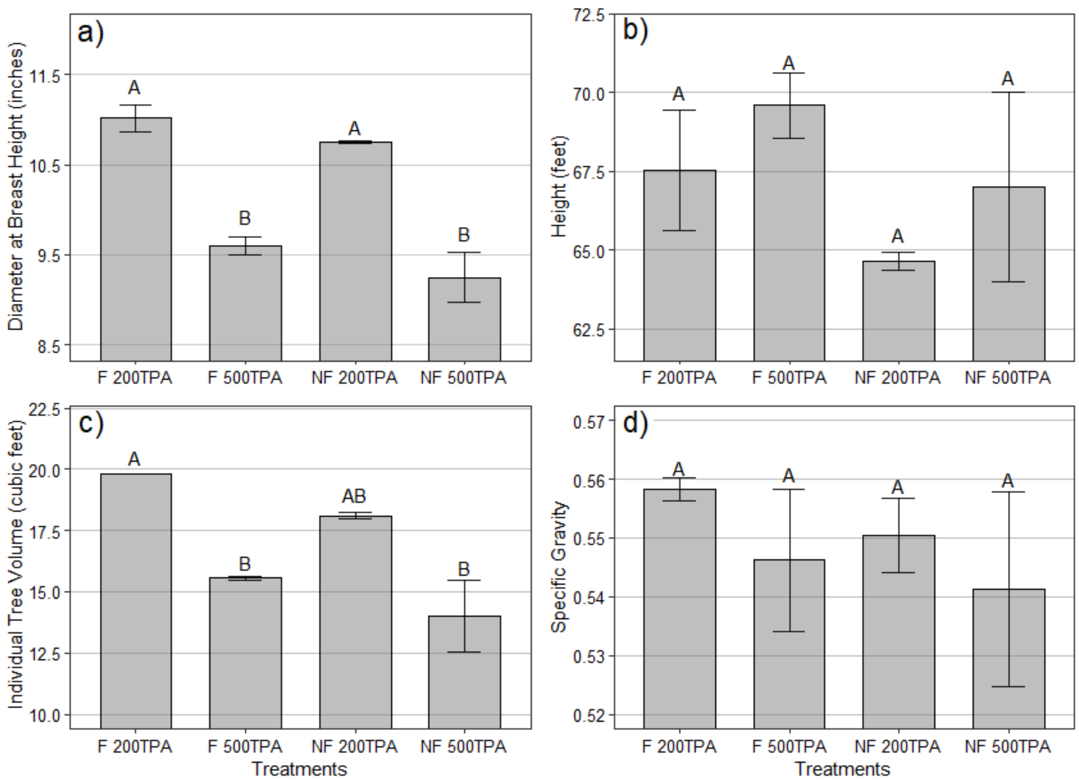

Figure 1—Fertilized 200 trees per acre (F 200TPA), fertilized 500 trees per acre (F 500TPA), unfertilized 200 trees per acre (NF 200TPA), and unfertilized 500 trees per acre (NF 500TPA) treatment means and standard errors for a) d.b.h. (inches), b) height (feet), c) individual tree volume (cubic feet), d) wood disk specific gravity without bark at breast height. Ordered letters show significant differences from Tukey HSD post-hoc test.

was no significant interaction between thinning and fertilization for d.b.h. (p = 0.651). Total height ranged from 64.0 to 70.6 feet, with no significant differences among treatments (p = 0.416, fig. 1b).

The F 200TPA treatment had significantly higher individual tree volume than the F 500TPA and NF 500 TPA treatments, by an average of 5 cubic feet per tree (p = 0.017, fig. 1c). Others have shown individual tree volume increased after thinning, due to increased resources available to the remaining trees (Albaugh and others 2017). Height is not generally affected by thinning or N fertilization, as such, the volume response to treatment predominately results from diameter increases (Albaugh and others 2017). Individual tree volume growth after a thinning comes as a tradeoff to stand volume growth.

