THE GENETIC AND ECONOMIC EFFECT OF PRELIMINARY[1] CULLING IN THE SEEDLING ORCHARD

Don E. Riemenschneider[2]

ABSTRACT.--The genetic and economic effects of two stages of truncation selection in a white spruce seedling orchard were investigated by computer simulation. Genetic effects were computed by assuming a bivariate distribution of juvenile and mature traits and volume was used as the selection criterion. Seed production was assumed to rise in a linear fashion to maturity and then remain constant for the life of the orchard. Expected seed production was used to compute the number of acres that could be planted and volume gain over this acreage was estimated using predicted response to selection and white spruce volume tables. The added volume was compared to the cost of the orchard using the cost-price investment criterion. The cost-price of the volume gain was found to vary little over reasonable intensities of preliminary culling and the optimum intensity remained the same regardless of the juvenile-mature correlation.

Many economic analyses of forest tree improvement projects have already been done (Dutrow 1974). To date, however, most of these studies have dealt with clonal seed orchards (Davis 1967, van Buijtenen and Saitta 1972, Porterfield 1974) rather than seedling seed orchards. I began this study to investigate the genetic and economic potential of a white spruce seedling seed orchard by means of computer simulation. The goals were to determine (1) the effect preliminary culling had on genetic gain and economic return, and (2) the optimum level of culling.

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[2]Graduate Research Assistant, College of Forestry, University of Minnesota.

METHODS

A 4.5 acre white spruce (*Picea glauca* (Moench) Voss) seedling seed orchard in north-central Minnesota was used as the model population. The orchard initially contained 7,200 individuals representing 239 open-pollinated families. Early measurements of height growth and estimates of heritability have been reported (Mohn *et al*. 1975).

Although combined family and mass selection is likely to be more efficient, the problem was reduced to a manageable level by assuming that there will be two rounds of mass selection in the orchard. Merchantable volume will be the selection criteria. The first round of selection at 15 years after planting will represent juvenile selection or "preliminary culling". The second round of selection will be at 30 years after planting. This final selection will be on the basis of the mature characteristic. Approximately 450 individuals (or 6.25 percent) will remain after all selections have been completed. Gain from parental selection was not considered. A termination date was set at 50 years after planting.

With this culling schedule there will be two productive stages in the life of the orchard. From 15 to 30 years after planting, genetic gain will be the result of the correlated response of the mature trait to preliminary culling based on the juvenile trait. Seed production during this period should be increasing as the trees approach maturity. After final selection at age 30 genetic gain will be based on both rounds of selection. Seed production should reach its maximum and remain constant.

The intensity of preliminary culling will affect response to selection in both stages and total seed production in the first stage. It was necessary to quantify this effect and then determine the intensity that maximized the potential return on the orchard investment.

The genetic effect of preliminary culling were evaluated by assuming that the two selection criteria are bivariate normally distributed. The technique used in this study has been described by Brown (1967) and applied to a tree improvement problem by Namkoong (1970). The genetic effects of selection were computed as follows:

Let: u = the mature trait and

v = the correlated juvenile trait.

Assume that u and v are bivariate normal with phenotypic correlation r_p genotypic correlation coefficient r_a, and heritabilities h^2_u and h^2_v.

If $x = \frac{u - \bar{u}}{\sigma_u}$, $y = \frac{v - \bar{v}}{\sigma_v}$, and σ_u and σ_v are the phenotypic standard deviations of u and v, then x and y are standard bivariate normal with:

$\bar{x} = \bar{y} = 0$ and,

$\sigma_x^2 = \sigma_y^2 = 1.0.$

The selection procedure in terms of the univariate distribution of x and y will be to discard all individuals where $y<b$ at the preliminary culling and to discard all individuals where $x<a$ at the final selection.

To determine the culling levels, univariate y is divided into 40 intervals, and for each level of culling at $y - b$, the truncation point $x = a$ is obtained, which gives $p\ (a,b\colon r_p) = P$ where:

$p\ (a,b\colon r_p)$ = the fraction of the population retained after truncation of a bivariate distribution, discarding all individuals where $y<b$ and $x<a$, and

P = the portion of the population the breeder wishes to retain after both rounds of selection (6.25 percent).

