THE ECONOMICS OF TREE IMPROVEMENT
PROGRAMS IN THE NORTHEAST

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ABSTRACT.--A simple break-even, benefit-cost analysis
is presented which will provide an initial evaluation
of profitability associated with tree improvement pro-
grams. White spruce (Picea lauca (Noench) Voss) and
black spruce (Picea mariana (Mill.) B.S.P.) are used as
case studies. Several ideas for increasing the profit-
ability of tree improvement work are discussed in
relation to sensitivity analysis of initial assumptions.

The objective of this paper is to discuss analytical tech-
niques for evaluating the economics of tree improvement and to
provide some best estimates regarding the profitability of certain
tree improvement programs in the Northeast. Only best estimates
can be provided because adequate data are simply not available.
A final, definitive evaluation cannot be made until improved pro-
geny are harvested. Yet, because tree improvement work is so long-
term and expensive the forest geneticist must be concerned about
the "Does it pay?" question quite early in a program. The prin-
cipal difficulty with such early evaluations is that the analyst
usually ends up comparing accurately computed costs with minimal
benefits (Carlisle and Teich, 1977).

Economic evaluation of tree improvement includes two major
approaches: program justification (does it pay) and program
optimization. The paper begins by presenting a simple break-even
approach to program justification which requires a minimum of
proven data. Then this technique is applied to both black spruce
(Picea mariana (Mill.) B.S.P.) and white spruce (Picea glauca
(Moench) Voss) in the Northeast. Finally, some relevant findings
available from program optimization studies in the southern United
States are discussed.

PROGRAM JUSTIFICATION

Since heritability estimates, selection intensities, genetic
correlations, and other factors are so uncertain for new tree
improvement programs, a break-even, benefit-cost analysis is
useful. Benefit-cost ratios show the present value of benefits
divided by the present value of costs and a ratio of 1.0 or greater
indicates a rate of return equal to or higher than the interest
rate used in the analysis. Using the break-even, benefit-cost
approach, we simply compute what the genetic improvement must be
in order that the investment in tree improvement just pays the
desired rate of return; i.e. what the genetic improvement must be
in order that the benefit-cost ratio is just equal to 1.0.

To illustrate, consider a situation for southern tree
improvement programs. Suppose the present value of tree improve-
ment costs is $8,000 per acre of seed orchard. Further, suppose
that the average seed production is 240,000 plantable seedlings
per acre each year from orchard ages 10 through 30 years (30
pounds of seed per acre times 8000 plantable seedlings per pound).
Naturally, seed yield tends to build and then level off as an
orchard develops, but it is easiest in this break-even approach to
assume a constant average seed production over the commercial life
of the orchard. At an 8 x 10 foot spacing, some 441 acres of
genetically improved plantation can be regenerated annually per
acre of seed orchard.

Assuming a 25 year rotation and setting the present value of
costs equal to the present value of benefits (B/C = 1) and using
an 8 percent interest rate, we have:

$$\$8,000 = \frac{(441 \cdot x) \dfrac{1.08^{20} - 1}{.08 \ (1.08)^{20}}}{(1.08)^{35}} = \frac{(A) \ (B)}{(C)}$$

where: x = the required added value of genetic improvement per
           acre of plantation at time of harvest,

       A = the required added value of genetic improvement per
           acre of seed orchard (value per acre of plantation
           multiplied by acres regenerated from stock from one
           acre of orchard),

       B = a discounting factor giving the present value of
           receiving one dollar each year for the 20 year
           production life of the orchard   (ages 10 through
           30 years), and

       C = a discounting factor required to bring benefits back
           35 years in time (the 10 years until commercial seed
           production plus 25 years until the first improved
           plantation is harvested).

Solving for x:

$$\$8{,}000 = \frac{(441x)\,(9.8181)}{(14.7853)}$$

$$\$27.32 = x$$

In other words, each acre of improved plantation must be
worth $27.32 more than the unimproved stand in order for the
benefit-cost ratio to be 1.0 and the return on the tree improve-
ment investment to be just 8 percent. At $120 per thousand board
feet or $10 per cord, this required value increase translates to
228 board feet or 2.7 cords, respectively. With this information,
questions such as: 1) is this required response attainable and
2) what percent volume increase does this represent above the
volume harvested from existing unimproved stands, become
important. These questions are likely much easier for the
geneticist to respond to. In the southern United States, such
analyses have lead to the conclusion that required value increases
are almost certainly attainable, and tree improvement work has
continued with little additional justification. A more detailed
and more complex economic analysis could await better data.

