CROWN-QUALITY ASSESSMENT AND THE RELATIVE ECONOMIC IMPORTANCE OF GROWTH AND CROWN CHARACTERS IN MATURE LOBLOLLY PINE

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ABSTRACT

The size and number of knots in 2.6-meter loblolly pine (*Pinus taeda* L.) veneer bolts was significantly negatively related to the dollar value of veneer from those bolts in a multiple-regression model which also included bolt size, taper and sweep. However, when this model was used to predict whole-tree dollar value, the impact of quality-related improvements in stem knottiness on dollar value of a tree was insignificant in comparison to the impact of tree size. Individual branching traits and combinations of branching traits could be measured more repeatably on standing trees than could a subjective crown-score, but crown and branch traits, like stem knot traits, were either unimportant to tree value or were important only as a function of their relationships to tree size. Increasing the relative value of high-grade veneer shifted the regression coefficients for the crown and branch traits in a direction suggesting a greater influence of stem quality on tree value. The relative importance of crown and branch traits to tree dollar value for other product outcomes should be evaluated, and economic and genetic information combined in a multi-trait index, before the final decision is made to include or discard such traits in future rounds of selection.

INTRODUCTION

Lessons learned during the first generation of loblolly pine (*Pinus taeda* L.) improvement provide a means by which time and resources can be allocated more efficiently in advanced generations. One aspect of first-generation improvement which merits reassessment is the evaluation and improvement of crown quality.

Crown quality is reflected in the final product through (1) the number, size and distribution of knots and associated defects, and (2) the vigor and productivity of the plant. A number of composite and individual-traitmeasures of crown quality have been discussed for their potential utility in breeding programs for a variety of species (Campbell 1961, Strickland and Goddard 1965, Bailey et al. 1974, Bannister 1980). The North Carolina State University-Industry Pine Tree Improvement Cooperative employed a six-point subjective scale for the assessment of crown quality in first-generation progeny tests. This crown score incorporated traditional 'crown-form' characteristics as well as individual branch traits into a single measure. Some improvement has been observed in the overall crown quality of progeny from first-generation orchards in loblolly pine (Woessner 1965, J.T. Talbert, pers. comm., 1982), likely a result of the heavy emphasis placed on crown traits in the first round of selection. However, the subjective crown score used in the first generation has been found to have a low repeatability

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across tree graders and among trials (Paschke 1979), and proved to be very weakly inherited in a 5-year old unselected population of loblolly pine (Stonecypher et al. 1973). Much of the imprecision associated with crown score may result from the subjective nature of the trait. Several branch, crown and foliar characteristics must be evaluated simultaneously by the tree grader in establishing a crown-score value, introducing the potential for differences in interpretation and relative weighting by different graders. This same complexity may also lead to an inflated measurement error for a 'composite' trait in comparison to individually-specified traits. In addition, subjective crown scores have traditionally included traits such as apical dominance, crown shape and foliar density, under the assumption that such traits are important to stem form and knottiness, and plant vigor. Such traits are difficult to define and to measure precisely, and are likely to be accompanied by considerable environmental variation. Since it is of interest to minimize the total number of traits included in a selection program, it may be of value to incorporate only that small number of traits which are the most directly related to plant size, straightness and knot size and density, and which can be measured consistently and accurately.

The impact of stem knots on product quality and recovery in loblolly pine has been well documented (Von Wedel et al. 1968, Blair et al. 1974, Phillips et al. 1980), but the relationship between crown and branch properties and grade yields across a range of tree sizes and product outcomes has yet to be explored for mature trees. If one or a small number of individual branching traits were to demonstrate at least as strong a relationship with whole-tree value as did crown score, exhibited as good or better heritability, and could be measured accurately and repeatably, then a case could be made for substituting one or more separate branching traits for crown score in loblolly pine selection programs.

MATERIALS AND METHODS

A study was initiated in the autumn of 1982 to evaluate the contribution of various combinations of crown and branch traits to the dollar value of a stem after adjustment for tree height, diameter and stem straightness, and to investigate the repeatability of standing-tree measures of branching properties in comparison with crown score over separate grading trials. The study consisted of two phases. The first phase focused on the development of a model relating the size, form and knottiness of 2.6-meter loblolly pine veneer bolts to the estimated dollar value of those bolts. In the second phase, measurements were taken on standing, and subsequently felled, trees, and these measurements were used to predict whole-tree dollar value based on the relationship derived in Phase I. This whole-tree value could then be regressed on a variety of whole-tree characteristics.

