*Table 2.* — Coefficients of genetic prediction (CGP) for black walnut tree height for University Farm (UF), Union County (UC), and Pleasant Valley (PV).

| | | Plantation age | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 1 | UF | 0.84 | 0.35 | 0.36 | 0.21 | - | 0.09 | - | - | 0.06 | 0.00 | - | 0.00 |
| | UC | 1.19 | 0.95 | 0.86 | 0.56 | - | 0.48 | - | - | - | 0.42 | - | 0.34 |
| | PV | - | - | - | - | - | - | - | - | - | - | - | - |
| 2 | UF | | 0.52 | 0.50 | 0.39 | - | 0.21 | - | - | 0.18 | 0.14 | - | 0.15 |
| | UC | | 0.79 | 0.75 | 0.53 | - | 0.46 | - | - | - | 0.41 | - | 0.33 |
| | PV | | 0.97 | 0.45 | 0.26 | 0.22 | 0.12 | 0.17 | 0.13 | - | 0.13 | 0.19 | 0.14 |
| 3 | UF | | | 0.54 | 0.42 | - | 0.27 | - | - | 0.23 | 0.19 | - | 0.19 |
| | UC | | | 0.92 | 0.69 | - | 0.61 | - | - | - | 0.56 | - | 0.47 |
| | PV | | | 0.28 | 0.19 | 0.17 | 0.18 | 0.16 | 0.22 | - | 0.25 | 0.27 | 0.25 |
| 5 | UF | | | | 0.30 | - | 0.19 | - | - | 0.15 | 0.14 | - | 0.15 |
| | UC | | | | 0.55 | - | 0.49 | - | - | - | 0.44 | - | 0.35 |
| | PV | | | | 0.18 | 0.18 | 0.17 | 0.19 | 0.20 | - | 0.25 | 0.28 | 0.27 |
| 6 | UF | | | | | - | - | - | - | - | - | - | - |
| | UC | | | | | - | - | - | - | - | - | - | - |
| | PV | | | | | 0.17 | 0.18 | 0.18 | 0.19 | - | 0.22 | 0.23 | 0.24 |
| 7 | UF | | | | | | 0.23 | - | - | 0.18 | 0.21 | - | 0.22 |
| | UC | | | | | | 0.46 | - | - | - | 0.41 | - | 0.35 |
| | PV | | | | | | 0.17 | 0.18 | 0.20 | - | 0.22 | 0.23 | 0.24 |
| 8 | UF | | | | | | | - | - | - | - | - | - |
| | UC | | | | | | | - | - | - | - | - | - |
| | PV | | | | | | | 0.21 | 0.22 | - | 0.23 | 0.24 | 0.25 |
| 9 | UF | | | | | | | | - | - | - | - | - |
| | UC | | | | | | | | - | - | - | - | - |
| | PV | | | | | | | | 0.25 | - | 0.29 | 0.29 | 0.29 |
| 10 | UF | | | | | | | | | 0.13 | 0.18 | - | 0.17 |
| | UC | | | | | | | | | - | - | - | - |
| | PV | | | | | | | | | - | - | - | - |
| 11 | UF | | | | | | | | | | 0.22 | - | 0.23 |
| | UC | | | | | | | | | | 0.29 | - | 0.27 |
| | PV | | | | | | | | | | 0.35 | 0.38 | 0.38 |
| 12 | UF | | | | | | | | | | | - | - |
| | UC | | | | | | | | | | | - | - |
| | PV | | | | | | | | | | | 0.41 | 0.41 |
| 13 | UF | | | | | | | | | | | | 0.25 |
| | UC | | | | | | | | | | | | 0.28 |
| | PV | | | | | | | | | | | | 0.41 |

although single-tree plots are efficient for estimating genetic parameters, they may not be practical for individual tree selection.

As expected when large block × family effects are present, family rankings among blocks within a location are inconsistent; the highest ranking family in one block may be below average in height in another block. The lack of consistency is so great that it is not surprising that there is also a lack of consistency among mean family performance from one outplanting location to another. However, some faster growing families tend to be faster growing at all locations, although they may be few in number. Perhaps the strategy for walnut improvement should be to select the consistently faster growing families even at a risk of sacrificing some growth gains, since such consistently high performers are not always the fastest growing families at all locations — i.e., selection for broad adaptability. The alternative to this strategy would be to select specific families for specific sites. Such a multiple selection approach is not a viable one in an improvement program limited by the low number of sites suited for walnut culture.