Although only very limited data are available, it is useful to evaluate tree improvement programs in the Northeast using the break-even, benefit-cost approach. Three separate programs are considered: a "traditional" grafted seed orchard program for both black and white spruce and an alternative approach to improving black spruce which is being initiated by the province of New Brunswick. Assumed data for traditional black spruce and white spruce programs are in Tables 1 and 2, respectively. Nearly all these data were obtained from Teich (1975) and Morgenstern (1975) with costs updated to 1977 using an eight percent inflation rate. As these figures imply, several of the costs were assumed to be similar for both species. Another assumption implicit in this analysis is that plantation management of these species will be routine by the time the first improved seedlings are available (10 to 13 years from program initiation). If this is the case, the "extra" costs associated with conversion to plantation manage-ment from natural stand management need not be considered.

Table 1. Costs and Orchard Statistics Associated with a Traditional Black Spruce Tree Improvement Program (1977 dollars)

Costs:	Cost per acre of orchard	Program age
Forest Selection	$ 3171	0
Grafting and orchard establishment	954	3
Orchard Maintenance	117	3-53
Controlled pollination, seed collection, etc.	212	11
Nursery production of 2-2 progeny	318	16
Establishment of progeny tests	636	20
Total present value of cost @ 8%	$2,528	0

Yield:	
Plantable seedlings per acre of orchard (16 x 16)	92,000
Plantation spacing	8 x 8 ft.
Acres of improved plantation established annually from one acre of seed orchard	[1] 35 a.
Commercial seed production begins (age from program initiation)	13 yrs.
Rotation age for improved plantations	50 yrs.
Orchard life	50 yrs.

[1] Based on selection of 50 phenotypes and an 11 acre orchard, which is sufficient to produce one million plantable seedlings annually according to Morgenstern's (1975) estimates.

Table 2. Costs and Orchard Statistics Associated with a
Traditional White Spruce Tree Improvement Program
(1977 dollars)

Costs:	Cost per acre of orchard	Program age
Forest Selection	$ 317 [1]	0
Grafting and orchard establishment	1,087	3
Orchard maintenance	117	3-33
Controlled pollination, seed collection, etc.	212	7
Nursery production of progeny	318	12
Establishment of progeny tests	636	14
Total present value of costs @ 8%	$2,690	0

Yield:

Plantable seedlings per acre of orchard (15 x 15 thinned to 30 x 30, weighted average)	250,000
Plantation spacing	3 x 8 ft.
Acres of improved plantation established annually from one acre of seed orchard	367
Commercial seed production begins (age from program initiation)	10 yrs.
Rotation age for improved plantations	45 yrs.
Orchard life	30 yrs.

[1] Based on selection of 50 phenotypes and an 11 acre orchard which will yield nearly five million plantable seedlings annually according to Teich (1975).

Using an 8 percent interest rate and data from the programs outlined in Tables 1 and 2:

Black Spruce

$$\$2,528 = \frac{(135x)\ (11.7752)}{127.55}$$

$203 = x = the required value increase per acre of improved plantation in order to return 8 percent to the black spruce program

White Spruce

$$\$2{,}690 = \frac{(367x)\ (9.8181)}{68.9139}$$

$$\$51 \quad = x = \text{the required value increase per acre}$$
of improved plantation in order to
return 8 percent to the white spruce
program.

No doubt, tree improvement work is much more easily justified
with white spruce given the customary grafted seed orchard
approach. These results show that the needed value increase is
some four times higher for black spruce than for white spruce. At
$7.00 per cord stumpage the required volume increase (assuming
there were no thinnings or that a similar volume was removed in
thinnings from both improved and unimproved plantations) would be
29 and 7 cords for black and white spruce, respectively. The
required 7 cord increase for white spruce represents an approximate
13 percent increase over unimproved plantations at an 8 x 8 foot
spacing and on site index class 70 lands (Stiell, 1976; p. 184).
If the tree improvement efforts increased the amount of sawtimber-
-sized material and it was valued at $35/MBF, required growth is
5.8/MBF and 1.5/MBF for black and white spruce, respectively.
Naturally a combination such as 3.6 cords and 730 board feet for
white spruce would also be sufficient,

However, such a simple volume approach does not adequately
account for improvement in traits such as specific gravity,
straightness, crown characteristics, and others. Nor does it
account for factors such as the black spruce's greater resistance
to spruce bud worm as compared to white spruce. Recognition of
these factors demands a more detailed analysis. Further, stumpage
prices used above are current; what will they be 50 years from
now? Stumpage prices have been subject to a real price increase
in the past (U.S. Forest Service, 1974) and using a conservative
1.5 percent annual real price rise over a 50 year period, stumpage
prices will increase to $14.74 per cord and 573.68 per MBF. The
required volume increase for white spruce would become a combi-
nation such as 1.7 cords and 346 board feet with the higher
stumpage prices.

