USE OF THE FAKOPP TREESONIC ACOUSTIC DEVICE TO ESTIMATE WOOD QUALITY CHARACTERISTICS IN LOBLOLLY PINE TREES PLANTED AT DIFFERENT DENSITIES

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Abstract–A Fakopp TreeSonic acoustic device was used to measure time of flight (TOF) impulses through sample trees prior to felling from 27-year-old loblolly pine (*Pinus taeda* L.) plantations established at different planting densities. After felling, the sample trees were sawn into lumber and the boards subjected to edgewise bending under 2-point loading. Bending properties evaluated included MOR (modulus of rupture) and MOE (modulus of elasticity). Regression methods were used to relate these bending properties to the TOF measurements collected from the standing trees. Results suggest TOF measurements alone are unlikely to be adequate when predicting MOR and MOE of loblolly pine lumber from standing trees growing at different planting densities.

INTRODUCTION

Southern pine plantation forests are among the most productive in the world. Much of this productivity is attributable to the application of intensive management practices that have dramatically increased growth rates over the past 25 years or so (Fox and others 2007, Stanturf and others 2003). These practices have resulted in growth rates of as much as 8 green tons per acre per year on some sites with a potential of as much as 10 green tons per acre per year (Stanturf and others 2003). While overall growth rates can be considered a general estimate of productivity, particular product objectives must be taken into account for specific assessments of productivity. For example, Amateis and Burkhart (2012) found a significant correlation between initial planting density and the amount of wood produced for particular product objectives. Where the production of solid wood products is the goal, the quantity of sawtimber can be maximized by planting fewer trees at wider spacings. When pulpwood is the management objective, planting densities of about 680 trees per acre have been found optimal.

While the application of intensive management practices has been shown to increase productivity, the ultimate value of wood harvested from loblolly pine (*Pinus taeda* L.) plantations is determined by both quantity and quality. In a recent study that examined the effect of planting density on wood production, Amateis and Burkhart (2013) found a positive relationship between planting density and visual grade of lumber off the green chain. Higher planting densities produced a greater proportion of board feet per acre graded 2 or better. The better grades associated with higher planting densities offset, to some degree, the smaller quantities of lumber produced at higher densities. In short, the concern is that many of the intensive management practices that have boosted pine plantation productivity in recent years may be having offsetting, or negative impact on some measures of wood quality (Biblis and others 1993, Clark and others 2008, Pearson and Gilmore 1980). Therefore, to properly assess value per acre, managers need estimates of both quantity and quality (Amateis and Burkhart 2013; Clark and others 2004, 2010).

Estimates of wood quantity are obtained from field measurements or from models that provide predictions of harvested wood from stand and tree variables that are highly correlated with tree volume and stand yield. Either way, destructive sampling is not needed to estimate wood quantities. Estimates of wood quality, however, are not so easily obtainable because they rely on information about wood properties that are not readily observable or directly measureable. Therefore, since the development of acoustic devices, interest has grown in their use as a non-destructive and efficient tool to collect information about wood quality characteristics. The fundamentals of acoustic wave propagation through trees and logs have been known for some time. From them, devices implementing two measurement methods have been developed: time of flight (TOF) for standing trees and resonance for logs (Wang 2011). While the devices and methods differ, both rely on the movement of acoustic waves through wood as a

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convenient way to obtain information on wood properties. However, since wood characteristics can vary greatly within a tree or log, both radially and longitudinally, the application of TOF and resonance methods for assessing them has not been straight forward or standardized. For example, Mahon and others (2009) studied the use of TOF methods for identifying trees with high stiffness. They determined a number of potential paths that an acoustic wave might travel both longitudinally and radially and tested some alternatives and the effect of probe placement on TOF measures. They found that placing probes on opposite faces of the tree minimizes the variance of TOF measures. In a study using both TOF and resonance methods, Grabianowski and others (2006) applied a three-probe TOF system where the three probes were lined up on the same side of the tree. Results showed significant correlation between TOF and resonance measurements, but the TOF measurements were on average higher suggesting that the TOF method is measuring outerwood TOF rather than a weighted average TOF, which includes bark, given by the resonance method. In order to bring measurements from both methods in line, Wang and others (2005) and Mora and others (2009) developed models for adjusting observed tree TOF values to equivalent log velocities.

