MEASURING GENETIC GAINS BY PROJECTED INCREASES IN FINANCIAL RETURNS

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Abstract.--A new approach to projecting economic gains from genetically selected forest trees estimated increases in revenues from loblolly pine that ranged up to 150 percent or $20 per acre per year. The method combines data from genetic trials with mathematical growth models that project specific stand characteristics. Product value functions use these characteristics to determine value gains at harvest. The approach shows promise of becoming a valuable tool for evaluating genetic crosses, and for assessing impacts of genetically improved stock on management programs.

Additional keywords: Loblolly pine, *Pinus taeda*, height growth, diameter growth, survival, genetic selection.

In forest genetics programs, one ultimate measure of gain is the increase in revenues from commercial plantations of improved trees. In each step of tree improvement programs, starting with selections from wild populations, geneticists must place either explicit or implied values on inheritable characteristics. The development of an improved method of measuring financial gains of selected genetically improved stock began with a search for more accurate ways to relate tree characteristics with harvest revenues.

Most applications of economic analysis to forest genetics problems have focused on evaluating financial returns from entire research or seedling production programs. Several such studies are notable.

Early analyses sought to determine what rate of genetic gain would justify investment in tree improvement programs. Lundgren and King (1966) viewed accelerated growth rates from superior seeds as an apparent increase in site index of improved jack pine and red pine planting stock. For alternative rates of return ranging from 4 to 6 percent, they concluded that the gain in site index necessary to offset costs for tree improvement could be attained readily. For example, returns of approximately 7 percent were projected if site indexes of class 55 land could be increased by only 2 units.

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A study by Davis (1967) estimated the gains necessary to make southern pine improvement programs financially self-sufficient. An increase of only 1 cord at rotation, or its value equivalent in quality increase, was needed to offset net costs for superior seeds of approximately $10 per pound. Such volume increases were considered virtual certainties.

An analysis of the financial returns and increased future harvests from an accelerated forest genetics program for southern pine indicated a rate-of-return of 12.4 percent (Row 1967). In another study of improved southern pines, Swofford and Smith (1972) evaluated the economic advantages of the tree improvement program for the National Forests in the South. They expressed the results as aggregate implications for harvesting and inventory volumes. Improved trees would increase yields from National Forests in the South by 24 percent.

None of these studies developed estimates of gain for specific genetic characteristics. The first study that made notable improvements in this direction was Porterfield's (1974) application of goal programming to compute gains from public and private genetic improvement programs for loblolly pine. With this model, profit impacts of various roguing intensities and wildstand selection intensities were calculated. Goals were changed, absolutely or relatively, in response to assumed market conditions. Economic criteria included specified internal rates-of-return and benefit-cost ratios. Greatest profits accrued where many clones were selected, grafts were closely spaced, and orchards were intensively rogued.

Our approach diverges from these precedents in several respects. We have not attempted to evaluate tree improvement development programs, but to provide a tool for economic decision-making among genetic source material within a program. In this approach specific measures of genetic gain--increased height and diameter growth, improved form, and higher survival rates--are used to modify the component functions of existing stand models that project growth of unimproved plantations. The modified models can be used to simulate growth and yields of genetically improved plantations under different site quality, spacing, and management assumptions. This approach minimizes errors that occur when the design of genetic tests creates conditions that vary substantially from commercial plantations.

Previous projections of economic gain from genetic manipulation have relied on general percentage estimates of increased volume. This tends to minimize influences of tree and stand characteristics on stumpage price and harvesting costs. Yet, these characteristics have been shown to significantly affect the financial returns from timber growing (Row 1973; Dutrow et al 1970). Stand conditions that have particular influence are tree size and volume per acre. Values assigned herein reflect price functions that account for stand influences. The sensitivity of improved plantation to other factors, such as altered growth rates or costs, can also be ascertained.

Analytical advantages were made possible by use of a relatively new computer system called MULTIPLOY (Row 1974). It is a special computer language for evaluating a wide range of timber investments.

MODIFYING A GROWTH MODEL TO SIMULATE GENETIC GAINS

Forest mensurationists have developed numerous models for projecting timber stand development with varying levels of detail. In particular, Clutter and his associates at the University of Georgia have developed mathematical functions to describe the growth of unimproved loblolly pine plantations. We devised a procedure for modifying these functions for increased growth rates of genetically improved planting stock.

