INDEX SELECTION FOR VOLUME AND STRAIGHTNESS IN A LOBLOLLY PINE POPULATION

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Abstract.--Relative economic values for stem volume and bole straightness score were experimentally determined for use in combined family, and multiple-trait selection indexes. Selection indexes were constructed for a population of loblolly pine using different sets of relative economic values and sensitivity of genetic gain in total economic value to these changes was determined. Predicted gains in total economic value were relatively insensitive over a substantial range of relative weights.

Keywords: Selection index, relative economic values, sensitivity analysis, Pinus taeda.

Tree breeders must select on the basis of several traits to maximize genetic gains and returns from tree improvement. Faster growth is usually the primary criterion for selection, but other traits like wood density and bole straightness may strongly influence yields of specific products and the economic value of trees.

The improvement of several traits can be accomplished by tandem selection to improve one trait at a time, or by selecting only individuals that exceed culling levels for each trait. However, index selection has been shown to be theoretically superior to either of these (Hazel and Lush, 1942). Also, the accuracy of selection may be increased when information from relatives is considered in addition to information from candidate trees. The theoretical advantage of such indexes for seed orchard rogueing was demonstrated by Namkoong (1965). Information from relatives and for multiple traits can be incorporated in a combined family and multiple trait index and these have been used in applied forest tree selection programs (Arbez et al., 1974, Wilcox et al., 1975). Even though the theoretical advantage of combined multiple-trait indexes is clear, several problems have limited their use by forest tree breeders (Namkoong, 1969, Arbez et al., 1974). Selection indexes combine economic and genetic information in a multiple regression equation to predict the worth of an aggregrate genotype. Non-linearity or discontinuities in value functions make indexes more difficult to construct, or even inaccurate, and future trait values are uncertain. Unavailable or inaccurate estimates of economic or genetic values also have limited the use of selection indexes in forest tree improvement. An index based on poor parameter estimates is unlikely to be optimum (Williams, 1962).

The lack of reliable estimates of relative economic values may be the factor most limiting the use of selection indexes in forest tree breeding. The manner in which changes in specific traits impact total value has been described only for a few traits influencing pulp or paper yields or quality, (van Buijtenen, 1974). Studies estimating relative economic values for traits affecting yields or quality of solid-wood products are few.

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This paper describes a procedure to estimate relative economic values for volume and straightness for planted loblolly pine, (*Pinus taeda* L.). These values were used to construct selection indexes and to determine the sensitivity of selection results to changes in relative economic values.

METHODS

Approach

Detailed stem measurements were taken from 11-, 12-, 13-, and 14-year-old trees felled in progeny tests. A yield model and a merchandising simulator were used to forecast volumes and the value of products that could be realized from each stem at age 25. Linear regression was used to determine how changes in volume and in subjectively determined straightness scores were related to forecasted values for individual trees. These relative economic values were used to construct selection indexes and to determine the sensitivity of the index to changes in these values.

Straightness and Value Determination

Trees selected for this study were from Weyerhaeuser Company's supplemental genetic tests near Piney Green, North Carolina. Trees were selected using data recorded in the spring of 1978. Ninety trees were chosen from the eight plantations (North and South Coastal tests planted in 1964, 65, 66 and 67). Twelve trees were selected in each of six straightness classes (1 thru 6), to represent the range of diameters and heights in the tests. Straightness scores were subjectively assigned to each tree based on degree of sweep, spirality, crooks, and lean relative to other trees in the test planting (Anonymous, North Carolina State University). A score of 1 was assigned to the straightest trees.

Diameter outside bark, bark thickness, and stem deviation from a string line from the center of the butt to the center of a 2" top were measured for each 2' 1" segment on felled trees.

Measurement trees averaged 12.5 years of age from planting. Basal area, trees per acre, minimum and maximum diameter, and average height of the dominant and co-dominant stand were inputs to a yield model which estimated the current yield from stand tables and then projected the stand table to forecast yields at age 25. The assumption was made that each tree maintained its relative position in the stand table from age 12.5 to age 25 (Strub, 1979). Height at age 25 was estimated by adding the difference between current and 25-year height to measured height at age 12.5 Actual and projected stand parameters are shown in Table 1.