A new approach to improving black spruce which is being tried in New Brunswick (D.P. Fowler, personal communication) involves the selection of some 200 superior trees which are then felled for cone collection. Seed from these collections are subsequently sown and several plantations established. One of these plantations is designed as a seed orchard. The prospective orchard is planted at a close spacing using single-tree plots. The other plantations are used as tests. At age 10, results of the family tests are used to rogue the orchard, with a final roguing at age 15. The final orchard contains the best 20 families. The useful life of the orchard is 45 years and a very short rotation of 30 years is planned for improved plantations. Assumed data for this approach are shown in Table 3.

Table 3.   Costs and Orchard Statistics Associated with the New Brunswick Approach to Black Spruce Tree Improvement (1977 dollars)

Costs:	Cost per acre of orchard[1]	Program Age
Forest selection	$1,500	0
Orchard establishment	800	2
Orchard maintenance	117	2-47
Establishing family tests	2,400	2
Total present value of costs @ 8%	$5,458	0

Yield:

Plantable seedlings per acre of orchard	200,000
Plantation spacing	8 x 8 ft.
Acres of improved plantation established annually from one acre of seed orchard	294 a.
Commercial seed production begins (age from program initiation)	10 yrs.
Rotation age for improved plantation	30 yrs.
Orchard life	45 yrs.

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[1] Assumed orchard size is 5 acres which is sufficient to produce 1,000,000 plantable seedlings annually, making the scale of this program comparable to that outlined in Table 1.

For the new black spruce program

$$\$5{,}457 = \frac{(294x)\ (11.6546)}{21.7245}$$

$35 = x =$ the required value increase
per acre of improved planta-
tion in order to return
8 percent to the "new" black
spruce program.

The new program being initiated in New Brunswick looks favor-
able compared to the traditional program. Again using $7.00 per
cord, the required volume increase to justify the program (at 8
percent) is only 5 cords. The new program requires only 17 percent
as much volume gain as does the traditional program (5 cords
versus 29 cords). However, the risks associated with the new
program may be higher. Initial costs for the new program are
double those for the customary program and most of the advantage
of the new program derives from the assumed shorter rotation age
of 30 years for improved plantations and the assumption of a
higher seed yield. Using a 30 year rotation age in the traditional
black spruce program (Table 1) results in x = $45 or only a 6.4
cord requirement to break-even (down from 29 cords). In other
words, given the assumptions presented in the two programs
(Table 1 versus Table 3), the genetic gain from the "new" program
will only have to be 17 percent as much as that required from the
traditional program, but assuming a 30 year rotation in both programs,
the genetic gain expected from the new approach must be 78 percent
of that expected from the traditional program in order for both
programs to be equally profitable. The higher seed yields assumed
with the new program account for its remaining advantage.

SENSITIVITY ANALYSIS

Such a simple approach as break-even, benefit-cost analysis lends itself well to the "What If" type of question. For example, what if tree improvement results in a shortened rotation age? What if seed production can be increased? A number of such questions are answered for white spruce in Table 4 using $7 per cord and an 8 percent interest rate.

Table 4.   Sensitivity Analysis for the White Spruce Tree Improvement Program

Change	Required volume increase per acre of improved plantation (cords)	Percentage change from base volume
1. As calculated in text	7.3	0%
2. Rotation age is shortened to 40 yrs.	5.0	-32
3. Seed yield can be increased by 15 percent	6.4	-12
4. Age to commercial seed production is only 7 yrs.	5.8	-21
5. Required rate of return is 6 percent	2.6	-64
6. Stumpage price increases by 1.5 percent per yr.	3.5	-52
7. Changes 2, 3, and 4 together	3.4	-53
8. Changes 2, 3, 4, and 6 together	1.6	-78

If tree improvement work with white spruce can reduce rotation age to 40 years, the volume response due to tree improvement can be 32 percent less than with a 45 year rotation and still earn an 8 percent return on investment (Table 4). With these relatively long rotations, the influence of interest rate is great (Table 4).

There is an almost direct relationship between seed yield and profitability of tree improvement work (Porterfield, 1974) as shown by the 15 percent increase in seed yield and the 12 percent drop in required volume (Table 4). This fact emphasizes the importance of orchard management techniques such as insect control and fertilization, which are carried out to increase seed yield. Low seed yield is the principal reason for the less favorable position of black spruce.

Briefly considering the traditional black spruce program, a doubling of seedling yield to 184,000 per acre of orchard would lower the required volume (at $7 per cord) from 29 cords to 14.5 cords (a change directly proportional to the change in seed yield). With a doubling of seedling yield plus a 30 year rotation for improved plantations (assumptions nearly identical to those made for the "new" program; see discussion in the last section) the required volume response is only 3 cords. Under these conditions, the new program would actually have to result in higher genetic gains than the traditional program to assure its financial equivalence.