Specific Gravity

Increased tree growth after thinning can change ring width and the ratio of earlywood:latewood. Wood specific gravity at breast height ranged from 0.52 to 0.56 with no significant differences among treatments (p = 0.734, fig. 1d). Moreover, we found that wood specific gravity was not affected by fertilization or thinning in the largest and most valuable section of the tree for timber production. In addition, there were no significant differences in over-bark specific gravity throughout the height of the trees ($p > 0.05$). An increase in specific gravity of just 0.02 can significantly increase dry pulp wood yield (Mitchell 1964). A larger sample size may have increased our sensitivity to detect differences in specific gravity at that scale (Williamson and Wiemann 2010). Ring specific gravity following fertilization decreases with increased volume growth; however, this effect may last for just 2 or 3 years post N fertilization (Love-Meyers and others 2009). At the whole-disk level, fertilization did not significantly affect specific gravity (Antony and others 2015, Rodriguez and Tomazello-Filho 2019), which our findings support (fig. 1d).

Height to Live Crown

Without thinning, HTLC significantly increased from age 18 to 24 (p = 0.022, fig. 2). At age 24, we found no significant HTLC differences (p = 0.624) or interactions (p = 0.807) with fertilization. Thinning to 200TPA likely allowed more light lower in the crown than the 500TPA treatments (Yu and others 2003). Additional light would have allowed the 200TPA to retain leaf area lower in the crown, which would support and retain lower branches. Nine years post-thinning, HTLC averaged 39.3 and 30.3 feet, in the 500TPA and 200TPA plots, respectively. This difference in HTLC over time results in a merchantable log free of live branches (~0-32 feet) in the 500TPA

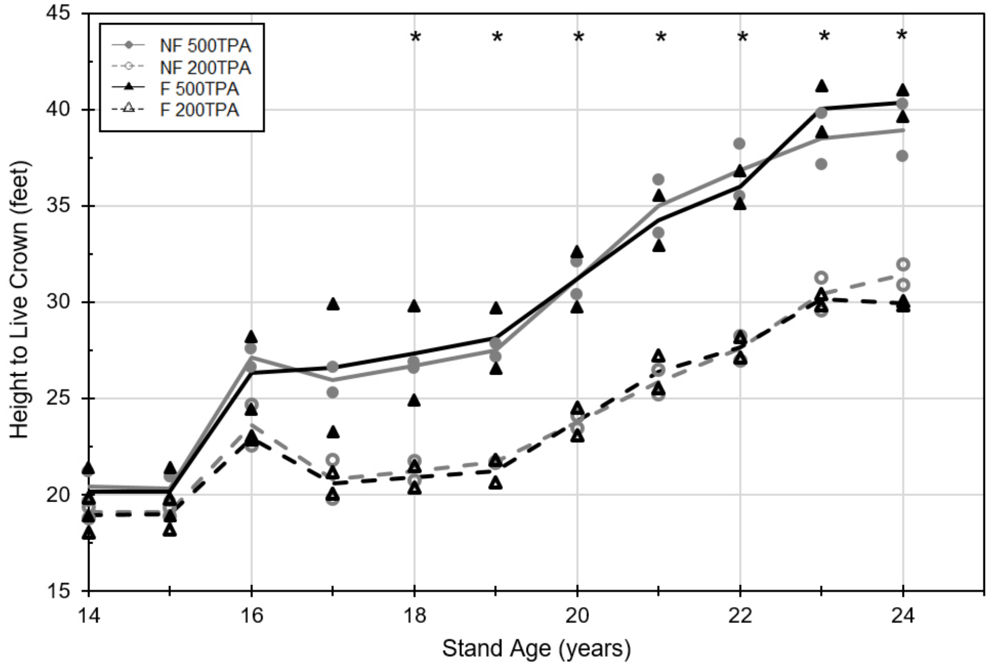

Figure 2—Height to live crown over time for fertilized 200 trees per acre (F 200TPA), fertilized 500 trees per acre (F 500TPA), unfertilized 200 trees per acre (NF 200TPA), and unfertilized 500 trees per acre (NF 500TPA) treatments. Points show mean per plot, where lines show treatment average. Includes data for 11 measurement trees per plot over time. Significant thinning effects by year are denoted by asterisk (*, $p < 0.05$). There were no significant fertilization effects or interactions.

treatment after age 21, whereas the 200TPA treatments still retain live branches below 32 feet and within potential high timber value log length.