The gain made in x by truncation selection in y is:

$\Delta G_{x/y} = i_1\ h_x\ h_y\ r_a$ (Falconer 1960)

where: i_1 = the selection intensity in y,

$h_x = (h_x^2)^{\frac{1}{2}}$,

$h_y = (h_y^2)^{\frac{1}{2}}$, and

τ_a = the genotypic correlation between x and y.

Assuming a large population, the selection intensity i_1 is computed by the stochastic relation $i_1 = \frac{Z\ (b)}{Q\ (b)}$

where: $Z(b)$ = the ordinate of $N\ (0,1)$ at $y = b$, and

$Q(b)$ = the standardized univariate normal density function integrated from b to $+\infty$.

$\Delta G_{x/y}$ represents the genetic superiority of seed produced between the preliminary culling and the final selection.

When the final selection is made by truncation at x = a, the total genetic gain obtained in x is given by:

$\Delta G_x = i_2 h_x^2$ (Falconer 1960) where: i_2 = the selection intensity in x after truncation selection at y = b and x - a; and

h_x^2 = the heritability of x.

The method of computing i_2 is described by Young and Weiler (1961) and a mathematical proof is given by Weiler (1959). The expected mean of x after both rounds of selection ($\bar{x}'$) can be written in terms of a univariate distribution.

$$E(\bar{x}') = \frac{Z(a) \quad Q(A) + r_p \, Z(b) \quad Q(B)}{P}$$

where: $A = \frac{b - r_p a}{\sqrt{1 - r^2 p}}$, $B = \frac{a - r_p b}{\sqrt{1 - r^2 p}}$, and

r_p = the phenotypic correlation coefficient.

And because the original distribution of x has mean 0, $\bar{x}' = i_2$.

ΔG_x represents the genetic superiority of seed produced after the final selection.

$\Delta G_{x/y}$ and G_x are expressed as a percent of $\bar{u}$ by multiplying times the coefficient of variation of u.

The amount of seed produced by an orchard is equally as important as genetic gain. Seed production was assumed to begin 15 years after planting and then rise linearly to a constant level of 250 cones/tree/year (Nienstaedt and Jeffers 1970) at 30 years after planting. Total yearly seed production was then computed as the average per tree production times the number of trees in the orchard.

The volume growth in excess of normal yield produced by this improved seed is:

$$V = \frac{A \cdot Vn \cdot G}{100}$$

where: A = the number of acres regenerated based on 8 x 8 foot spacing and 70 percent average seed viability,

Vn = normal yield per acre on medium site land with 40 year rotation (Stiell and Berry 1973), and

ΔG = percent genetic superiority of the seed depending on the stage in which it was harvested.

The schedule of activities that were included as costs are shown below:

Year		Activity
	Selection Phase	
1		Select parents and collect open-pollinated seed
1		Extract and prepare seed
	Nursery Phase	
2		Prepare bed
2		Sow
2,3		Maintain seedbed
4		Transplant
4,5		Maintain transplant bed
6		Lift and wrap stock
	Orchard Phase	
6		Purchase land
6		Prepare site
6		Plant
6-55		Maintain
20		Measure
20		Mark and cull
21-35		Collect seed
35		Measure before final selection
35		Mark
36-55		Collect seed

Estimates of the cost of each activity were obtained from individuals who participated in the project or from organizations that had experience in similar operations. An inflation rate of 4 percent was included when estimating future costs. Costs that occur between 15 and 20 years after planting, especially seed collection, will vary with culling intensity. As culling intensity is increased, these costs are reduced.

The investment criterion used to evaluate culling alternatives was the cost-price relation (Lundgren 1973). This is the price at which a product must be sold in order to break even on the investment. Because output is produced over a period of years, this price was necessarily assumed to be constant. It was computed by dividing cost by output ($/cord) in terms of present equivalents. The present equivalents of cost and output were obtained using standard discounting procedures and an interest rate of 8 percent.