Bolt Analysis

Data collected in a 1968 U.S. Forest Service study of veneer recovery from 39 mature North Carolina-source loblolly pines— wereused, along with an Autumn, 1982 estimate of relative dollar values of veneer by sheet size and

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Results from the U.S.F.S. study are discussed by Schroeder and Clark (1970) and by Phillips et al. (1979, 1980). The author gratefully acknowledges their assistance in providing the data.

grade to construct a regression model relating veneer dollar value for 2.6-meter veneer bolts to bolt dimensions, form and knot traits, to be used in Phase II of the study. Large-end and small-end inside-bark diameters, taper, deflection, total knot number, average knot diameter and the number of knot-free faces had been measured on each of the 226 bolts included in the present study. From this data, Smalian bolt volume and a measure of knots per square foot (KPF)– were calculated for each bolt.

Stepwise regression techniques were used to select the set of bolt traits which predicted bolt dollar value most accurately and precisely. Quadratic terms for both bolt diameters and for deflection were also included in the stepwise analysis. Due to a high degree of intercorrelation among the bolt variables chosen in the stepwise procedure, a principal components analysis was performed on the bolt variables to produce a set of independent and uncorrelated linear combinations of these variables. These components could then be evaluated independently for their influence on bolt dollar value. Components were dropped from the model if they explained little of the variance in the X-space and an insignificant portion of the variability in bolt dollar value. The retained subset of principal components and the partial regression coefficients relating these components to bolt dollar value were then used to calculate biased but more stable estimates of regression coefficients for the original X variables (see Webster et al. 1974).

To test the impact of fluctuations in relative veneer-grade values, and to evaluate the specific effects of an increased premium placed on high-grade veneer, the original relative values applied to full- and half-sheet A/B-grade veneer were multiplied by 1.5, new bolt values were calculated, and biased regression coefficients were recalculated by the methods described above. For simplicity, the two value models will be referred to as V2 and V3, to represent the ratio of A/B to C/D product values in the two models.

II. Whole-Tree Analysis

In the autumn of 1982, 27 mature loblolly pines representing a range of D.B.H., straightness and crown score– values were selected from thinned and unthinned plantations growing at the Schenck Demonstration Forest in Raleigh, North Carolina. All sample trees were chosen to have a similar growing space, and no open-grown trees were included in the study. In addition to D.B.H., straightness score and crown score, the following branching characters were assessed on the standing trees:

1. Branch angle (degrees): 90 is perpendicular to the bole.

3/ Pricing figures for southern pine veneer were obtained from Random Lengths (October, 1982) and adjusted to the following relative dollar prices: Full-sheet A/B - 1.0; Full-sheet C/D - 0.5; Half-sheet A/B - 0.9; Half-sheet C/D - 0.4; Strip - 0.4; Fishtail - 0.3.

4/ Measured as the maximum deviation of the bolt surface from a string line stretched across the sweep.

5/ KPF = KNOT # $\Big/ \left[\left(\frac{\pi}{4}\right) \text{ X } \left(\frac{\text{L.E.D.} + \text{S.E.D.}}{2}\right)^2 \text{ X } \left(\frac{1}{144}\right) \text{ X BOLT LN. X \#CLR. FACES}\right]$.

6/ Straightness was assessed on a 1 to 5 scale, with 1 being perfectly straight and 5 having severe sweep in two planes. A 1 to 6 crown score was employed with 1 being an 'excellent' crown and 6 representing a 'poor' crown.

2. Branch diameter (1 to 4 scale): 1 is small, 4 is very large, relative to the surrounding stand.

3. Branches per whorl: average number of major branches at a node.

4. Live-branch number: total number of major living branches.

5. Live-crown ratio (percent): crown length/total tree height.

6. Pruning (1 to 3 scale): 1 is good, 3 is poor, relative to the surrounding stand.

Branch diameter and angle and the number of branches per whorl were assessed in the middle-third of the live crown. Crown score and each of the branching traits were assessed a total of three times by two different graders on each sample tree to provide an indication of the repeatability of these traits.

All 27 trees were felled, and measurements taken of total height, length of the living crown, total number of living branches over 1" (2.5 cm.) in diameter, and average branch angle (degrees) and branch diameter (inches) in the middle-third of the live crown. The trees were then delimbed and bucked into 2.6-meter veneer bolts to a minimum 8" (20-cm.) small-end diameter, and the same bolt traits were assessed on each section as had been measured in the U.S.F.S. study. Merchantable height and volume were calculated as the sum by tree of the lengths, or Smalian volumes, of all veneer bolts having inside-bark small-end diameters of at least 8" (20 cm.). These bolt measurements were entered into the stabilized regression equations derived in Phase I, to produce a predicted dollar value by bolt for each of the two veneer-pricing models. Finally, bolt values were summed by tree, yielding a predicted whole-tree dollar value for each of the 27 sample trees under each relative pricing model.