Taper

We found significant increases in inside-bark diameter with thinning at 4.5, 14, 24, and 34 feet and with fertilization at 4.5, 34, and 44 feet ($p < 0.05$, fig. 3). There was no significant fertilizer by thinning interaction ($p > 0.05$). We found no significant treatment effect on the taper slope for the first (4.5-14 feet, $p = 0.458$) and second (14-24 feet, $p = 0.983$) logs (fig. 4a-b). These results show that thinning increases the inside-bark diameter of the stem (4.5-34 feet) without increasing the slope, or taper, of the log within the most valuable section.

CONCLUSIONS

In this study, we found that reducing stand density from 500 to 200 trees per acre increased inside-bark diameter of the first and second log without changing taper or wood specific gravity at the individual tree scale. These results would be positive for a mill operator to know that thinned stands from similar sites yield larger logs where the only potential quality difference would be live branches lower on the stem when compared to unthinned stands. For a timberland manager, whose primary economic incentive is to produce more value, these results provide information about the tradeoffs of individual tree value and stand volume in thinned and unthinned stands.

If the trends in diameter, height, volume, specific gravity, HTLC, and taper remain the same through the life of the stand, there are potential tradeoffs between producing rapidly growing wood and clear wood. Based on our results, this tradeoff is influenced by HTLC, in other words, lower live branches, and increases in volume growth with thinning. Currently, the selection of optimum silvicultural treatment, be it fertilization or thinning or a combination of both, is driven by the balance between volume production and individual stem size. Few mills pay a premium for high quality individual stems and consequently, the economics currently tilt the scale in favor of volume production.

In future work at the Appomattox, VA, site, we aim to collect similar data at the time of harvest, near year 30, to assess second thinning and fertilization effects on wood quality. With this study, we hope to inform future research evaluating fertilization and thinning effects on wood quality at second thinning and harvest at other Regionwide 19 sites that differ by location and soil type.

