Wood Quality/Technology

Moderator:

ALEX CLARK
USDA Forest Service

INFLUENCE OF THINNING AND PRUNING ON SOUTHERN PINE VENEER QUALITY

Mark D. Gibson, Terry R. Clason, Gary L. Hill, and George A. Grozdits[1]

Abstract—This paper presents the effects of intensive pine plantation management on veneer yields, veneer grade distribution and veneer MOE as measured by ultrasonic stress wave transmission (Metriguard). Veneer production trials were done at a commercial southern pine plywood plant to elucidate the effects of silvicultural treatments on veneer quality, yield, and modulus of elasticity. Forty-nine trees, totaling 1,312 ft^3, were selected from an intensively managed, 50-year-old loblolly pine (*Pinus taeda* L.) plantation at the Hill Farm Research Station of Louisiana State University at Homer, LA. Trees were selected from each of four treatments, pre-commercially thinned (PCT), pruned (PRN), pre-commercially thinned & pruned (PCT&PRN), and control (CTRL)[no thinning or pruning]. Twelve trees were selected per treatment, except for the PCT&PRN treatment that had thirteen trees. Each tree was felled, bucked into a log 17-foot-long plus trim, transported to the plywood plant, scaled on the log yard, bucked into two 101.5-inch-long peeler blocks (butt and top), conditioned in a drive-in steam chest (vat), rotary peeled into 1/8-inch-thick veneer using the plant's normal production process, then dried in a veneer drier. The length and width of full-sized veneer sheets, full-length random width strips (including half sheets) and half-length fishtails and strips were recorded to establish veneer yields. Full-sized sheets were graded visually according to U.S. Product Standard PS 1-83 in the green condition and after drying to establish veneer quality and drier degrades [A, B, C, D, and U (Utility) grades were identified] and by a Metriguard veneer tester for MOE determination. Five Metriguard groupings were assigned as follows: G1 (0-435ms, 2.44×10^6 psi), G2 (436-475ms, 2.17×10^6 psi), G3 (176-525ms, 1.86×10^6 psi), G4 (525-700ms), and G5 (> 700ms). Only the G1, G2, and G3 groupings are used to produce laminated veneer lumber (LVL); hence, the G4 and G5 groupings were combined into a below grade category. When G1, G2, and G3 veneer classifications were combined, all intensive silvicultural treatments had a higher number of veneers qualify compared to the CTRL treatment in both butt and top blocks. Also, the number of veneers qualifying for LVL production in the top blocks exceeded that in the bottom blocks for all treatments. It is also interesting to note that the percentage of G1, G2, and G3 veneers in the top block exceeded that in the butt block in all treatments except the PRN treatment. Compared to the CTRL treatment, the PCT and PRN treatments had slightly faster average sound transmission times in veneers produced from both butt and top blocks, which corresponds to stiffer veneer. However, these faster transmission times did not significantly alter the MOE range (G-Rating). The percentages of qualifying G1, G2, and G3 veneers were about equal in each treatment, but the intensively managed trees produced more G-grade qualifying veneers. The top blocks produced more G-grade qualifying veneers in all except the pruned treatment. The average Metriguard grade for all treatments was G2. The relationship of MOE to visual grade is the subject of a future paper.

INTRODUCTION

Research priorities change, but one area that continues to be a high priority among government, non-industrial, and industrial organizations is growth and yield. Maximizing growth and yield relies on proper timing of silvicultural operations such as thinning and pruning. In loblolly pine plantations, these treatments can be instrumental in improving log and lumber volumes as well as dry veneer yields. Increased volume is important, but equally important, if not more so, is the grade of the veneer produced.

Lynch and Clutter (1998) state "grade is an essential determinant of value for southern pine plywood." Phillips and others (1979) reported that loblolly pine yielded 54 percent of the original log volume in dry usable veneer, while slash pine produced 55 percent. They also found loblolly pine produced 5 percent A-grade, 12 percent B-grade, 37percent C-grade, and 46 percent D-grade dry,

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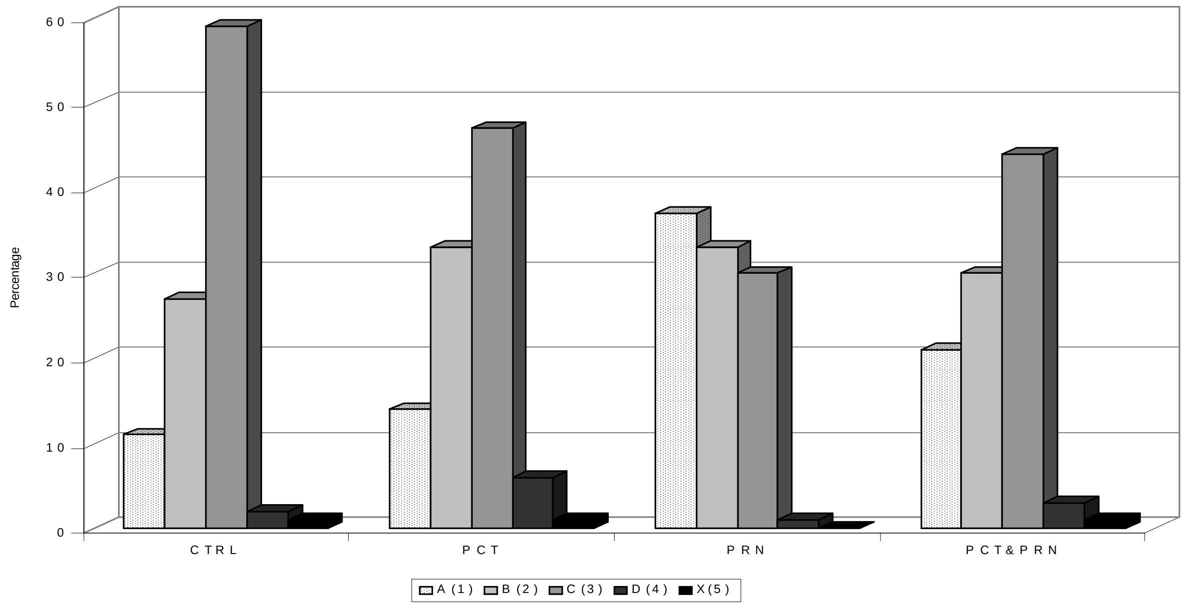

Figure 1—Dry veneer visual grade percentage yield by treatment (butt and top blocks combined).

untrimmed veneer. Woodfin (1973) reported that 55 percent of the total green plywood peeler block volume is recovered as dry, untrimmed veneer for four major western species. Funck and Sheffield (1985) indicated that dry veneer recovery was between 43 and 55 percent of peeler block volume. MacPeak and others (1987) showed dry veneer recovery of 48.3 percent for fast-grown 20- to 25-year-old loblolly pine, while "mill run" tree-length logs in a control group averaged 54.7 percent dry veneer recovery. Schroeder and Clark (1970) obtained a 60 percent dry veneer recovery when peeling 405 loblolly pine blocks. A more detailed description of the production process for rotary peeled veneer appears in Koch (1970, 1985).

This paper reports the results of a preliminary study designed to evaluate the effects of thinning and pruning on veneer yield, quality, and modulus of elasticity from an intensively managed, mature (50-year-old) loblolly pine plantation.