The "new" improvement program for black spruce is very sensitive to the effect of orchard size. If we assume a 10 acre orchard capable of producing 2,000,000 seedlings annually, costs in Table 3 will be halved, except for orchard maintenance which will be unchanged. The required volume response to earn 8 percent for a 10 acre orchard is then 3 cords per acre of improved plantation, identical to that for a traditional grafted orchard with more liberal estimates of seedling yield than those estimated by Morgenstern (1975) and with a shorter rotation. Such a gain seems entirely feasible given current expectations for improving black spruce. Thus, there may be significant "economies of scale" associated with the new approach to black spruce improvement, and interorganizational cooperatives could be investigated to achieve such economies. In the traditional white and black spruce programs, a larger planting program and orchard would reduce per acre costs of selection if the same number of phenotypes were selected. However, increasing scale would result in much less reduction for the traditional programs than for the "new" program.

Once heritability estimates and genetic correlations are available it becomes possible to compute a sound estimate of the actual rate of return from tree improvement because genetic gains and resultant economic benefits can be estimated with confidence. Seed yields can likewise be more firmly established for on-going programs. Major analytical techniques include linear programming (van Buijtenen and Saitta, 1972), goal programming (Porterfield, Zobel, and Ledig, 1975) and computer simulation (Dutrow and Row, 1977). In the latter study, actual 8-year-old progeny test data were simulated to rotation age and an average 29 percent increase in present net worth was obtained for improved plantations regenerated from unrogued loblolly pine (Pinus taeda L.) seed orchards

Analysis of on-going programs has significant implications for new programs but can also serve to guide future generation tree improvement work. Each component part of the improvement program (e. g. roguing, progeny testing, forest selection, and others) can be ranged independently and a plan for total program optimization attained. A summary of recent findings relevant to the Northeast include:

1. The optimum set of selection criteria to be used during forest selection is quite sensitive to the goals of the tree improvement program, therefore establishment of definite tree improvement goals prior to forest selection should be an absolute requirement.

2. Expenditures on forest selection appear too low. Increasing expenditures by a factor of 2 or 3 would greatly increase profits.

3. Given two traits, A and B, with a positive genetic correlation, it can be most cost effective to select for gain in A through its correlation with trait B. For example, bole straightness and desired crown characteristics had a genetic correlation of 0.65 in the study cited above (Porterfield, Zobel, and Ledig, 1975) and greater gain in straightness per dollar spent on wild-stand selection was often obtained by selecting for improved crown characteristics. Thus, if trait A were phenotypically apparent, it could be selected for in order to achieve gain in a highly positively related trait, B, (which might not be phenotypically apparent) with little loss in genetic efficiency and a gain in economic efficiency.

4. Since genetic gain is fixed once a seed orchard is established (prior to roguing it is fixed at one level and after roguing at another) profitability is directly proportional to seed yield from the orchard. Greater seed yield means higher return on investment.

5.   Higher roguing intensities for traits such as volume with relatively low heritabilities appear to increase profitability of tree improvement work since progeny testing greatly improves the selection process. A strategy of bringing more clones into the orchard at a closer initial spacing and using a high roguing intensity (such as 1 in 4) has been suggested for loblolly pine. The closer initial spacing would mean less reduction in seed yield after intensive roguing.

6.   Recognizing the rising trend in the real price of stumpage greatly increases computed returns from tree improvement. With loblolly pine the benefit-cost ratio for existing programs using 6 percent interest increased from 9.5 to 33.0 simply through recognition of an average annual 3.2 percent real price increase for stumpage. The long time frame for tree improvement increases the importance of taking this factor into consideration.

CONCLUSIONS

     Managers of tree improvement programs are often asked to justify tree improvement expenditures. This is a difficult task since little definitive data are available early in a program. Certainly the manager would like to do something more than point out other successful programs. Break-even, benefit-cost analysis offers a means of obtaining a best estimate of profitability specific to a new program. Little time is needed to assemble input data and as long as the required volume (value) gain to assure a benefit-cost ratio of 1.0 is reasonable, further program justification may not be necessary. This technique was demonstrated with both black and white spruce.

     As more data become available, a more complete analysis using an optimization technique such as linear programming or computer simulation can provide valuable insights as to the profitability associated with each component of the improvement program. Adjustments can be made to increase returns from the existing program and plans to maximize profits from advanced generation work can be formulated. In general, such analyses of on-going programs have lead to the conclusion that not only are tree improvement efforts profitable but that greater initial investments would have resulted in even higher returns.

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