RESULTS

In the Minnesota orchard, heritability for height at 8 years after planting was 0.35 with a coefficient of variation of 34 percent. On the basis of these estimates it was felt that a heritability of 0.30 for volume with a coefficient of variation of 20 percent would provide a conservative estimate of gains from selection.

Seed produced from age 16 to age 30 ($\Delta G_{X/y}$) and from age 31 to age 50 (ΔG_X) were found to be genetically superior (fig. 1 and 2). When levels of culling are low, $\Delta G_{X/y}$ is also small because i_1 is small. But when levels of culling rise, $\Delta G_{X/y}$ also rises appreciably. If all selection is done at age 15, $\Delta G_{X/y}$ is 6 percent, 8 percent, and 11 percent for correlations of 0.5, 0.7, and 0.9, respectively.

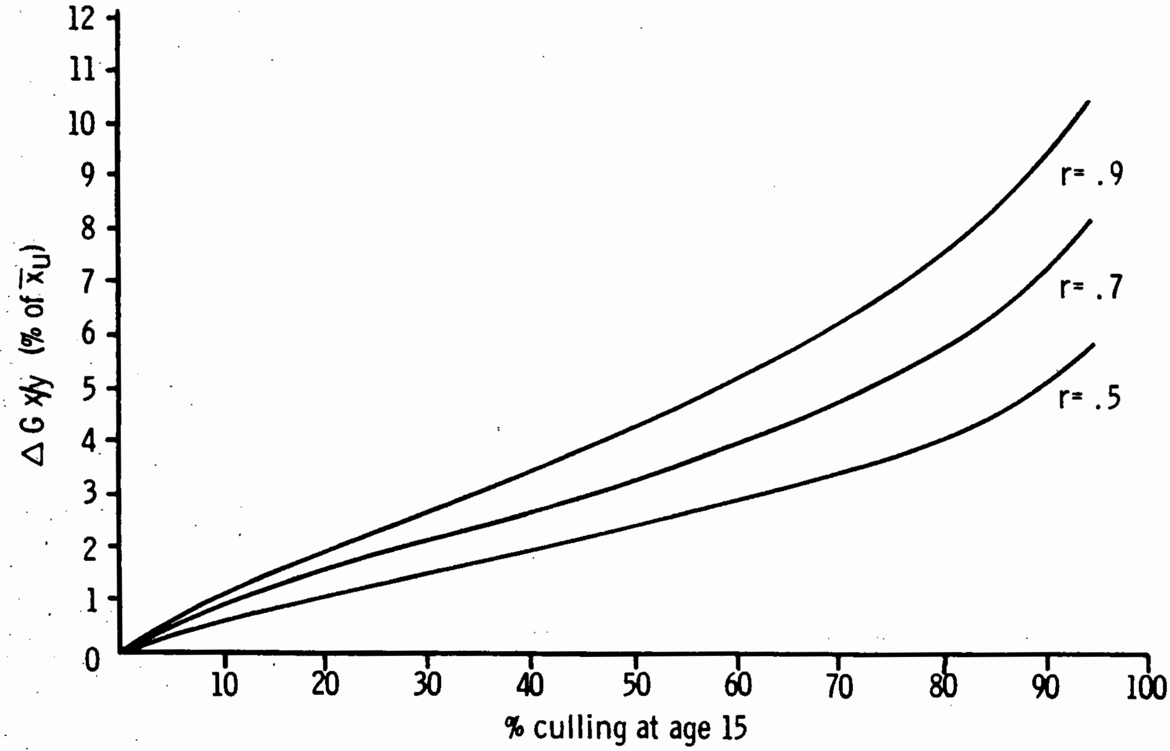

Figure 1.--Gain in the final selection criterion with preliminary culling.