METHODS

Forty-nine trees were selected from an intensively managed, 50-year-old loblolly pine plantation located at the Hill Farm Research Station of Louisiana State University in Homer, LA. Trees were selected from each of four treatments, pre-commercially thinned (PCT) [average dbh 19.3 in], pruned (PRN) [average dbh 19.1 in], thinned & pruned (PCT&PRN) [average dbh 19.2 in], and control (CTRL) [no thinning or pruning, average dbh 15.6 in]. Twelve trees were selected per treatment, except for the thinned & pruned treatment that had thirteen trees. Each tree was felled, bucked into a 17-foot-long log plus trim, transported to the plywood plant, scaled on the log yard, bucked into two 101.5-inch-long peeler blocks (butt and top), conditioned in a drive-in steam chest (vat), rotary peeled into 1/8-inch-thick veneer using the plant's normal production process, then dried in their veneer drier. The length and width of full-sized veneer sheets (53-inch x 101.5-inch green and 51-inch x 101.5-inch dry), full-length random width strips (including half-sheets) and half-length fishtails and strips were recorded in both the green and dry condition to establish veneer yields. The facility produces veneer for a laminated veneer lumber (LVL) plant and for a commodity plywood sheathing plant. The plywood production

Table 1—Cubic-foot log volume and veneer recovery percentage by treatment

Treatment	Volume yield: Log (ft^3)	Veneer recovery: Green (pct)	Veneer recovery: Dry (pct)
Control	237	60	58
Pre-commercial thinned & pruned	373	69	66
Pre-commercial thinned	358	72	69
Pruned	344	64	61
TOTAL	1,312	67	64

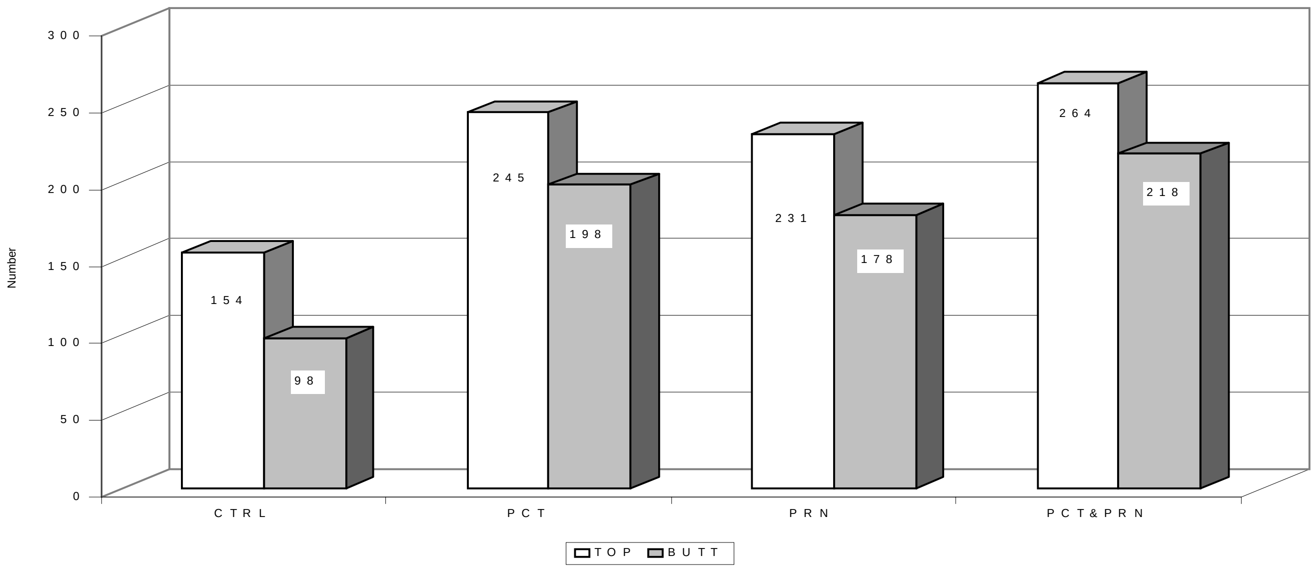

Figure 2—Number of full-sized veneer sheets qualifying for the G1, G2, and G3 grade classifications within each treatment for butt and top peeler blocks.

facility manufactures 245,000 ft^2 per 8-hour shift on a 3/8-inch basis. The LVL plant requires sorting the veneers by their modulus of elasticity values (MOE), which is done by a Metriguard Model 2600 FX veneer tester. The plywood plant requires visual grading for separation of core and face veneer as well as face veneer classification. Accordingly, the full-size sheets were visually graded according to U.S. Product Standard PS 1-83 in the green condition and after drying to establish veneer quality and drier degrades [A, B, C, D, and U (Utility) grades were identified] and by Metriguard for MOE determination. The correlation of veneer stiffness and LVL performance is constantly monitored by testing LVL samples and adjusting the acceptable ranges of veneer ultrasonic sound transmission rates. Five classifications (G1, G2, G3, G4, and G5) are assigned, although only veneers in the G1 through G3 groupings are actually used to produce LVL. The five groupings correspond to the following Metriguard grades, millisecond ranges, and MOE values: G1 (0-435ms, $2.44x10^6$ psi), G2 (436-475ms, $2.17x10^6$ psi), G3 (176-525ms, $1.86x10^6$ psi), G4 (525-700ms), and G5 (> 700ms). The G4 and G5 groupings were combined into a below grade category. A VHS camcorder was used to record both the Metriguard grade and the APA visual grade of the veneers. The plant provided a certified veneer grader whose grades were recorded onto the videotape. Metriguard readings and visual grades were transcribed from the videotape onto paper for entry into Microsoft®-Excel.

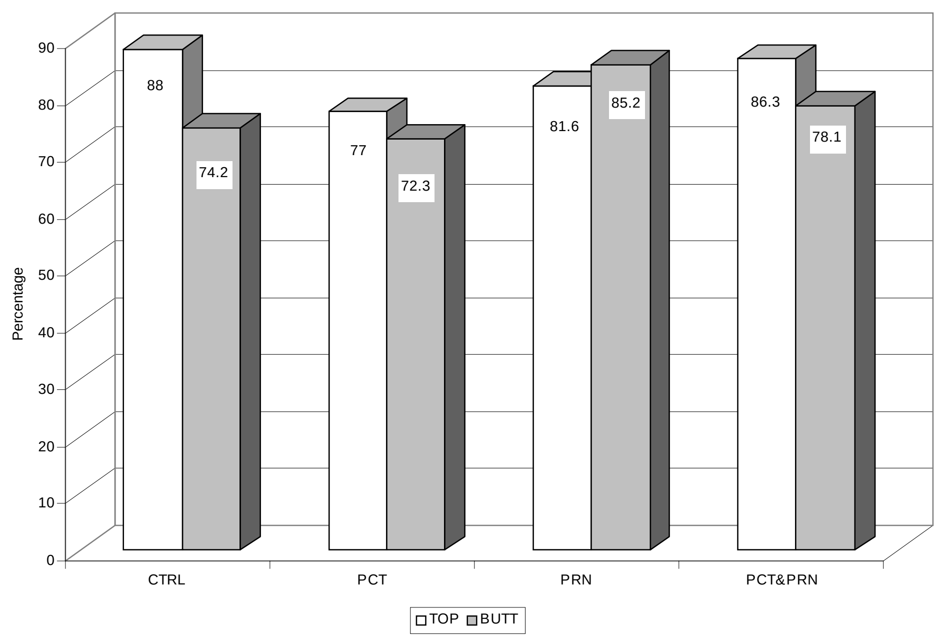

Figure 3—Percentage of full-sized veneer sheets qualifying for the G1, G2, and G3 grade classifications within each treatment for butt and top peeler blocks.