The same stepwise regression techniques and model-selection criteria used in Phase I were employed at the whole-tree level to choose the set of standing-tree traits and the set of felled-tree traits which best predicted tree dollar value under the V2 pricing model for the 27 trees in the study. Crown score, standing-tree branch traits and felled-tree branch traits were examined in separate analyses and compared later. After the best set of predictive variables was chosen, tree dollar values calculated from V2 and V3 were regressed separately on this set of variables. A principal components procedure was again employed to ensure maximum stability of the regression equation; however, none of the components calculated from any of the variable sets met the criteria for exclusion from their respective models. Since principal-components estimates of regression coefficients are identical to ordinary-least-squares estimates for the full-model case, the original least-squares coefficients were retained for all models. Each set of partial regression coefficients was interpreted to be a set of relative economic values for the traits in that model.

Analyses of variance were performed on each of the individual crown and branch traits and on the linear combinations of branch traits which appeared together in the final economic value models. From these analyses, repeatability was calculated as the ratio of tree-to-tree variation in a given trait or combination, over the sum of tree and tree-by-trial variances. Partial correlations were calculated between felled-tree and standing-tree measures of each branch trait, among the standing-tree and among the felled-tree branch traits, adjusted for tree size and straightness, using the GLM/MANOVA procedure of SAS (SAS Institute Inc. 1982). The same techniques were also used to calculate partial correlations between each standing- or felled-tree branch trait and knot number and average knot diameter in the merchantable bole, adjusted for all of the remaining traits in the model.

RESULTS AND DISCUSSION

Bolt dollar value was predicted best in this study by a linear combination of bolt large-end diameter (LED), LED squared, taper, deflection, knot number and average knot width, for both the V2 and V3 veneer-pricing models. Heterogeneity of regression slopes for each variable across trees, across bolt positions, and across 4" (10-cm.) LED classes was tested and found to be nonsignificant at O(= 0.10. As more emphasis was placed on A/B-grade veneer by shifting from V2 to V3, a significantly greater negative emphasis was placed on knot number and width, reflecting the increasing importance of quality to bolt value.

The principal-components procedure broke the six bolt variables chosen above into six components. One of the components explained a nonsignificant portion of the variation in the X-space and in bolt value for both V2 and V3. The removal of this component increased the coefficient of variation for a given model only slightly (from 23.1% to 24.0% for V2, and from 27.8% to 29.3% for V3), and successfully reduced the standard errors for all six recalculated regression coefficients from their ordinary-least-squares levels. The final equations for V2 and V3 are presented in Table 1.

Table 1. Equations relating bolt dollar value to bolt characteristics under two veneer-pricing models.

VARIABLE	b_{V2} a/	t b/	b_{V3}	t
Intercept	-32.28	***	-29.11	***
Large-end diameter	2.82	ns	1.78	ns
(Large-end diameter)^2	0.42	***	0.51	***
Taper	-12.47	***	-12.03	***
Deflection	-5.56	*	-6.04	*
Knot number	-0.33	*	-0.51	*
Knot diameter	-3.18	*	-6.53	***

a/ The V2 pricing model assigns twice the relative dollar value to A/B-grade veneer that it does to C/D-grade, while the V3 pricing model applies three times more value to A/B-grade veneer, on a per-thousand-cubic-foot basis.

b/ ns: not statistically different from zero at $\alpha = 0.05$.
*: significantly different from zero at $.05 \leq \alpha < 0.01$.
***: significantly different from zero at $\alpha \leq 0.01$.

These equations were considered fixed for the remainder of the analysis. When the Schenck-Forest data were entered into the fixed bolt-value equations, predicted dollar values by LEDclass corresponded very well with actual dollar values from the same LED-class calculated from the original veneer-recovery study results.

Measurements collected from standing trees on individual branch traits and on combinations of two branch traits tended to be more consistent across trials than did the subjective crown score, as measured by the repeatabilities for these traits. Crown score showed a repeatability of 0.37, as compared to repeatabilities of 0.65, 0.48 and 0.69 for branch angle, branch diameter score and live-branch number. Repeatabilities for the sum of branch angle and branch number (0.62) and for the sum of branch diameter score and branch number (0.63) also exceeded that for crown score.

When predicted whole-tree dollar value was regressed on a variety of whole-tree characteristics, merchantable height alone accounted for 98% of the variability in dollar value for both the V2 and the V3 value models. Total tree height was a much poorer predictor of tree dollar value, both alone and in combination with other traits, than was merchantable height, and so was not included in further analyses. Of all the whole-tree variables measured in the study, the best two-variable predictive model included merchantable height and diameter, and the best three-variable model included straightness score along with these two. This three-variable model will be referred to as the 'base model', because the best models of a given size always were found to include these three variables.