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# Using Economic and Decision Making Concepts to Evaluate and Design a Corporate Tree Improvement Program

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### Abstract

This paper describes how economic and decision making techniques were used, for a corporately owned timber tract to evaluate an existing Douglas-fir tree improvement program and to plan its future direction. We designed tree improvement alternatives to meet the projected seed requirements over time. The alternatives differ in the amount of gain they will provide, and in their cost. Considered are the collection of cones from designated parents in wild stands, first-generation seed orchards of two types, second-generation seed orchards of two types, and combinations of first and second generation orchards. After ensuring that each alternative is cost-effective, its net present value is calculated to determine the economically desirable alternative. For the specific case examined, interim seed collection should be from designated parents in wild stands,

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the existing first generation seed orchard should be retained, and work toward a second generation orchard should continue. Although the results presented are specific to this example, the methodology of identifying and analyzing tree improvement alternatives is useful both to evaluate existing tree improvement plans, and to plan further work.

*Key words:* *Pseudotsuga menziessi* (Mirb.) Franco, economic analysis, decision making.

Economic analyses of tree improvement programs have been reported in the literature since the mid-sixties (see Lundgren and King 1965; or Davis, 1967). Considering the long time horizon spanned by a tree improvement program, one may initially think that such programs would not be economically desirable. These early studies, however, showed tree improvement to be an appealing investment when evaluated with traditional measures such as net present value and internal rate of return. Since these early studies, there have been many more results reported in the literature and the conclusion that characterizes these reports is that tree improvement generally pays.

Many of the studies (such as Carlisle and Teich, 1971, 1975; Ottens and Charlisle, 1976; Dutrow and Row, 1976; Porterfield and Ledig, 1977; Ledig and Porterfield, 1981; and Fins and Moore, 1984) conclude that if certain conditions are met (such as amount of gain, or number of hectares included), tree improvement is a profitable venture. Other studies can be characterized as helping to guide the design and implementation of the tree improvement program (see Van Buijtenen and Saitta, 1972; and Porterfield, 1976). The analysis presented here is in the latter spirit as, in addition to simply determining whether the benefits of tree improvement exceed their costs, the methodology allows identification of an economically efficient tree improvement program. Since the severe recession in the North American forest industry during the early 1980's, forest management expenditures, including those for tree improvement programs, have come under increasing scrutiny to determine if funds are being wisely spent. This paper describes how a company analyzed its current program and future options to determine an economically efficient strategy for future tree improvement work. Organizations under financial constraints could adopt a similar approach.

The Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) tree improvement program evaluated in this paper is for a corporately owned tree farm located in the United States Pacific Northwest. The program, initiated in the late-sixties, is designed to provide improved seed for a 40,000 ha management area with an average Site Index of 33 m (using King's (1966) measure for a breast height age of 50 years). A forest planning model is employed to determine the scheduling of forest harvests over time, and the cash flow resulting from these harvests. The tree improvement program must integrate with the forest planning to deliver its potential. Because of the proprietary nature of the firm's value and yield estimates, this analysis is performed using published estimates of future values and yields.

The initial guiding strategy of this tree improvement program was the "progressive" approach (Silen, 1966). Mild phenotypic selection (1 in 10) for size was applied to trees along forest roads by 4 different forest land owners. The resulting collection of about 400 trees is intended to represent a seed zone of about 250,000 ha covering an elevation range from 300 to 900 m in the western foothills of the Cascade Mountains of Oregon. Nine progeny tests have been established using wind-pollinated seed and a seedling seed orchard was formed from random, single-pair matings among the same (roadside selected) parent trees. Although capital had been invested in the program, the corporation was interested in determining if the current program was the best alternative, whether a change in strategy was appropriate, or even if the program should be abandoned as a poor use of corporate funds.

## Options

Tree improvement may be thought of as practicing any strategy that will genetically improve the average quality of trees regenerated within a seed zone or management area. The most basic level of tree improvement we analyze is the collection of seed from designated trees in wild stands that have been proven superior through progeny tests. The cost of obtaining progeny test data for wild trees will likely preclude this strategy except in the case where the progeny tests are being established in conjunction with a more intensive tree improvement program. For the program described here, more intensive options are a first generation program, a second generation program or a combination of first generation followed by second generation. More generations could be added but for a species such as Douglas-fir, the time horizon of further generations is too distant to significantly effect economic analysis.