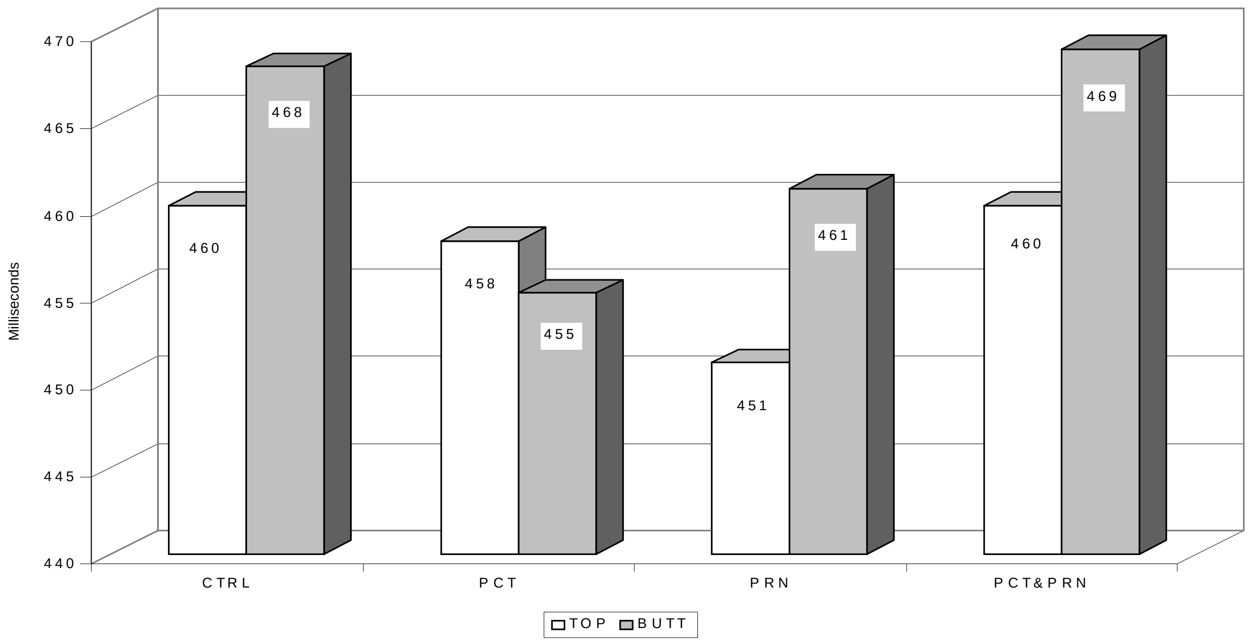

Figure 4—Mean metriguard millisecond transfer rate for full-sized veneer sheets in the G1, G2, and G3 grade classifications within each treatment for butt and top peeler blocks (faster transmission rates indicate stiffer veneers).

RESULTS AND DISCUSSION

Log Cubic-Foot Volume Yield

Table 1 shows the mean cubic-foot volume yield of the logs by treatment. The pre-commercially thinned and pruned treatment yielded 57percent more volume than the control. Pre-commercial thinning alone produced 51 percent more volume and pruning alone generated 45 percent more volume than the control. All silvicultural treatments produced volumes greater that of the control treatment; however, volume in the pruned treatment was the lowest for all silvicultural treatments. One possible explanation for this decrease is the volume of pruned logs was affected by loss of crown area and the consequent decrease in photosynthate. Hence, less material was available for wood formation. Because thinning was not done in combination with the pruning, the growth rate was not stimulated sufficiently and resulted in less volume production.

Dry Veneer Yield

Table 1 also shows the veneer recovery percentages of green and dry veneers by treatment, i.e., the percentage of the original log volume that became green or dry veneer. The pre-commercial thinning and pruning treatment produced 14 percent more dry veneer than the control. Pre-commercial thinning alone produced 19 percent more dry veneer than the control and pruning alone yielded 5 percent more dry veneer than the control. All silvicultural treatments improved veneer recovery above that of the control treatment.

Visual Grade Yield

Figure 1 illustrates the dry veneer visual grade percentage yields for each treatment. A higher percentage of A-grade and B-grade veneers were produced by the silvicultural treatments when compared to the control treatment. A-grade dry veneer yield in the pruned treatment was 236 percent greater than that for the control treatment. B & Better dry veneer grade yield in the pruned treatment was 69 percent of the total compared to 38 percent for the control treatment, a dramatic increase. The percentage of C-grade veneer was greatest in the control treatment.

Metriguard Classification

Figure 2 compares the butt peeler block with the top block for each of the treatments. When G1, G2, and G3 veneer categories were combined, all intensive silvicultural treatments had a higher number of veneers qualify compared to the CTRL treatment in both butt and top blocks. The number of qualifying veneers in the top blocks exceeded that of the bottom blocks for all treatments. Top peeler blocks have less taper than butt blocks and consequently have fewer round-up losses during veneer production.

The percentage of G1, G2, and G3 veneers in the top block exceeded that in the butt block in all treatments except the PRN treatment as shown in Figure 3. The percentages of qualifying G1, G2, and G3 veneers were about equal in each treatment (figure 3), but the intensively managed trees produced a greater number of G-grade qualifying veneers (figure 2). Again, the top blocks produced more G-grade qualifying veneers in all except the pruned treatment (figure 3).

Compared to the CTRL treatment, the PCT and PRN treatments had slightly faster average sound transmission times in veneers produced from both butt and top blocks, which corresponds to stiffer veneer (figure 4). However, these faster transmission times did not significantly alter the MOE range (G-Rating); hence, the average Metriguard grade for all treatments was G2.

CONCLUSIONS

Log Cubic-Foot Volume Yield

Log volume yield was highest in the pre-commercially thinned and pruned treatment (28 percent of the total volume, i.e., 57 percent more than the control) and lowest in the control treatment (18 percent of the total volume).

Dry Veneer Yields

Dry veneer volume yield (recovery) was highest for the pre-commercially thinned treatment, 69 percent compared to 58 percent in the control.

Visual Grade Yield

A-grade veneer yield in the pruned treatment was 236 percent greater than that for the control treatment. B & Better dry veneer grade yield in the pruned treatment was 69 percent of the total compared to only 38 percent for the control treatment.

Metriguard Classification

When G1, G2, and G3 veneer categories were combined, all intensive silvicultural treatments had a higher number of veneers qualify compared to the CTRL treatment in both butt and top blocks. The number of qualifying veneers in the top blocks exceeded that of the bottom blocks. Compared to the CTRL treatment, the PCT and PRN treatments had slightly faster average sound transmission times in veneers produced from both butt and top blocks, which corresponds to stiffer veneer. The average Metriguard grade for all treatments was G2.