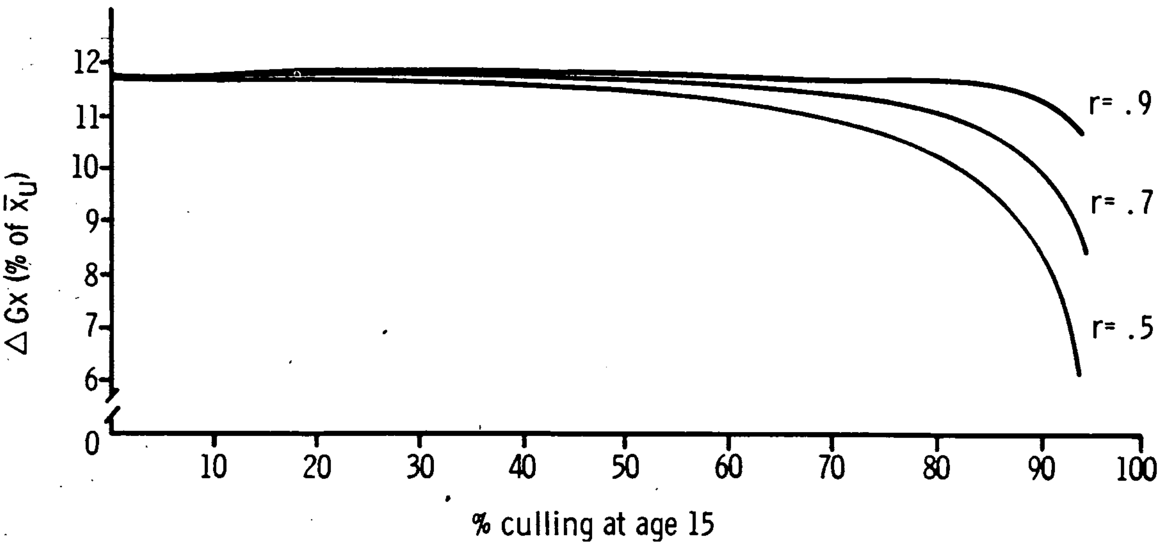

Figure 2.--Gain in the final selection criterion after two rounds of truncation selection.

At low and intermediate levels of culling, ΔG_X does not decrease appreciably. Maximum ΔG_X is 12 percent when i_1 = 0.0 for all correlations. For correlations of 0.5, 0.7, and 0.9, ΔG_X is reduced to 6 percent, 8 percent, and 11 percent if all selection is done at age 15. The drop in ΔG_X is not great until high levels of culling are reached and the drop is more severe if the correlation between traits is low. At the maximum culling level $\Delta G_{X/y}$ should equal ΔG_X because there will be no second round selection. The fact that the values obtained agree closely provides a good check on the computational procedures employed.

The present equivalent of the predicted volume in excess of normal yield maximizes at an intermediate point (figs. 3 & 4). This is because the volume gain from pre-final selection seed is a function of both seed production and $\Delta G_{X/y}$, which vary inversely as culling level increases, the curve maximizes at an intermediate point. Because stable seed production is assumed after year 30, only genetic gain after 30 years influences volume gain. The curve decreases slightly at high levels of culling. The importance of early seed production and selection can be seen in the relative heights of the two curves. Although this early production is low, it contributes significantly to the total volume gain when considered for the entire investment period. More volume is produced at higher correlations, but the maximum point is reached at about 50 percent culling.