Table 1.--Parameters for actual and projected stand

	Actual stand at age 12.5	Stand at age 25
Mean D.b.h.	5.9 in. (15.0 cm)	8.5 in. (21.6 cm)
Std. Deviation	1.1	1.3
Mean Height	39.1 ft. (11.9 m)	68.4 ft. (20.8 m)
Std. Deviation	4.1	4.8
Mean Volume	---	10.4 ft^3 (0.29 m^3)
Std. Deviation	---	3.9

A taper model used measured and forecasted diameters and heights to estimate diameters for each 2' 1" segment at age 25. Estimates from the taper model were input to a merchandiser simulator to estimate the worth of each tree. Value of each stem was the value of products less mill processing costs. These may vary significantly from processor to processor, and over time. The total log volume was classified into chip-n-saw, chips, or plywood for each straightness class (Table 2). The forecast growth above the measured height was assumed to be straight for every tree. This portion of the bole was too small to contribute significantly to chip-n-saw volume and therefore had little impact on differences among trees in total value. That is, our model chipped the upper portion of the stem assumed to be straight.

Table 2.--Summary of log values from a merchandising model

	Value $ Per Tree			% of Log Yield		
Strt. Class	Avg.	Min.	Max.	Chip-n-saw	Chips	Plywood
1	10.18	1.12	22.21	70.42	29.58	----
2	10.85	1.10	23.11	70.75	29.25	----
3	9.41	1.16	23.52	64.56	32.16	3.28
4	9.39	1.21	26.18	68.62	31.38	----
5	8.13	.99	19.80	58.14	35.44	6.42
6	7.89	.96	22.39	56.26	43.74	----

Estimating Relative Economic Values

A Kruskal-Wallis one-way analysis of variance showed no significant differences among mean tree total values for 6 straightness classes at the .80 confidence level. Moreover, the range among mean values for the 6 classes was small ($2.29) when compared to the mean range of values within straightness classes ($21.78). This suggested that most of the variation in value was related to size.

Covariance analysis was used to compare linear regression of value on volume for the 6 straightness classes. The regression model was $y = b_0 + b_1 X$ where; Y is the total value per tree and X is volume per tree. The apparent similarity between classes 1 and 2, 3 and 4, and 5 and 6 led us to compare three combined classes; i.e., 1 + 2, 3 + 4, and 5 + 6 (Table 3). Slopes of these three lines were not statistically different at the 90% confidence level. Regressions differed in level between classes 1 + 2 versus 3 + 4 and 3 + 4 versus 5 + 6 at the 99% confidence level.

Economic values for volume and straightness score were determined by calculating the change in average tree value per unit change in each trait.

Table 3.--Regression equations for three combined straightness classes

Straightness Class	b_0	b_1	Volume/Tree (cu.ft.)	Average Value Per Tree at Mean Volume $\hat{\bar{Y}}$ ($)
1 + 2	-6.59	1.82	10.6	12.34
3 + 4	-6.15	1.68	10.5	11.32
5 + 6	-6.06	1.55	10.2	10.06
All Classes Combined		1.68	10.4	

The change in stem value associated with a unit change in volume was estimated by the slope of the regression through all points in all three classes combined; i.e., $1.68. Average value per tree was adjusted for differences in average volumes among straightness classes by calculating at the overall mean volume (10.4 cu.ft.) for each class (Table 3). Adjusted value per tree increased from $10.06 for class 5 + 6 to $12.34 for class 1 + 2. Therefore, the average increase in value for each unit of straightness score was ($12.34 - $10.06)/ (5.5 - 1.5) = $2.28/4 = $0.57. The relative economic values for volume and straightness were then; $1.68/$0.57 3:1.

Index Selection

Combined family, multiple-trait indexes were constructed following procedures described by Wilcox, et al. (1975). These incorporated individual and full-sib family information for each trait in a single index value assigned to every tree in a test. We assumed that the components of variance (or covariance) for full-sib family means estimated half the additive genetic variance (or covariance) in constructing indexes for each test.

Narrow-sense heritabilities for volume and straightness on an individual basis are presented in Table 4 as well as genotypic correlations between the two traits. Standard deviations were calculated from estimates for the eight tests. Selection to improve straightness would be easier than for increased volume since it has a higher heritability. The average genotypic correlation between volume and straightness (-.152) indicates a positive relationship since decreasing straightness scores indicate improved straightness. This positive genotypic correlation indicates that selection for volume or straightness will result in improvement in the other as well.

Selection indexes were constructed for four sets of relative economic values: (1, 0), selection for volume improvement-straightness score not considered; (1, -0.33), straightness given one-third as much weight as volume; i.e., our experimentally-determined set of weights; (1, -0.5), straightness given one-half as much weight as volume; and (1, -1), both traits given equal weight.