Future Implications

The combined effects of increased log volume yield (45-57 percent above the control), higher dry veneer yields (5-19 percent above the control) and the dramatic increase in B & Better dry veneer grades (24-82 percent) support the potential for rotary peeling veneer mills to increase productivity, product yield and promote value-added products when they peel log supplies from intensively managed pine plantations.

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EFFECT OF SILVICULTURE ON THE YIELD AND QUALITY OF VENEERS

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Abstract—The structural and aesthetic value of wood is typically sacrificed in an attempt to meet demand. This paper addresses the financial and quality aspects of silvicultural choices as it relates to wood veneers. Five trees each were harvested from an uneven-aged stand and from the following even- aged stands: intensive plantation, conventional plantation, and natural regeneration. The 48-year old loblolly pine trees were peeled at a veneer mill and graded visually (plywood grades) and ultrasonically (LVL grades). The intensive plantation trees, pruned at an early age to produce a large, clear bole, possessed the lowest quality veneer, both in terms of visual and ultrasonic grade. Although these trees did produce large quantities of clear wood, the early, rapid growth rates resulted in a exaggerated conical shape and thus a large slope of grain. The most desirable veneers came from those trees with a modest growth rate during the juvenility period—from the natural regeneration and uneven aged stands.

INTRODUCTION

The primary objective of most current timber management strategies is optimization of wood fiber volume, generally at the expense of wood quality. A shift in public values coupled with harvesting restrictions and the unavailability of old-growth timber has resulted in a higher percentage of the wood basket being supplied by plantation and intensively managed timber stands. The trees which come from these plantation forests are harvested at a young age when compared to virgin and old growth trees, and will thus contain a higher percentage of juvenile wood and invariably lessened physical and mechanical lumber properties.

The effect of silvicultural treatments on the physical properties of wood has been extensively studied. Thinning and fertilization have been shown to significantly alter overall wood specific gravity (Choong and others, 1989; Lear and others, 1977; Cown and McConchie, 1981), earlywood/latewood specific gravity distribution (Choong and others, 1989; Crist and others, 1977), knot size, location, and quantity (Whiteside and others, 1977; Guldin and Fitzpatrick, 1991), tree form (Guldin and Fitzpatrick, 1991), fiber length (Cown and McConchie, 1981; Crist and others, 1977), and juvenile wood formation (Zobel and VanBuijtenen, 1989; Ruark and others, 1991). Although numerous studies have inferred relationships between physical and mechanical wood properties, in actuality the correlations between physical and mechanical properties are low. The best correlation exists between specific gravity and stiffness, with correlation coefficients generally around 0.5 (Schroeder and Atherton, 1973; Senft and others, 1962). Similar correlation coefficients exist between specific gravity and strength (Doyle and Markwardt, 1966; Senft and others, 1962). Thus, although the effect of silvicultural practices on physical properties is somewhat understood, the stiffness and strength of the resulting wood cannot be determined from these physical properties.

The response of mechanical properties to silvicultural treatments is less understood. Bendtsen and Senft (1986) looked at mechanical and anatomical properties in individual growth rings of plantation-grown eastern cottonwood and loblolly pine and found that a large percentage of juvenile wood exists along with a marked decrease in stiffness and strength for the first 10-15 growth rings. Senft and others (1986) found similar findings for a natural stand of 60-year-old Douglas-fir trees. Similar studies have also been conducted (Moody, 1970; Pearson and Gilmore, 1971; Yamamoto and others, 1976), but their conclusions were limited to one type of silvicultural treatment.

This primary objective of this paper is to establish relationships between silvicultural regimes and the one area lacking in the literature: veneer quality. This paper will define some of the relationships between silviculture and veneer quality and value.

METHODS

Five loblolly pine (*Pinus taeda L.*) trees were selected and felled from forest stands subject to different reproduction cutting methods at the Crossett Experimental Forest, Crossett, Arkansas. The reproduction cutting methods investigated in this study are: (a) intensive plantation (the Sudden Sawlog study), (b) conventional plantation (Methods of Cutting study), (c) even-aged natural regeneration (Methods of Cutting Study), and (d) uneven-aged (Good

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Table 1—Average harvested tree statistics from each silvicultural regime

	Intensive plantation	Conventional plantation	Natural regeneration	Uneven-age 50-year trees
No. of Observations	5	5	5	5
Height (ft.)	94.2	93.8	98.6	88.6
Ht. base live crown	41.2	57.0	60.2	40.2
Age (years)	48	48	48	47
Average dbh (in.)	21.1	15.3	16.4	16.4
BAF10 (sq. ft.)	90	118	76	72

Farm Forestry Forty). A thorough description of each stand can be found in Baker and Bishop (1986). In the Sudden Sawlog study, at age 48 the stand had a basal area of 101 sq. ft, and an average dbh of 21.5 inches. The stand was thinned at age 9 to 100 trees per acre (tpa), and at ages 19, 24, and 27 to a final stand density of 41 tpa. The stand was mowed biennially and trees were pruned to 34 feet. The conventional plantation stand was 48 years old, had a basal area of 143 sq. ft. and an average dbh of 15.1 inches. The stand was thinned every 3 years from ages 12 to 30 to a final stand density of 116 tpa. There was no pruning or understory control. The natural regeneration stand at harvest was 48 years old, had a basal area of 90 sq. ft, and an average dbh of 16.3 inches. The stand was originally clearcut and allowed to regenerate naturally. The stand was thinned to a basal area of 80 sq. ft. in at ages 37, 42, and 47. The trees were not pruned, with understory control via prescribed burning at ages 37, 42, and 47. The uneven-aged stand varied from seedlings to approximately 100 years of age. The basal area at time of specimen selection was 65 sq. ft. The stand was thinned to a basal area of 60 sq. ft. at ages 37, 42, and 47. Trees harvested from this stand are traditionally dominant and co-dominant. The trees selected for this study were approximately 48 years of age, regardless of dominance status.

Trees with crooked boles were eliminated from the selection process, thus minimizing the presence of reaction wood. Immediately upon felling, the bole was bucked into 10-foot lengths starting from the stump and proceeding to a 4-inch diameter top. The logs were transported to a local veneer mill, peeled, dried, and then passed through a Metrigard stress-wave timer for determination of transit time. The stacks of veneer were transported to the Southern Research Station, Pineville, LA for visual grading by an American Plywood Association certified grader.

RESULTS AND DISCUSSION

A summary of the harvested tree statistics is shown in table 1. The height of the even-aged trees were all approximately 95 feet whereas the competition of dominant trees in the even-aged stand limited the height of the even-aged trees to 88 feet. The most dramatic differences in the stands were dbh and height to live crown. The greater spacing and understory control allocated the intensive plantation trees resulted in much larger dbh growth. These factors, along with pruning to a minimum 34 feet height, also resulted in the lowest height to live crown. Thus, although the volume of wood per tree from the intensive plantation stands was greater than the other stands, only the lower 40 percent of the bole contained potential knot-free wood. The other even-aged stands had live crowns approximately 60 percent of the total tree height.

The quantity of veneers that resulted from the 5 trees from each stand is shown in figure 1. The average number of veneers that came from each tree in the intensive plantation, conventional plantation, natural regeneration, and uneven-age stands was 126, 65, 81, and 62, respectively.