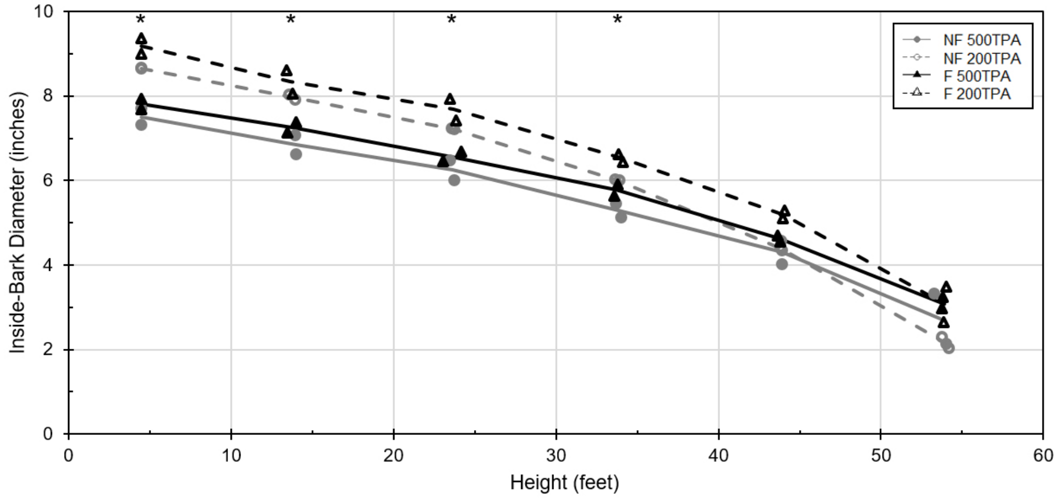

Figure 3—Diameter inside bark (inches) by height (taper) for fertilized 200 trees per acre (F 200TPA), fertilized 500 trees per acre (F 500TPA), unfertilized 200 trees per acre (NF 200TPA), and unfertilized 500 trees per acre (NF 500TPA) treatments. Points show mean per plot, where lines show treatment average. Data shown is from breast height to 54 feet, which is the tallest common diameter measured for all trees and does not include the total height of the tree. Significant thinning effects by year are denoted by asterisk (*, $p < 0.05$).

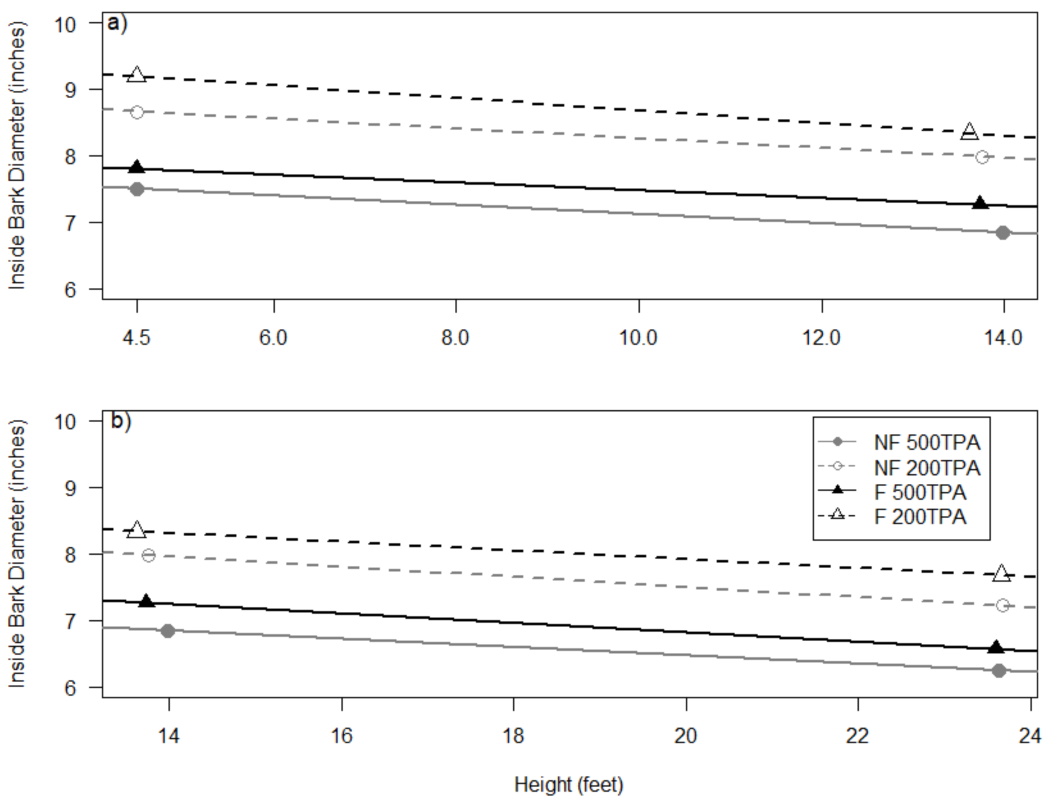

Figure 4—Linear relationship between the inside-bark diameter (inches) end points of the a) first log, 4.5–14 feet, and b) second log, 14–24 feet, for fertilized 200 trees per acre (F 200TPA), fertilized 500 trees per acre (F 500TPA), unfertilized 200 trees per acre (NF 200TPA), and unfertilized 500 trees per acre (NF 500TPA) treatments. There were no significant differences in the slope of the lines between treatments for the first and second log.

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