Since the branching and crown traits measured in this study were assumed to impact stem quality, and ultimately stem value, as a result of a correlated impact on merchantable-bole knottiness, two whole-tree knot traits - average knot diameter and KPF - were the first variables to be added to the base model and evaluated for their influence on tree dollar value. KPF did not influence the value of a tree significantly in either the V2 or the V3 models, although its negative impact did increase as more emphasis was placed on high-grade veneer. Average knot diameter contributed significantly to tree dollar value above and beyond the base model. However, this trait had a positive coefficient in both the V2 and the V3 models, suggesting that the impact of knot width on tree value was more a reflection of its strong positive correlation with D.B.H. (r=0.74) and with merchantable height (r=0.69) than of its negative effect on product quality, under the pricing models used here.

The addition of different combinations of standing- and felled-tree branch/crown traits to the base model added little to the ability of the resulting model to predict tree value (Table 2). Felled-tree branch traits, either singly or in groups, yielded poorer predictions of tree dollar value than did the corresponding standing-tree measures or crown score in every case, despite the fact that felled-tree branch traits were better correlated with knot number and knot size in the merchantable bole (Table 3). This may be a result of a particularly strong pattern of intercorrelations among the felled-tree branch traits, and between these branch traits and tree size, which could introduce substantial error into the regression model. Among the standing-tree branch characters, only branch angle proved a significant addition to the base model at o<=0.10. No single felled- or standing-tree branch trait was significantly more important to tree dollar value than was crown score. However, a combination of the base model with branch angle and live-branch number was a significantly better predictor of tree dollar value than was the

Table 2. Regression equations relating whole-tree characteristics to tree dollar value predicted from two veneer-pricing models.

VARIABLE	b_{V2}a/	t	b_{V3}	t	VARIABLE	b_{V2}	t	b_{V3}	t
Merch. Ht.	13.5	***	13.7	***	Merch. Ht.	14.0	***	14.1	***
D.B.H.	29.8	*	28.4	*	D.B.H.	23.7	*	22.4	*
Strt. Score	-4.1	ns	-2.5	ns	Strt. Score	-6.9	*	-5.4	*
Crown Score	-5.7	ns	-5.7	ns	Branch angle	-0.8	*	-0.5	ns
C.V. ($\hat{Y}_{\bar{X}}$)b/	8.9		9.6			5.8		6.4	
Merch. Ht.	13.5	***	13.7	***	Merch. Ht.	13.9	***	14.0	***
D.B.H.	28.0	*	26.0	*	D.B.H.	25.7	*	24.0	*
Strt. Score	-3.6	ns	-2.8	ns	Strt. Score	-7.3	*	-5.9	*
Branch angle	-1.1	*	-0.8	*	Branch diameter	-8.8	ns	-10.3	ns
# Live branches	2.3	ns	1.9	ns	# Live branches	1.2	ns	1.0	ns
C.V. ($\hat{Y}_{\bar{X}}$)	5.6		6.5			6.2		6.6	

a/ The V2 pricing model assigns twice the relative dollar value to A/B grade veneer that it does to C/D-grade, while the V3 pricing model applies three times more value to A/B-grade veneer, on a per-thousand-cubic-foot basis.

b/ C.V. ($\hat{Y}_{\bar{X}}$) is the coefficient of variation of a new prediction of bolt dollar value at the mean of all X_i.

Table 3. Correlations of standing-tree and felled-tree measures of branch traits with crown score and with size and number of knots in the merchantable bole.

TRAIT	STANDING-TREE WITH:				FELLED-TREE WITH:	
	CROWN SCORE	FELLED	KNOT #	KNOT DIAM.	KNOT #	KNOT DIAM.
Branch angle	-0.42	0.49	-0.08	-0.40	-0.16	-0.18
Branch diam.	0.11	0.24	0.15	0.24	0.15	0.38
Branches per whorl	-0.23	0.32	-0.16	-0.32	-0.58	0.11
# Live branches	0.33	0.44	0.25	-0.10	0.31	-0.14
Branches per foot	0.13	0.28	0.10	0.20	0.11	-0.10
Live-crown ratio	0.19	0.73	-0.12	0.23	0.01	-0.15

base model plus crown score. It was also noted that crown score, when added to the end of each of the best four- and five-variable models (the base model plus one or two branching traits), did little to improve these models. Apparently, once the branch components of crown score are accounted for, little economic benefit is accrued by including crown form components in the value model.