The visual quality of the veneers and thus their usefulness in the manufacture of structural plywood is summarized in table 2. The trees from the plantation stands produced veneer that was inferior in visual grade to the corresponding trees in the natural regeneration and uneven-aged stands. Approximately 60 percent of the veneers from the intensive plantation stand were graded as D or X. This is due to the resulting knots from the extremely large limbs in this stand. The conventional plantation stand had much fewer D or X grade veneers, but 66 percent of all veneers from this stand were C grade. The natural regeneration and uneven-aged stand produced the best visual grade veneers, with approximately 32 percent of all veneers falling into the A or B grade. This is due primarily to the clear boles in conjunction with very little taper.

Table 2—Percent yield for all veneers from each of the silvicultural regimes based on visual grade

	(Percent yield per grade)					
Management type	A	B	Cp	C	D	X
Plantation: Intensive	3.0	15.5	9.0	12.4	***50.7***	***9.4***
Plantation: Conventional	2.5	9.6	10.2	***65.7***	11.4	0.6
Even Age: Natural regeneration	***16.1***	***13.9***	7.7	35.1	27.0	0.2
Uneven Age: 50-year old trees	***14.3***	***18.6***	7.8	47.9	11.4	0.0

The percent yields of veneers from various stands as graded by transit time via a stress wave timer are summarized in table 3. These values are indicative of veneer stiffness and are essential in the layup of structural products such as laminated veneer lumber and to a lesser degree oriented strand board. A trend similar to the visual grades is observed: the intensive plantation possessing the highest percentage of low stiffness veneers, conventional plantation containing mostly middle grades, and the natural regeneration and uneven-aged stands producing the highest percentage of high stiffness veneers.

The quality of the veneers for each stand varies greatly from the pith to the bark and with vertical location within a tree. A summary of veneer visual grade and veneer stiffness as a function of location within a tree are, respectively, summarized in figures 2 and 3. Although trees from the intensive plantation stand did produce some high quality veneers, these high value veneers were limited to a small region below the live crown and some distance from the juvenile core. The juvenile core and almost all of the veneers at or above the live crown in the intensive plantation stand were of poor visual and structural quality.

From a forest management economics perspective, the quantity and quality of veneer production must translate to per-acre values. The number of trees per acre, their size, and the timing of the stand cost and revenue stream establish the financial return to investment. Dollar values for dry veneer by grade were solicited from buyer sources and reporting services. These values were reduced by harvesting, transportation, and manufacturing costs to establish the value for the expected veneer production from standing stumpage. Stand inventory records were used to reconstruct the diameter distributions and trees per acre for each silvicultural treatment. Tree values were based on their expected veneer yields and financial statistics were calculated. Forest management costs were established using published sources and personal communication (Clason 2000, Dubois and others 1999, Watson and others 1987, Yoho and others 1971).

Table 3—Percent yield for all veneers from each of the silvicultural regimes based on ultrasound propagation times.

	Percent yield per Metrigard (t) range				
Management type	<400	400-469	470-539	540-609	>610
Plantation: Intensive	0.0	11.9	43.3	***36.0***	***8.8***
Plantation: Conventional	0.0	32.4	***49.8***	15.0	2.8
Even Age: Natural regeneration	0.0	***41.3***	35.1	21.5	2.0
Uneven Age: 50 year-old trees	***0.7***	***41.7***	41.4	15.3	1.0

Figure 1—Veneers peeled from 5 trees each of the following silvicultural regimes: (1) intensive plantation, (2) conventional plantation, (3) natural regeneration, and (4) uneven age.

The lowest cost silvicultural system (in dollars expended) was the natural regeneration at $268.97 per acre. The highest cost was the sudden sawlog system at $705.47. The cost for the conventional plantation was $288.23 and for the uneven-aged stand was $358.22. In the case of the uneven-aged stand, the initial value of the stand which produced the revenue stream was also counted as a cost (capital investment).

In terms of internal rate of return (IRR), three of the four systems were similar in financial returns to the capital invested over the 50-year period. The two plantations averaged 9.6 percent and the naturally regenerated stand averaged 10.1 percent IRR. These were in contrast to the uneven-aged system which returned an average of 5.8 percent. The large tree diameters boosted the total veneer yield for the sudden sawlogs, though it was mostly D-grade. The veneer yield from the other three stands was comparable, but the clearcut/natural regeneration stand had the advantage of low cost regeneration, and the uneven aged stand had the disadvantage of high capital investment in the form of initial growing stock.

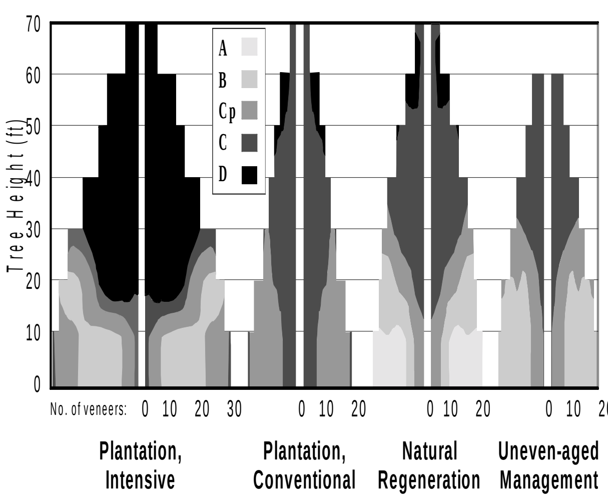

Figure 2—2-dimensional maps of veneer visual grade by location within a tree. Maps are based on the averages of 5 trees per silvicultural regime.

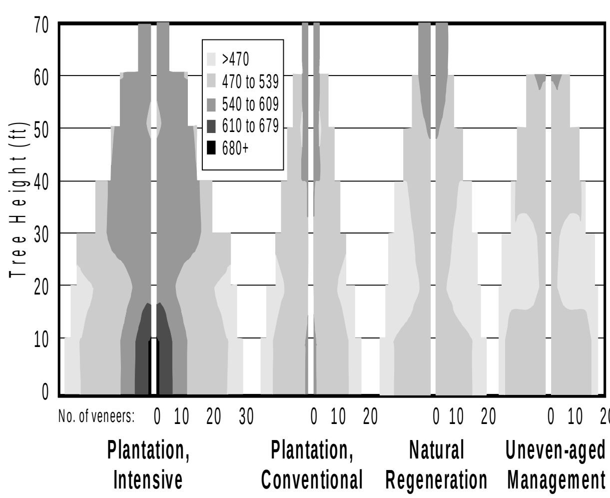

Figure 3—2-dimensional maps of ultrasound transit time, shown in microseconds, for veneers by location within a tree. Due to the inverse relationship, lower transit times correspond to stiffer veneers. All maps are based on the averages of 5 trees per silvicultural regime.

Even-aged systems reflected the natural presence of loblolly pine in the early successional stages of the southern forest and seemed to be the most efficient silvicultural system for management based on financial returns. How those forests are regenerated and managed reflect the objectives of the landowner in regard to the outputs desired. There are legitimate reasons for choosing an uneven-aged system (Baker and others 1996), however, the higher proportion of good veneer grades is offset by the investment carried in growing stock unless careful attention is given to those growing stock levels. As structural grades of plywood continue to be replaced by oriented strand board (OSB), the economics associated with veneer production will change to favor higher grades and lower the relative value of the lower grades, thus affecting the returns of the silvicultural systems accordingly.