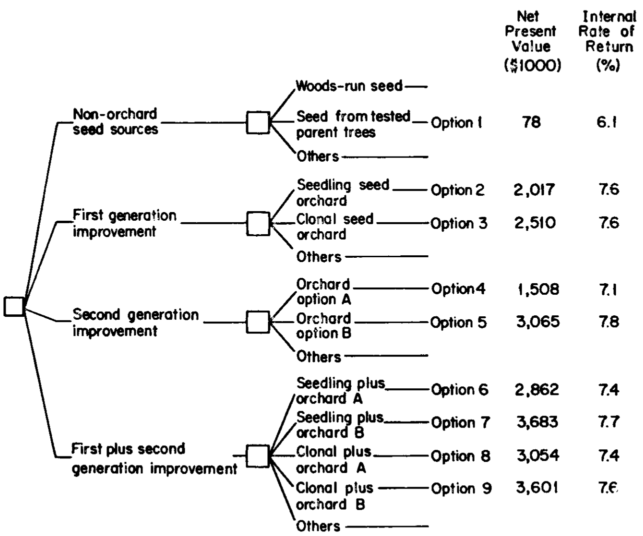

*Figure 1.* — The tree improvement decision tree showing the options that have been evaluated, their net present values (evaluated using a 5-percent real discount rate), and their internal rates of return.

*Table 1.* — Selection intensity and projected total gain in volume for nine tree improvement options (see text for details).

| Option | Selection Intensity | | | | Projected Gain (% Volume) |
|---|---|---|---|---|---|
| | Progeny-tested | | | Individual in Family | |
| | Parent | Mid-Parent | Family | | |
| 1 | 60/120 | - | - | - | 2.6 |
| 2 | - | 30/400 | - | - | 9.8 |
| 3 | 50/400 | - | - | - | 12.5 |
| 4 | 150/400 | - | 50/150 | 2/100 | 22.0 |
| 5 | 150/400 | - | 60→50/150 | 2/100 | 22.0 |
| 6 | 150/400 | - | 50/150 | 2/100 | 22.0 |
| 7 | 150/400 | - | 60→50/150 | 2/100 | 22.0 |
| 8 | 150/400 | - | 50/150 | 2/100 | 22.0 |
| 9 | 150/400 | - | 60→50/150 | 2/100 | 22.0 |

*Figure 1* illustrates the nature of tree improvement choices in the form of a decision tree and includes the options that we evaluated. To conform with standard decision tree conventions, the square nodes represent decision points. Each branch represents a possible strategy. Decision trees are constructed so that the choice to follow a given branch automatically precludes all others[5]). *Table 1* presents features of selection and projected volume gain for each option.

Our first-generation breeding strategy allows going through the tree improvement cycle only once. The second-generation only option skips the seed orchard phase of the first generation cycle, and goes directly into the cycle once more, building from first generation selection and progeny testing phases. Such a strategy may be best if first generation gains are too small to warrant the cost of an orchard, or if a second generation orchard could be producing soon after a first generation orchard would produce, or if there was a lull in seed requirements during the period when seed from a first generation orchard would be available.

First plus second generation options involve going through the complete cycle twice. Gains from first generation seed orchard production are followed by additional gains when the second generation seed orchard comes on line. This strategy produces the greatest genetic gain through time but is also the most costly.

### Marginal Analysis

To correctly compare alternatives each must be internally cost-effective. It makes little sense to compare a first generation alternative to a second generation alternative if the first generation alternative is not cost-efficient but the second generation alternative is. In such a case one might choose the second generation alternative over first generation only because a poorly specified first generation alternative was posited. Thomson *et al.* (1987) documents our use of marginal analysis which ensured that the options compared here were internally cost-effective.

### Calculating Net Present Values

The economic results presented here use the standard economic measures of net present value and internal rate of return. Net present value is discounted benefits minus discounted costs. Discounting is used to adjust for the difference in timing between the expenditure of costs and the receiving of benefits. As the discount rate increases, both discounted benefits and discounted costs decrease. Because the costs of tree improvement occur much sooner than the benefits are received, increasing the discount rate decreases the discounted benefits much more severely than it does discounted cost. As the discount rate rises, therefore, the net present value falls. The discount rate at which the net present value falls to zero is the internal rate of return.