Partial regression coefficients for the best four- and five-variable V2 and V3 models are presented in Table 2. Despite the generally low levels of statistical significance associated with crown and branch traits in all of the models examined in the study, the signs of the regression weights for these traits, and the changes in the impact of these traits on tree value as a greater premium is placed on high-grade veneer, help to explain the role of crown and branch traits in determining tree dollar value. Branch angle in both value models had a negative impact on tree value. This result was initially surprising, since an increasing branch angle (i.e. flatter branches) has been shown to correlate fairly well with decreasing knot diameter. However, branch angle was poorly correlated with knot diameter in the lower two 2.6-meter veneer bolts on a given tree, and these bolts tend to contribute the most to total tree value. Also, branch angle in this study and in previous studies (Faulkner 1969, Strickland and Goddard 1965) has exhibited a consistent negative relationship with tree height, indicating that the tallest trees are often those with the steepest branches. The importance of merchantable height to tree value in this study, combined with the observed negative correlation of merchantable height and branch angle (r=0.43), could be 'swamping out' any knot-size benefits of increasing branch angle in favor of the height increase correlated to a decreasing branch angle. This conclusion is supported by the positive shift in the impact of branch angle which was observed when a greater value was given to high-grade veneer. The seemingly-contradictory positive relationship of live-branch number with tree dollar value could be explained similarly. Crown score and branch diameter score, both of which associate a higher 'quality' with a decreasing score, are negatively related to tree dollar value, suggesting that these traits might be influencing tree value through an effect on product quality. However, the strong negative correlation of crown score with merchantable height, and the lack of a change in the dollar impact of crown score with a changing emphasis on high-quality products, indicate that this trait likely is affecting tree value only as a function of its correlation with tree size. Only branch diameter score is relatively uncorrelated with tree size, and as a result, is the only trait of the four discussed here that could by impacting tree value primarily by way of stem quality. This trait, however, was not a significant influence on tree dollar value in any of the models examined in the study.

Although the regression weights given to most of the crown and branch traits in this study did not differ significantly from zero, the least-squares coefficient on each variable can be taken to represent the best point-estimate of the dollar-value impact of a unit change in a trait in a multi-trait model. If the variables are standardized by their standard errors, then individual regression coefficients in a given model can be directly compared. In this study, the relative dollar impacts of the standardized traits remained fairly constant regardless of the model in which they appeared. Merchantable height was four to five times more important to dollar value than was D.B.H., which in turn received five to ten times the weight of straightness, five times the weight of crown score, three to five times the weight of branch angle, five to ten times the weight of live-branch number, and five times weight of branch diameter. However, these standardized relative weighting are directly applicable to a selection index only if the genetic and pheno parameters used in the formulation of the index, and the phenotypic measu ments ultimately entered into the index formula, are also standardized. In addition, it should be noted that the relative economic values estimated in this study are somewhat specific to the product and pricing criteria used in establishing tree dollar value, although adjustments of 150% in relative ye grade values in this study did not change the final relative economic values significantly.

CONCLUSIONS

The number and average diameter of knots measured on the surface of loblolly pine peeler bolts significantly impacted the dollar value of veneer coming from those bolts, under a pricing model in which high (A/B) grade veneer was assigned at least twice the value of lower grades. However, when dollar value was predicted for whole trees under the same veneer pricing assumptions, the reduction in product quality associated with increases in knot site and number had an insignificant impact on whole-tree value in comparison with the correlated, positive impact of increasing tree size. For this reason, attempts to increase the quality of peeler bolts indirectly through crown quality improvements either had no effect on tree value or actually related to a decrease in tree value due to correlated decreases in tree diameter and/or merchantable height. This result does not necessarily suggest that crown or branch traits should be rejected out-of-hand as selection criteria in lobloll pine, however. The ultimate weight assigned to any trait in an index selecti program depends not only on the relative economic values of the index traits but also on the heritabilities and the genetic and phenotypic correlations among them. Although estimates of such parameters are not yet available for individual branching traits in mature loblolly pine, heritabilities estimated for these traits in young trees and in other species compare favorably with those estimated for crown score in a young loblolly pine population (Stonecypher et al. 1973). This study has demonstrated for one unselected population of mature loblolly pine that there are combinations of separately-measured branch characters which can be measured easily and more repeatably than a subjective crown score, and which ultimately may relate better to tree dollar value. Relative economic values for size, form and crown or branch traits should be evaluated for other product outcomes and combined with reliable estimates of genetic and phenotypic parameters for these traits in mature trees in a multi-trait index before the final decision is made whether to include crown or branch traits in future rounds of selection.

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