CONCLUSIONS

The quantity and quality of veneers was shown to be a function of silvicultural regime as well as location within a tree. Intensively-managed plantation stands produced the greatest number from each tree, averaging 126 veneers per tree. Although the trees were pruned to ensure a clear bole to 34 feet, the resulting veneers were of very poor quality, due to both excessive taper and a low live crown with large limbs. The trees from the conventional plantation stand only averaged 65 veneers per tree. The veneers were of better quality than the intensively-managed plantation stand, but still of mediocre quality. Trees peeled from natural regeneration and uneven-aged stands were of the best quality, averaging 81 and 62 veneers per tree, respectively. The veneers from these 2 stands produced the highest proportion of visual grades as well as the greatest proportion of high stiffness veneers.

The economics of forest stand management, in addition to individual tree values, also incorporate tree populations on a per-acre basis. Outcomes on which management decisions will be based are affected by investments and harvest schedules, as well as market values of the veneer grades produced.

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RAPID ASSESSMENT OF THE FUNDAMENTAL PROPERTY VARIATION OF WOOD

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Abstract—Genetic variation, site conditions, silvicultural treatments, seasonal effects, and their complex interaction are all vitally-important factors accounting for the variability and quality of the raw material produced - wood. Quality can be measured in several ways that generally influence the end use. The most desirable measure is the fundamental properties. The physical properties and strength characteristics at selected locations in the bole have been determined for three loblolly pine trees obtained from the Crossett Experimental Forest (Crossett, AR). The range and variation of properties within and between the trees has been summarized in the form of wood property maps. The creation of such property maps via traditional test methods require much time and expense. However, a new rapid assessment technique combining near infrared (NIR) spectroscopy with multivariate statistical techniques to predict these fundamental properties has shown great potential. This paper introduces the application of this developing methodology to wood quality issues by highlighting early results from a larger program that will define the range of properties for southern pine. The results from the standard test methods have been compared with those predicted from NIR spectra/multivariate analysis, and have been shown to provide excellent correlations.

INTRODUCTION

An improved understanding of genetic factors and silvicultural treatments on the chemical, physical, and mechanical properties of wood is important for producing raw materials that are optimized for specific material systems. Paper and pulp operations require sensitive measurement of chemical composition of wood chips to control processing conditions. It is reasonable to assume that manufacturers of wood composite products can derive similar benefits from data on physical and mechanical properties of the wood. This type of information is not routinely available because of the time and expense required to obtain the data.

Recent research has addressed the issue of rapid assessment methods that are capable of affordably evaluating fundamental wood characteristics. Near infrared (NIR) reflectance spectrometry (1,000 - 2,500 nm, 10,000 - 4,000 cm^{-1}) combined with multivariate statistical techniques has now been demonstrated to provide spectra of sufficient quality to permit chemical analysis of solid wood without sample preparation (Schimleck and others 1997; Meder and others 1999). The application of multivariate analysis to the NIR spectra of wood has reduced much of the problem of overlapping signals from the three main polymer constituents: cellulose, hemicellulose and lignin (Wallbacks 1991). NIR spectra have also been used to provide quantitative, non-destructive measurement of physical properties such as density (Meder and others 1999).

Several studies have been performed comparing the use of near infrared (NIR) and Fourier transform infrared (FTIR) with multivariate analysis for predicting chemical composition (Schultz and Burns 1990; Wallbacks and others 1991a,b; Meder and others 1999). It was observed that although both NIR and FTIR could be used to predict chemical composition, it was the NIR spectra which generally produced better correlations and was clearly the simpler and much faster technique.

This technique found acceptance in the pulp and paper industry and has been used to predict paper properties from the spectra of pulp (Wallbacks and others 1991a,b) as well as paper ageing studies in which the age of paper in service could be estimated (Ali and others 2001). Similarly this technique has been gaining use for online process monitoring in particleboard manufacture. In particular, it can facilitate the reduction in standard deviation of the board quality by adjusting the process settings accordingly, thus leading to substantial cost savings (Engstrom and others 1998; Johnsson and others 2000).

MATERIALS AND METHODS

The trees selected in this study are part of a larger program to study the variability and development of properties for southern pine. Three trees were selected from each site. The majority of this paper is concerned with a set of 55-yr old loblolly pine (*Pinus taeda* L.) trees felled from a natural regeneration stand in the Crossett Experimental Forest, Crossett, AR. Periodic understory control was conducted via a series of prescribed burns. Trees were also collected in

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South Carolina and two sites in Mississippi for comparisons. A set of 15-yr old loblolly pine trees was collected from a rapid growth experimental plot near Summerville, SC, in which a 6 x 6 ft spacing was chosen for the first 5 years and then 12 x 12 ft thereafter. Three extremely-fast grown loblolly pine trees were chosen from a seed orchard in Eastabuchie, MS. These were felled from a 29-yr old clonal stand in which the conditions were primed for cone production. The last set in this study is a set of 30-yr old slash pine (*Pinus elliottii* Engelm) trees, grown on a wet site, in DeSoto National Forest, MS. Important tree data such as the height, diameter at breast height (d.b.h.) and height to live crown are listed in table 1.

Modulus of Elasticity (MOE) and Modulus of Rupture (MOR)

The bending specimens were taken from disks 14 inches in height that were cut at 15 ft separations along the tree height. Two parallel cuts were made along the disks, north to south, approximately 0.5 inches either side of the pith. These slabs were further cut according to the ring of interest, in which one ring either side was included, such that the specimen was 3 rings high and 1 inch wide. The specimens were cut to 12 inches in length for testing, under three-point bending, in an Instron testing machine. Care was taken to avoid any regions with defects, such as knots, where possible. A 1-inch cut-off piece was used for specific gravity testing.

Near Infra-Red (NIR) Spectroscopy

NIR spectra were obtained using a FieldSpec FR (Analytical Spectral Devices Inc., Boulder, CO) at wavelengths between 350 and 2500 nm. Thirty scans were collected and averaged into a single spectrum. Two spectra were collected for each specimen.

Multivariate Analysis

Multivariate analysis of the NIR data was performed using The Unscrambler® vsn. 7.5 software package (CAMO, Corvallis, OR). Partial least squares (PLS) analysis was conducted on the spectra after averaging. The models were generated using full cross-validation; this is a method in which one sample is systematically removed from the data set; a model is created from the remaining samples, and this model is used to predict a value for the extracted sample. This process is subsequently repeated for all remaining samples (Martens and Naes 1992). No further manipulation of the spectral data was employed.