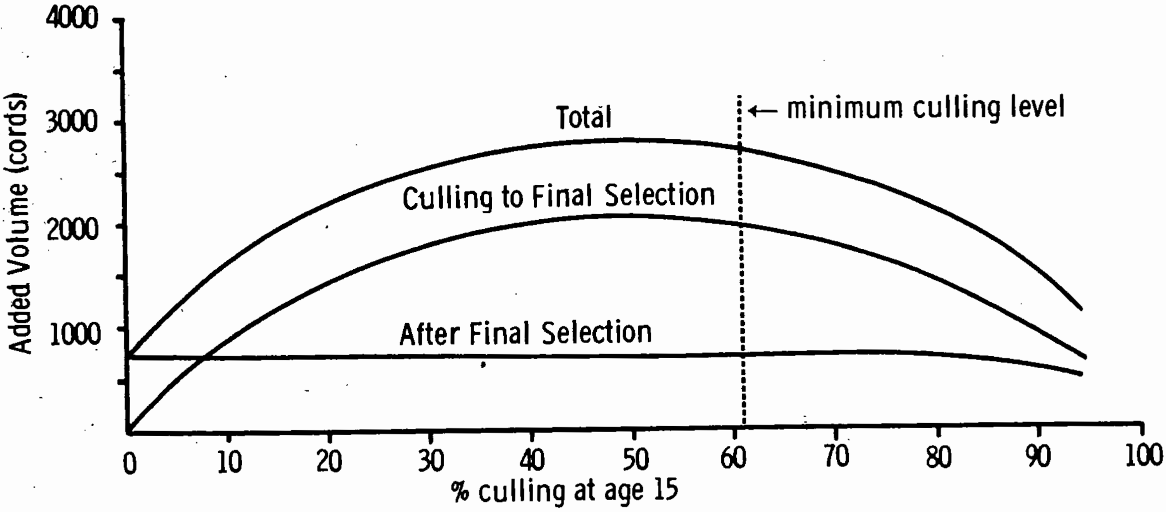

Figure 3.--Gain in volume at rotation age (juvenile-mature correlation = .7) (present equivalent).

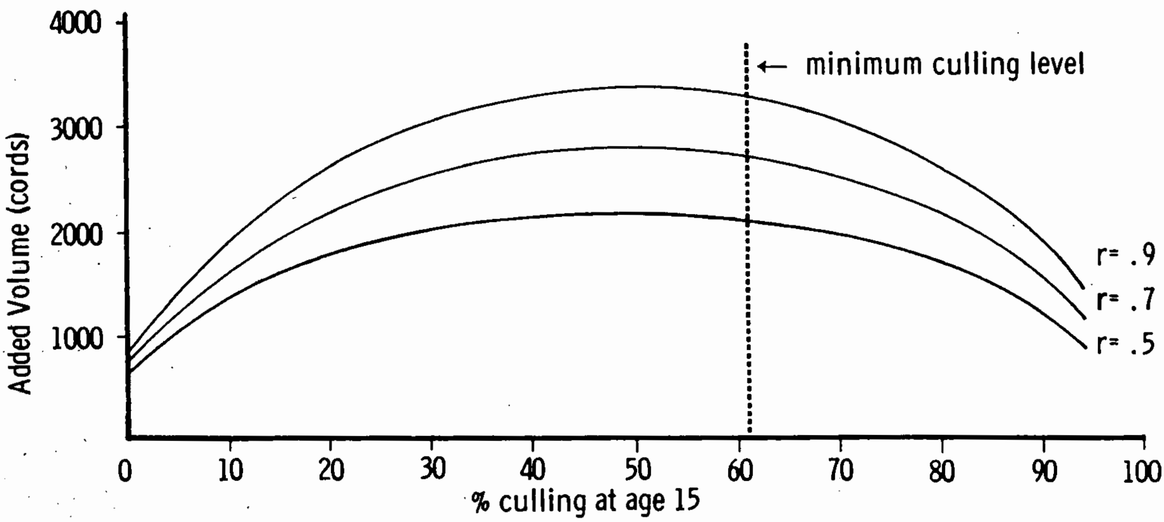

Figure 4.--Total gain in volume at roation age (present equivalent).

Total orchard seed production was assumed to be a linear function of the number of trees in the orchard. Obviously at low culling levels this linear relation will not exist because crowding will reduce average per tree production. Stocking data (Stiell and Berry 1973) indicate that overcrowding and mortality will occur in the model orchard unless 61 percent of the trees are removed at age 15. This would seem to be the minimum intensity of culling above which volume gain predictions may be accurate.