To demonstrate this approach we used estimates of probable gains calculated from data provided by the North Carolina State Cooperative Tree Improvement program. These data included 27 sets of tests of genetic crosses of loblolly pine, each with a check test and from 7 to 33 genetic crosses in each set. Each check and cross test had an average of 27 surviving trees. Altogether average growth values for 8-year remeasurements of some 472 genetic crosses were made available.

Increased height growth

A primary goal of genetic manipulation and an important selection criterion is improved height growth. The average height of each genetic cross was divided by the average height of the check test of unimproved trees to provide a height adjustment ratio. Distribution of height gains of superior trees is shown in ogive form in Figure 1. On the horizontal axis relative height increases or decreases (some trials were shorter than check trees) are depicted. The vertical axis shows the proportion of genetic trials that exceeded the relative increases in height. Average height increase was 3.5 percent, with a median of 2.6 percent. About 16 percent of the trials had height increases greater than 10 percent.

In projecting height in simulated stands, the estimated height at each age was multiplied by the increase ratio. The estimating equation for unimproved stands is:

$$\log_{10}(H) = 1.5469 - 11.406 / T + 10^{(2.9110 / T)} * (.76481 * \log_{10}(SI) - .83419)$$

where H is height of dominant trees, T is plantation age, and SI is site index (Lenhart and Clutter 1971). For each set of genetic trials, site index was derived from heights of the check trees by solving the formula above for SI, with H and T known.

Diameter increases

A second specific genetic characteristic is average diameter growth. A genetic diameter increase factor was computed from the ratio of average diameters of improved trees to check trees. Figure 2 shows the ogive curve of the distribution of diameter increase ratios. Average diameter increased 3.0 percent, with a median of 1.5 percent.

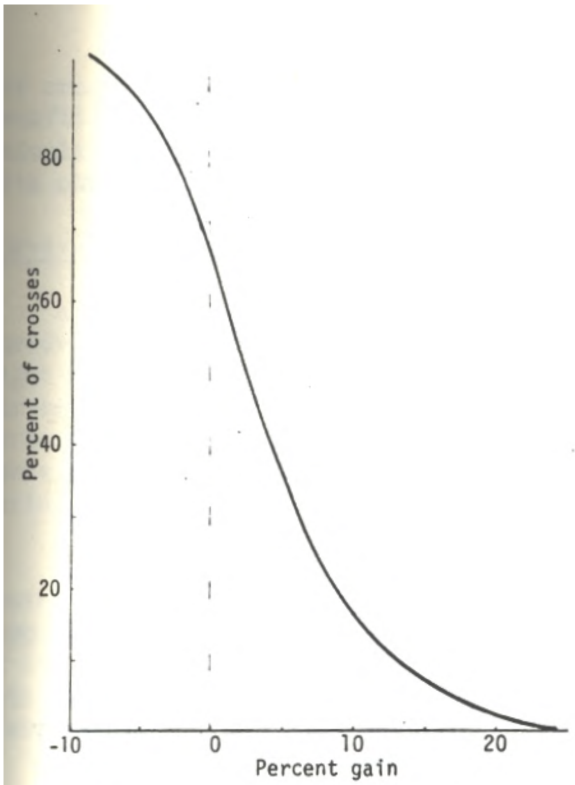

Figure 1.--Ogive of percent of crosses exceeding given percent gain in height.

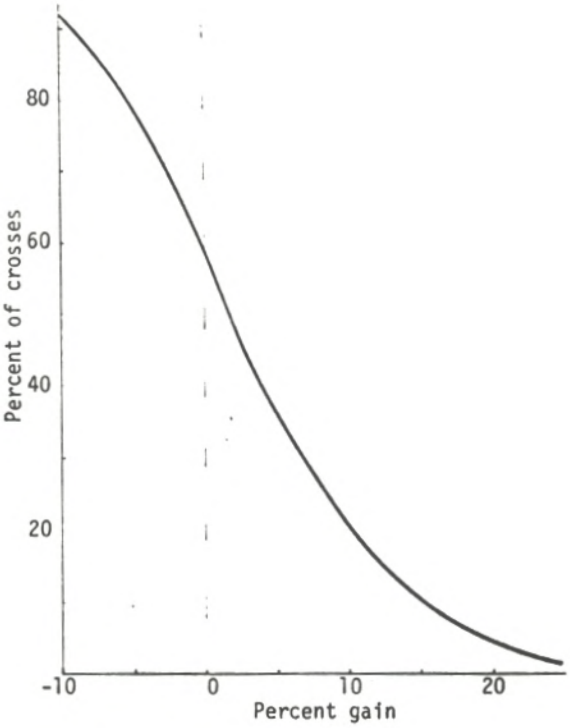

Figure 2.--Ogive of percent of crosses exceeding given percent gain in diameter.