Table 1-–Summary of the tree height, diameter at breast height, and height to live crown for the trees

Site	Tree No.	Height of Tree, ft.	D.B.H., in.	Height to Live Crown, ft.
Crossett, AR	1	92.7	16.4	73.6
	2	100.5	18.8	72.5
	3	98.1	20.9	78.6
Summerville, SC	1	59.7	10	24.3
	2	61.0	10.3	29.0
	3	59.3	9.8	29.5
Eastabuchie, MS	1	70.0	22.5	27.5
	2	75.0	23.3	26.0
	3	65.0	23.6	15.0
Hattiesburg, MS	1	47.5	6.2	31.0
	2	64.4	8.7	38.0
	3	56.5	8.4	45.7

RESULTS AND DISCUSSION

Tree Property Maps

Three trees were collected from each location and each of the following tree property maps (figures 1 through 4) is an average of the three trees taken. These tree property maps show the variation in a particular property within the tree. Figure 1 shows the variation of specific gravity in the 55-year-old trees from the Crossett site. The specific gravity for a given growth ring increases with tree height. The base of the tree provides the highest values of specific gravity, with the lowest derived within the juvenile core.

Although there exists a relationship between specific gravity and modulus of elasticity (MOE), this relationship is not strong as can be seen in figure 2. MOE appears to be more closely associated with juvenility, as pith-associated wood is more compliant than the corresponding mature wood. That is because MOE is more closely associated with microfibril angle (MFA) than with specific gravity (Megraw 1985). This strong relationship between stiffness and MFA also exists for strength as can be seen in figure 3.

The variation of MOE with tree location is not a constant from stand to stand (figure 4). Interactions such as live crown, specific gravity, and MFA result in a 3-dimensional maturation process that affects subsequent mechanical properties. These figures clearly show there is a large property variation within the tree. Thus, taking increment cores at breast height, a common technique, cannot be taken to representative of the whole tree.

Near Infra-Red (NIR) Spectroscopy

The NIR spectra of juvenile (rings < 8) and mature (rings > 24) wood obtained from loblolly pine, between 350 – 2500 nm, is shown in figure 5. It is clear to see that differences cannot be noted visually; the characteristic peaks show broad overlapping absorption bands arising from secondary overtones and combinations X-H stretching vibrational modes. NIR is, most importantly, sensitive to hydrogen bonding, thus making it very applicable to wood. The use of multivariate statistical techniques improves the extraction of information from the spectra, revealing any differences.

Multivariate Analysis

Figure 6 shows a prediction plot for the specific gravity in which the abscissa is the “true” specific gravity determined from standard test methods and the ordinate is the “NIR-predicted” specific gravity from the NIR spectra and multivariate analysis. It is clearly observed that the data follow the 1:1 line very well with a r-value of 0.82. Good correlations were also obtained for the mechanical properties as shown in figure 7 for the modulus of elasticity (MOE) and figure 8 for the modulus of rupture (MOR) with resultant r-values of 0.88 and 0.87 respectively. These findings are

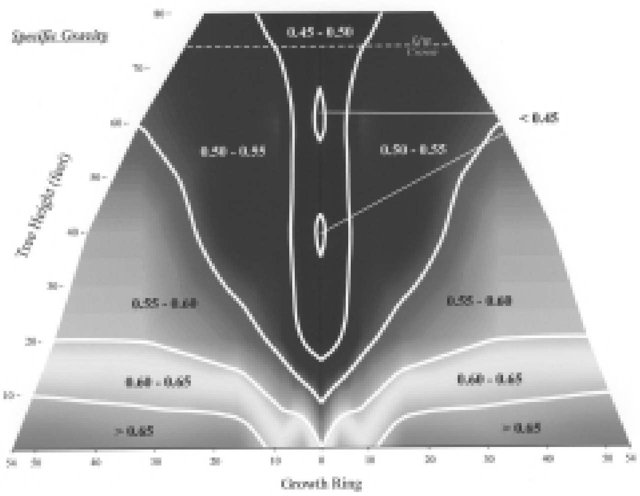

Figure 1—Specific gravity maps for trees harvested from 55-year-old loblolly pine (Crossett, AR).

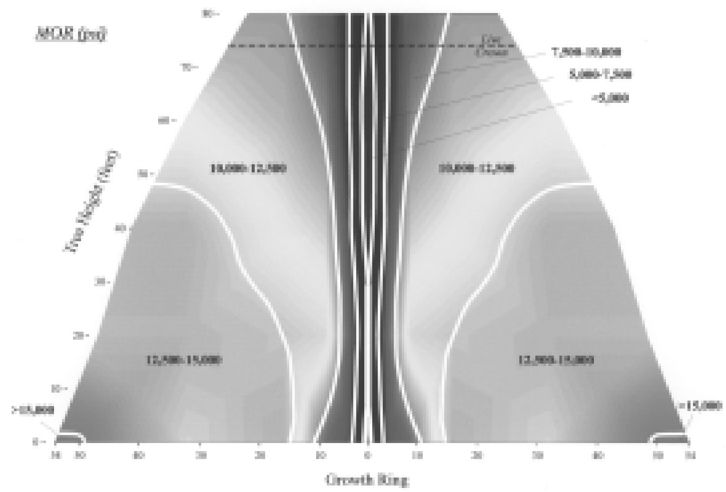

Figure 3—Modulus of rupture (MOR) maps for trees harvested from 55-year-old loblolly pine (Crossett, AR).

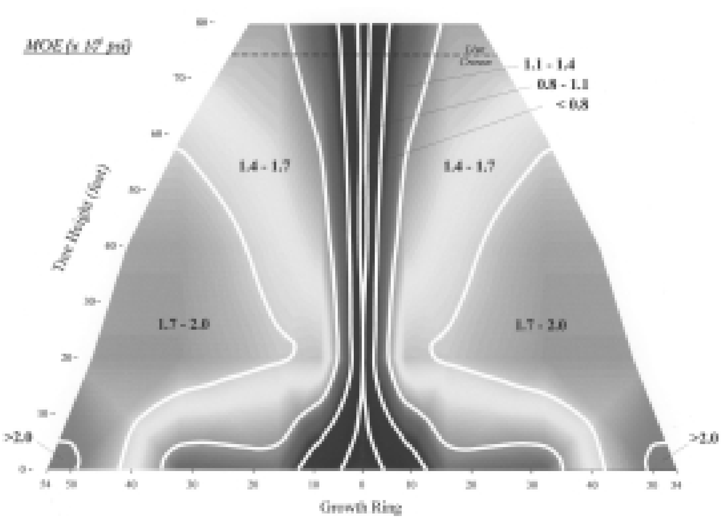

Figure 2—Modulus of elasticity (MOE) maps for trees harvested from 55-year-old loblolly pine (Crossett, AR).

consistent with Engstrom and others (1998) who obtained a similarly good correlation of 0.9 for particleboard MOR.

CONCLUSIONS

Property mapping of trees clearly reveals large variations with location within the tree. This was further extended to compare the MOE variation within trees from different stands. Naturally, differences were observed between the maps, with particular interest in the differences in their magnitude and their patterns. These maps show how growth conditions affect property variation within a tree and can be applied to silvicultural treatments to improve tree properties; however, the construction of such maps requires much time and expense with traditional test methods.

It has been shown that NIR spectroscopy, in conjunction with multivariate analysis, can be used to predict fundamental wood properties with excellent results, and in a much smaller time scale than by traditional testing. With further advances in technology, the development of a handheld portable field unit capable of assessing all major wood properties on standing timber may be possible.