Table 4.--Narrow-sense heritabilities and genotypic correlations for eight genetic tests used to construct selection indexes

Test	Heritability Volume	Heritability St. Score	Genotypic Correlation
North Coastal - 1964	.30	.55	-.210
65	.29	.40	-.384
66	.35	.29	-.134
67	.17	.24	-.072
South Coastal - 1964	_1	.35	_1
65	.23	.27	.179
66	.17	.26	-.376
67	.15	.25	-.070
Mean	.24	.33	-.152
Std. Deviation	.08	.10	.215

1 Estimate of family variance component for volume was negative, and these values were not included in further analysis.

All indexes were calculated using the same genotypic and phenotypic parameters. Therefore differences in expected genetic gains were the result of changing economic emphasis on volume and straightness score. Expected genetic gains in each trait from "pick-the-winner" selection based on index scores are given for each set of weights in Table 5. The proportion saved was 2% from each test. Percentage expected genetic gains were calculated by dividing the mean genetic gain for each trait by its respective average over all tests. These were 11, 12, 13, and 14 years of age.

Table 5.--Average expected genetic gains from selecting in eight genetic tests

Relative Economic Weights[1]	Expected Genetic Gain: Average Age 12.5[2]	% Gain	Straightness Score	
(1, 0)	0.99 (cu.ft.)	37	-0.32	10%
(1, -0.33)	0.94	35	-0.64	19%
(1, -0.5)	0.89	32	-0.75	23%
(1, -1)	0.73	28	-0.94	29%

1 (Volume weight, straightness weight)

2 Average age for 11-, 12-, 13-, and 14-year-old tests

Traits other than volume and straightness were not considered in the selection procedure; e.g., trees infected with fusiform rust, (*Cronartium fusiforme* Hedge and Hunt), or which had poor crown scores were not excluded, nor was relatedness among selects restricted. This was done to simplify the sensitivity analysis.

Sensitivity Analysis

We examined the expected change in total value for sensitivity to changing relative economic weights in selection indexes. This was determined by multiplying the predicted gain in volume and straightness (Table 5) by their respective economic values ($1.68/cu.ft. volume and $0.57/unit straightness score). This assumed that economic values for the two traits were the same at mid-rotation age and 25 years. These products and their sum, which is the expected net total value, are presented in Table 6 for each selection index. Sensitivity to changing index weights was calculated as a % of the net total gain predicted for our experimentally-determined set of economic weights.

Results and Discussion

Assigning no economic weight to straightness resulted in greater predicted genetic gain in volume than for any other set of weights, as expected. Predicted gains increased for straightness score and decreased for stem volume as proportionately greater weight was assigned to straightness score (Table 5).

Predicted change in net total value was reduced from our optimum set (1, -0.33) by 5% for both (1, 0) and (1, -0.5) (Table 6).

Table 6.--Expected genetic gains from index selection based on different relative economic values

Relative Economic Weights	Expected Genetic Gain in Economic Value ($): Stem Volume	Straightness Score	Net Total Value	% of (1, -0.33)
(1, 0)	1.66	0.18	1.84	95
(1, -0.33)	1.58	0.36	1.94	100
(1, -0.5)	1.50	0.43	1.93	95
(1, -1)	1.23	0.53	1.77	91

The contribution of stem volume to expected genetic gain in total economic value (1.66) was greater for (1, 0) than for the optimum set (1.58), however, this was offset by a greater contribution for straightness score (0.36 vs. 0.18) for the optimum index. Values for stem volume were lower than for the optimum index when straightness score was given more relative weight. Associated increases in value for straightness score were not large enough to offset these decreases and thus net total economic value was highest for the optimum index.

Predicted change in net total value was relatively insensitive to changes in relative economic weights in the range we examined. The 9% decrease in gain in net total value from the optimum index when the two traits were given equal weight (Table 6) represents approximately a 3% decrease in the net total value of the average tree at age 12.5. When unknown, but significant, weight is assigned to straightness score in the selection process, gains in net value for our model could be well below those for the range of relative weights considered. We reemphasize that these results apply only to our model. Specifically, one in which merchandising for the highest value product yields mostly chip-n-saw logs. Also, significant changes in manufacturing costs or market prices will necessitate a reexamination of these conclusions. Changes in genetic parameters for the selection could also affect the outcome of an analysis like the one presented. For example, if stem volume and straightness score had a negative genetic correlation, selection for increases in one would imply decrease in the other, and perhaps greater sensitivity over a relatively small range of economic weights.

We recommend that when economic values are not easily determined, sensitivity analysis be done on the selection population to determine the impact of varying relative economic values. If one can confidently conclude that the true relative values for traits of interest lie in a range of values to which predicted genetic gains are insensitive, the costly process of determining economic values can be avoided.

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