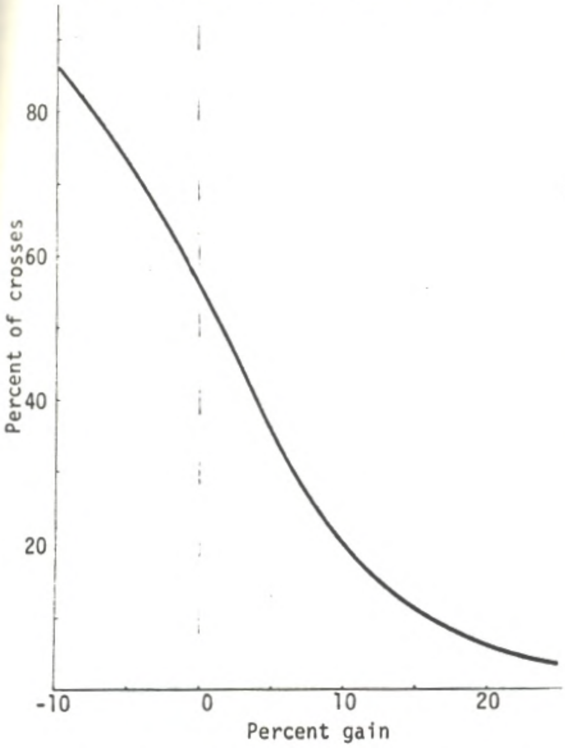

Figure 3.--Ogive of percent of crosses exceeding given percent gain in survival.

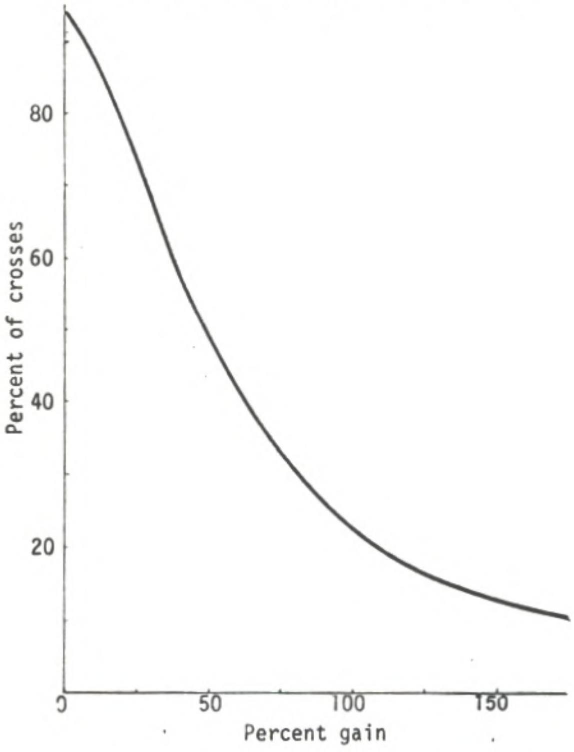

Figure 4.--Ogive of percent of crosses exceeding given percent gain in harvest value.

For projections of stand growth, this diameter adjustment factor was applied to expected minimum and maximum diameters of unimproved loblolly pine. Expected values were based on techniques developed by Lenhart and Clutter (1971) wherein a beta function is used to describe the distribution of basal area by diameter. The relative frequency of basal area occurring on stems with diameter D_i is:

$$f(D_i) = \frac{\Gamma(\alpha + \beta + 2)}{(D_{max} - D_{min}) * \Gamma(\alpha + 1) * \Gamma(\beta + 1)} * \left(\frac{D_i - D_{min}}{D_{max} - D_{min}}\right)^{\alpha} * \left(1 - \frac{D_i - D_{min}}{D_{max} - D_{min}}\right)^{\beta}$$

where $f(D_i)$ is relative frequency of basal area occurring on stems with diameter D_i; D_{min} is the minimum diameter of trees in the stand; and D_{max} is the maximum diameter of trees in the stand. Alpha (α) and beta (β) parameters are functions of age and were not altered in our derivation of expected values of improved diameters.