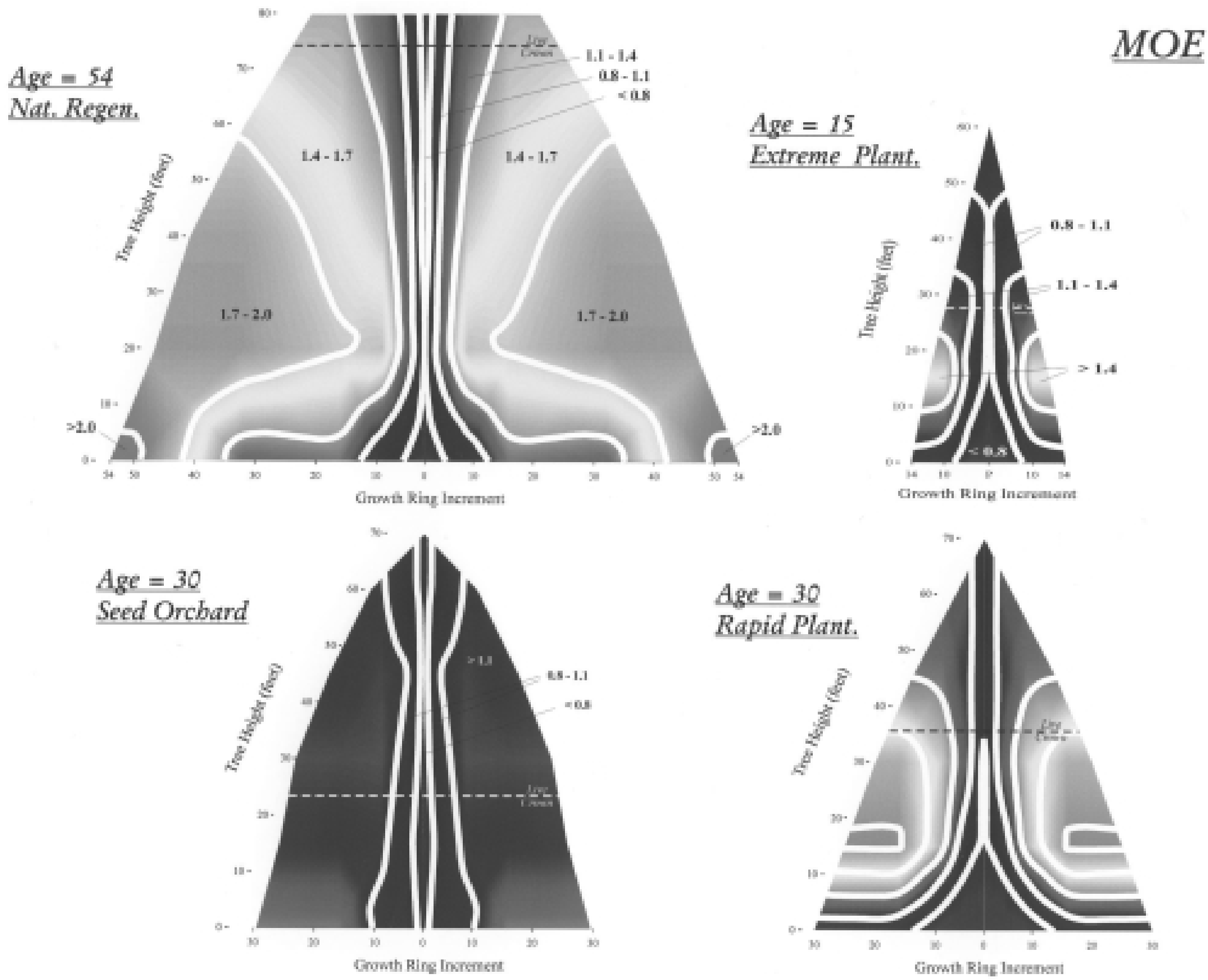

Figure 4—Modulus of elasticity (MOE) maps for trees harvested from (a) 55-year-old loblolly pine (Crossett, AR); (b) 15-year old-loblolly pine (Summerville, SC); (c) 30-year-old, seed orchard, loblolly pine (Eastabuchie, MS); and (d) 30-year-old slash pine (Hattiesburg, MS).

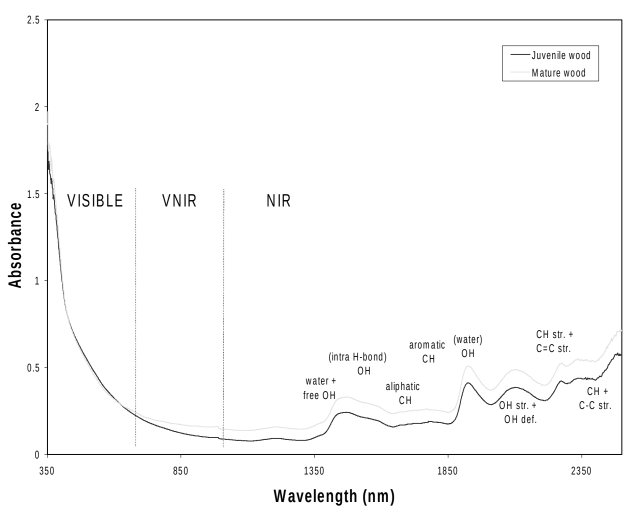

Figure 5—NIR spectra of juvenile and mature wood obtained from loblolly pine in the range of 350 – 2500 nm.

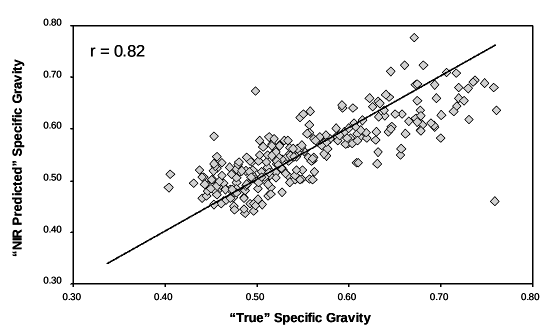

Figure 6—Comparison of "NIR-predicted" vs. "true" values for specific gravity.

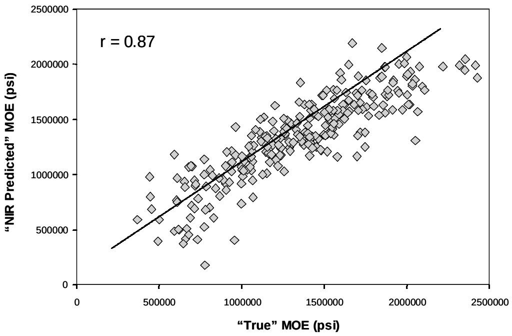

Figure 7— Comparison of "NIR-predicted" vs. "true" values for modulus of elasticity (MOE).

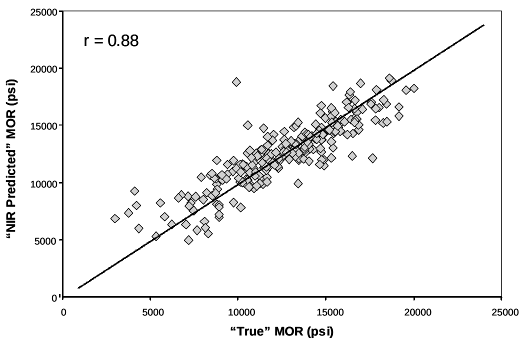

Figure 8—Comparison of "NIR-predicted" vs. "true" values for modulus of rupture (MOR).

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