The present value of costs that are not affected by culling level are shown below:

Activity		Cost
Selection and seed preparation		$ 693.33
Nursery handling		660.39
Land purchase and site preparation		131.80
Planting, maintenance, pre-culling measurements		1,952.30
Seed collection after final selection		2,769.28
	TOTAL	$6,207.10

The total present cost ranged from $14,282 at the minimum culling intensity of 61 percent to $8,131 at maximum culling.

The cost price of the gain in volume is a u-shaped curve (fig. 5). The cost/cord is high at low culling levels where $\Delta G_{x/y}$ is small; it reaches a minimum at 73 percent culling and increases at high culling levels because seed production is reduced. Again the curves optimize at the same culling level regardless of the correlation between traits. The minimum price does vary with the correlation coefficient.

The shape of the cost-price curve is flat for the most likely culling intensities. This indicates that a good deal of flexibility is permitted before the cost of production is measurably affected. Also, although the juvenile-mature correlation affects the economic feasbility of the program as a whole, it has little impact on the optimum intensity of preliminary culling.

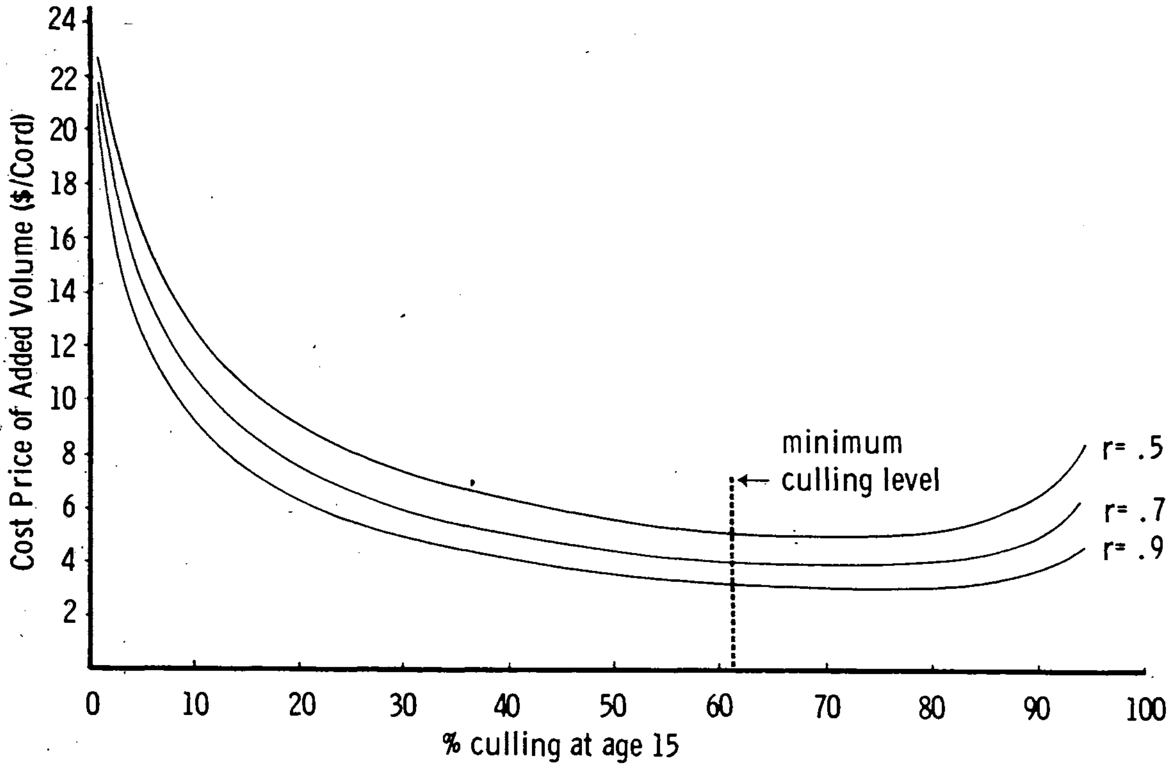

Figure 5.--Cost-price of volume gain.

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