MULTIPLOY divides the range between minimum diameter and maximum diameter into 20 intervals, computes the expected basal area in each interval, and converted this figure into the number of trees. Average diameter of the genetically improved stand was calculated from total basal area and number of trees.

<u>Adjustments for change in volume relationship</u>

Data from genetic trials enabled us to measure gains in height and diameter. These gains, however, may introduce changes in the form of the tree and anticipated merchantable volumes. Existing height-diameter-volume functions for plantations of unimproved loblolly pine had to be modified. Bailey and Clutter (1970) developed an original plantation volume function which was further transformed by Row (1973) into an aggregate stand function for plantation simulations. It has the form:

$$\log_{10}(Y/N) = -\ 3.1193 + 1.7133 * \log_{10}(D) + 1.3836 * \log_{10}(H)$$

where Y/N is volume per tree.

Two steps were necessary to adjust this function for estimating volumes of genetically superior loblolly pines. First, the equation was used to compute expected volumes of the trees in the genetic improved trials. Second, recorded volumes of genetically improved trees were compared to the expected volumes calculated in step one. The comparison of recorded-to-estimated volumes was expressed as a volume adjustment factor to compensate for the changed form of genetically superior trees.

Volume adjustments were computed for each genetic cross and each check. Calculated averages and standard deviations of the volume differences were small but still statistically significant. Sixty percent of the adjustments for crosses were within 5 percent of those for the check tests. The major benefit of deriving volume adjustment factors in the foregoing manner is that calculations for improved plantations blend measurements from genetic trials with observed growth rates of unimproved trees in plantation environments.

Survival of genetically improved trees

Although geneticists did not select loblolly seed sources for increased survival in plantations, our data suggested a difference in survival at age eight between the improved and check trees. An average survival rate of 91.7 percent characterized the genetic crosses, while the rate for checks was 86.3 percent. Survival rate distributions, however, appeared non-normal, and the variance of this trait was much higher than for the other measured characteristics.

We accounted for the difference in survival between selected and unimproved trees by transforming the survival rates into probit form. Probits computed for genetic trials were compared with probits computed for survival of check trials. The increase in survival of the genetic crosses compared with unimproved stock was statistically significant. The ogive curve for the distribution of survival probit increases is shown in Figure 3.

To calibrate our model for increased survival of improved plantations, probits were converted to probability estimates, P, such that P was the probability that natural plantations would have less survival than improved stock. Distribution of P would be uniform from zero to one only if survival rates of improved trees equaled those of natural plantations.

Studies by Lenhart and Clutter (1971) again provided a comparative basis with their expression for loblolly plantation survival distributions:

$$\text{Probit}(S) = 9.3745 - .67637 * \log_{10}(T) - .96269 * \log_{10}(N_o)$$

where S is the proportion surviving, T is the age of the plantation, and N_o the original number of seedlings planted per acre. The growth simulation routine in MULTIPLOY uses the generated P to compute survival at age 8 (to match the test measurements in this case) and expected survival rates at specified future years.

The combined effect of height, diameter, volume adjustment, and survival can be expressed in a general physical unit as change in volume. This net increase was computed for each trial by dividing total volume by the check volume. This net increase in volume was not used directly in the simulations, because the simulator could produce this data from the more specific characteristics.

An additional modification of the simulation system concerns the question of whether or not increased growth in early years of plantations of improved stock will continue at the same proportional rate. We did not attempt to answer this question in our model. Instead, several projections were made on a trial basis with a portion of the data. First with an optimistic outlook, improved rates of growth were assumed to continue until harvest. Second, as a pessimistic alternative, increased growth rates were assumed to regress toward normal rates according to a logarithmic function:

$$GG_{nj} = GG_{ni} \, (AA_i \; / \; AA_j)^F$$

where GG_{nj} and GG_{ni} are average increases in the rate of growth during periods in which AA_i and AA_j are midpoint ages, and F is an adjustment factor.

We made trial runs with a portion of the data using F factors of 0. (no decline), .2, and .4. Though the levels of rates of increase changed substantially, the relationships between physical and financial returns were not affected.

Other modifications

The simulation model is capable of similar modification for specific gravity, but data from these 8-year old plantations with only juvenile wood were not available. Infection rates for fusiform rust, while available, can not yet be used to modify the plantation simulator with sufficient validity.