In a comprehensive genetic study using Monterey pine (*Pinus radiata* D. Don) from two seedlots, Matheson and others (2002) applied several different acoustic wave devices to standing trees and logs to correlate acoustic wave velocity with average MOE of sawn lumber obtained by machine stress grading. They found that the speed of sound along felled logs was sufficiently correlated with average MOE of the boards to allow log segregation into MOE classes. A weaker, but still significant correlation was found between standing trees and board MOE for a control seedlot, but, unexpectedly, no significant correlation was exhibited for the orchard seedlot.

The purpose of this study was to relate TOF measurements made on standing trees from a loblolly pine spacing trial to the wood properties of boards recovered from those trees.

DATA

In the spring of 1983, a set of loblolly pine spacing trials was established in the Piedmont of Virginia and the Coastal Plain areas of Virginia and North Carolina. Three replicates containing 16 treatment plots in each replicate were established at each of four sites. Only the Lower Coastal Plain site in Virginia was used for this study. Of the 16 treatment plots available from each replicate, only the square planting densities of 6- by 6-feet (1,210 trees per acre), 8- by 8-feet (681 trees per acre), and 12- by 12-feet (302 trees per acre) were utilized. Thus, three plots of each of the three spacing treatments were used for the study reported here. Additional information about the study design, a history of the research results over the life of the study, and final growth and yield results at age 25 can be found in Amateis and Burkhart (2012).

At age 27 data were collected on all live standing trees from the three square spacing treatment plots at the three replicates on the Lower Coastal Plain site. Standing tree measurements included diameter at breast height (d.b.h.), total height, height to live crown, and product categorization as either sawtimber or pulpwood. Trees with a d.b.h. of at least 8.6 inches with a 16-foot butt log free of damage and disease, and straight such that a line connecting the center of the stem at any two points above the stump would not lie outside the tree bole were categorized as sawtimber.

From each treatment plot up to six trees were selected at random from the pool of qualifying sawtimber quality trees. For plots that did not have six qualifying trees in a particular replicate, additional qualifying trees from the same treatment plot in the other two replicates were used. An attempt was made to obtain 18 sample trees representing each treatment plot for a total of 54 sample trees. Due to the lack of suitable sample trees from the 1,210 trees per acre plots, however, the total number of sample trees was 48.

A Fakopp TreeSonic acoustic device was used to measure time of flight (TOF) acoustic velocities on the 48 sample trees prior to felling. The device consists of two probes, one with a start sensor and the other with a stop sensor, a portable scopemeter, and a hammer. The two probes were angled toward each other and inserted through the bark and cambium into the sapwood. The lower probe was positioned about 0.7 m above the ground and the upper probe 1 m directly above the lower probe on the same face of the stem. Three measures of TOF were obtained for each tree and averaged to obtain one estimate of TOF acoustic velocity for each tree.

Sample trees were felled and the butt log was cut from each tree, skidded off the plots, and subsequently transported to the sawmill. A portable Wood-Mizer sawmill was used to recover lumber from the sample logs. All logs were milled employing the same operator and sawn into structural 2-inch and non-structural 1-inch boards according to mill-run specifications. All 2-inch boards were graded green as #1, #2 or #3 by a certified grader according to national grading rules for structural light framing lumber (National Grading Rule Committee 2004). Following green grading, all #1 and #2 boards were racked on drying sticks and air-dried for several months reaching a stable moisture content of about 20 percent (table 1).

Out of the 2-inch boards green graded #1 and #2, 1 inside board (containing pith) and 1 randomly selected outside board per log were chosen for testing of mechanical properties resulting in 87 test boards. The center 80 inches of each board were extracted. If the sample board had a width of 6 inches or 8 inches, one edge was randomly selected and set down on the carriage. The board was then ripped to a width of 4 inches. Thus, each sample board was of dimension 2 x 4 x 80 inches.