FINANCIAL RETURNS FROM CROSSES OF IMPROVED TREES

Using the modified plantation simulation model, MULTIPLOY estimated financial gains at the end of a 24-year rotation for the 472 individual genetic cross tests. Further assumptions were necessary:

Management regime

Plantations would be established on bare old-field sites or extremely well prepared cutover timber stands. Seedlings would be planted 500 to the acre. Fusiform rust infection would be at the average rate experienced in the tests. The plantations would be left unthinned until age 24 and then clearcut. By the nature of the plantations and rotation length, the primary product would be pulpwood.

Prices and costs

The value of timber produced at the single clearcut felling at age 24 was derived from an equation developed from stumpage sales of National Forest pulpwood and sawtimber by Row (1973). The modified equation is:

$$PU = - 5.35 + 2.253 * D - .024 * D^2 + .452 * 0$$

where PU is price in cents per cubic foot. It gives higher values for larger diameters and heavier cuts per acre. Revenues were discounted at 7 percent compound interest. Since no inflation in timber prices was assumed, this is equivalent to using a discount rate of 10 percent or more if prices rise at the rate timber prices have risen over the last several generations.

For this analysis, costs of plantation establishment would be the same for all comparisons, and were thus disregarded.

Results

Financial returns were computed for all simulations in terms of both present net worth, and equivalent annual income. (We did not use benefit-cost ratios, and rates-of-return. They were not appropriate since no costs were assumed.) As in the comparisons of physical genetic characteristics, the returns from the simulation using the genetic gain ratios for individual crosses were divided by the financial returns from the check tests.

The distribution of increases of present net worth for the 472 simulations is shown in Figure 4. The standard errors and coefficients of variation exceeded those for any of the genetic traits analyzed. The ogive curve for the distributions is relatively flat.

From a financial viewpoint, however, the results are highly gratifying. Many trials indicated financial gains of up to 150 percent, with the average gain of 73 percent and the median 50 percent. Only a few of the 472 simulations of genetic crosses indicated a poorer financial return than the check test data.

Dependence of financial returns on genetic traits

To determine the relationship of increased financial gains on specific genetic characteristics, a regression analysis was made. The dependent variable was the proportional gain in present net worth or income per acre, and the independent variables were the relative gains in each genetic trait, their squares, square roots, and simple crossproducts. The resulting regression equation was:

$$GV = 97.4409 + 10.3877 * GH^2 - 67.9319 * \sqrt{GH} - 51.4453 * \sqrt{GD} + 12.8150 * GD^2 * GH$$

where GV, GH, and GD were the proportional genetic gains plus 1 for value, height, and diameter respectively. The regression variables removed 89 percent of the variance, but the standard error of estimate was still .241, or 33 percent of the average genetic value gain. The gain in value was most closely related to gain in volume (or GD^2 * GH in the equation), but this variable alone accounted for only 28 percent of the variance of value gain. Gains in survival and changes in form were marginally significant at the 5 percent probability level but added little to the accuracy of the equation.

A second measure of the effectiveness of the estimate of financial gain is to assume that the same genetic material as the best 30 percent of the crosses were to be used in commercial plantations, with correspondingly high rates of genetic improvement. Cut-off points above which 30 percent of the crosses exceeded were determined from Figures 1, 2, 3, and 4, and average increases in value at the end of the rotation for all selected crosses computed. The results were:

Criterion	Cutoff point	Average value increase
Height	+ 6.1 %	+ 128.9 %
Diameter	+ 7.5 %	+ 133.0 %
Volume	+ 20.0 %	+ 135.9 %
Harvest value	+ 84.0 %	+ 160.5 %

Though by the method of computation, the average value increase using the harvest value criterion is the best, it is surprising that the differential is as large as it is.

A number of both genetic and economic factors could alter these results. Inclusion of assumptions or measured data on persistence of increased growth rates, increases in specific gravity of wood, and resistance to fusiform rust needs attention. And various owners may wish to assume differing value functions for harvested wood, and management regimes for plantations.

SUMMARY

The evaluation procedure we have developed is capable of appraising individual crosses and sources of genetically improved seed using expected financial returns from timber harvests. By modifying or calibrating mensurational models of plantation development, simulations of resulting timber stands can generate descriptive information by which relative unit values of the harvest can be estimated. Simulated financial returns using data from 472 genetic crosses of loblolly pine showed a complex and highly sensitive relationship to increases in height and diameter growth.

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