The boards were kiln-dried to approximately 10 percent moisture content. Following drying, each board was re-graded by the same certified grader. Of the 87 #2 and better green graded boards, the drying process resulted in 29 boards being down-graded to #3. All test boards were then shipped to the Timber Products Inspection (TPI) lab. Upon receipt at TPI, the boards were stored at ambient conditions of 75 °F and 50 percent relative humidity awaiting testing.

In the lab, each board was subjected to edge-wise bending in accordance with ASTM D4761 testing protocols. A static bending load was applied to each board across a span of 68 inches (span to depth ratio of 17) at a testing speed that applied stress at a rate of 4,000 psi per minute. Deflection data were collected until the load reached 1,000 pound force, whereupon each board was loaded until failure. Data collected included strength (MOR), stiffness (MOE) and cause of failure (table 1).

METHODS AND RESULTS

Pearson correlation coefficients relating TOF to the average MOE and MOR across boards by tree were computed. Neither MOE nor MOR was significantly correlated with TOF (probability values of 0.1420 and 0.8253, respectively). A number of different linear regression equations were explored to link TOF with mechanical properties. No regressions for predicting MOE or MOR that included TOF as a regressor were significant.

Another effort was made to correlate the TOF with MOE of the outer and inner boards separately in the anticipation that board position might be a useful indicator variable. These regressions were also not significant.

Table 1–Mean values of time-of-flight (TOF) acoustic velocities, modulus of elasticity (MOE) and modulus of rupture (MOR) (standard deviation in parentheses) for sample boards sawn from 48 sample trees at age 27 years. Standard deviations are in parentheses

Planting density	Board position[a]	Number sample trees	Number sample boards	TOF	MOE	MOR
trees ac^{-1}				*m/s*	*10^6 psi*	*psi*
1,210	Inside		10		1.345 (0.374)	6,749 (1,966)
	Outside		11		1.286 (0.276)	7,155 (1,796)
	All	12	21	3468 (339)	1.314 (0.319)	6,961 (1,843)
681	Inside		16		0.994 (0.316)	4,945 (1,774)
	Outside		15		1.116 (0.293)	5,626 (2,062)
	All	18	31	3580 (318)	1.053 (0.306)	5,275 (1,918)
302	Inside		16		0.832 (0.240)	4,713 (1,375)
	Outside		19		0.954 (0.261)	6,192 (2,067)
	All	18	35	3305 (327)	0.898 (0.255)	5,516 (1,912)

[a] Inside boards contained pith.

DISCUSSION

Efforts to correlate TOF measurements collected on sample trees using the Fakopp TreeSonic acoustic device were unsuccessful with these data. There are a number of possible reasons for this. One of the most obvious is that our sample size consisting of one inside and one outside board per tree was small while the variability of MOE was very large. As Feeney and others (1998) have noted, the great variability in the structure and properties of wood in the radial, tangential, and longitudinal directions make the measurement of the propagation of ultrasound through wood a challenging task. A larger sample size might have yielded more positive results.

We also had no information about the position of each board within the tree in relation to the position of the Fakopp probes when the TOF measurements were taken. Obviously, additional TOF measurements with alternative probe placements might have led to better correlations with MOE. Another source of variation in our data was the impact of knots on mechanical properties. The correlation of MOE with wood density weakens when testing full-sized sample boards as done in this study (Biblis and others 2004). Grabianowski and others (2004) have also documented the impact that local climatic effects, such as wind direction and speed, can have on acoustic velocity measurements. No measurements of or accounting for any of these effects was made.

At present, sawlog markets are not rewarding landowners for growing loblolly pine trees with particular mechanical properties. However, future markets may account for trees that can produce lumber meeting overall stiffness grades or MOE values that meet particular design specifications. In order for that to happen, it is likely that a more robust method of non-destructively estimating mechanical properties will be needed.

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