Because this tree improvement program is designed to complement the overall forest management program, economic analysis uses the four-year planning periods chosen for forest management planning[6]). The projected regeneration needs through the next 64 years, as calculated in the forest planning process, are used as an input to this economic analysis. Although the various options presented here provide differing timing and gain of improved seeds, each alternative is evaluated over the next 64 years under the same projected seed requirements. The implementation of a tree improvement program could affect the projected harvest flows, negating the validity of using these projections. The increased future volume generated by the tree improvement program arrives so far in the future, however, that the firm's forest planning strategy does not allow such distant harvests to feedback into the current harvest decision. When forest planning is tightly constrained over a long period, the future effect of tree improvement may affect immediate- or near- term harvest. Under such circumstances benefit calculations would have to include the effect of changing the near- term harvest flow.

All of the calculations presented here use estimates based on dollars of base year 1980. In other words, inflation is not included in the calculations. Gregersen (1975) has demonstrated that the effects of inflation are neutral for long-lived projects. Real costs were assumed to be constant over time. Real timber price appreciation rates were used in calculating benefits. Estimated inflation rates can be added to our results to determine nominal rates of return. Berck (1979) determined that Pacific Northwest land owners make timber harvest decisions consistent with a five-percent real discount rate; therefore, we report net present values for this rate. All calculations were performed using rates of three through nine percent to determine the sensitivity of the results to the chosen discount rate, and to facilitate the computation of the internal rate of return.

To calculate the net present value, one must project the stream of costs and of benefits, discount these, and subtract the discounted costs from the discounted benefits. For each option the cost to complete each step was projected for each period through the span of the program. These costs were then reduced by 46 percent to reflect that such costs can be written off as ordinary income[7]). Finally, the costs were discounted to the present at real discount rates from three to nine percent.

Benefits were calculated through using: 1) the DFSIM growth and yield prediction model (Curtis *et al.*, 1981) to estimate a base yield to which gains from tree improvement were added, 2) a projected future stumpage value (Haynes *et al.*, 1980), 3) a factor to translate increase in volume to increases in value, and 4) a capital gain tax factor. We estimate baseline value (the value of non-improved stands) by multiplying projected future values by estimated stumpage yield. The baseline forest management regime consists of planting 1,100 trees/ha, precommercial thinning at age 15 to 740 trees/ha, fertilizing with 225 kg/ha of nitrogen at ages 15, 22, 29, 36, 43, and clear-

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[5]) An option to consider a combination of branches would be represented as a new branch so that all branches remain mutually exclusive alternatives.

[6]) The method of analysis presented here is not dependent on the use of four-year planning periods. We mention their use so the reader will understand why we use chose four-year periods.

[7]) The tax effects for tree improvement programs are not fully settled. The position of the U.S. taxing authority, the Internal Revenue Service (IRS), appears to be that one can write off early costs as expenses, but cost for managing a productive seed orchard will have to capitalized as part of the regeneration costs (see IRS 1978; Revenue Ruling 78-264): The assumption of full write-off does not necessarily reflect the practice of a firm. This assumption has little effect on the financial results because the bulk of discounted cost is what appears in the early breeding and orchard costs and not in the management of a productive orchard. After-tax discounted costs may, however, be slightly understated.

cutting at age 50. The DFSIM model projects a yield of 745 m$^3$/ha for the given regime. Because the DFSIM model was developed from fully stocked stands we project a 10 percent fall down as full stocking is not expected on all hectares[8]) yielding an attainable harvest of 670 m$^3$/ha. Haynes *et al.* projects an average stumpage price for coastal Pacific Northwest Douglas-fir of $ 78.50/m$^3$ in 2030. We assume no real value change beyond this date. Baseline value, the product of yield and stumpage price, is $ 52,600/ha.

Expected volume gain at rotation age (50 years) was calculated using the results of progeny tests and an equation developed by Squillace and Gansel (1974). Their gain formula is a modification of the correlated response formula (Falconer, 1960) and uses a juvenile-mature correlation as a multiplier to adjust the familiar gain formula (Falconer, 1960). Heritabilities and phenotypic standard deviations, for comparing options, were calculated from measurements of total height at age 10 years in 7 of 9 progeny tests. Volume gain was calculated as 1.5 times height gain, an empirical relationship taken from volume tables. Projected gain in volume at age 50 was 60 percent of volume superiority at age 10 based on a juvenile-mature correlation of 0.6 for performance at ages 10 and 50 years (Lambeth, 1980).

Seed orchards were designed to fully meet demands for improved seed by an orchard age of 15 years. Expected seed yields were taken from historical yields of Douglas-fir[9]) and projected volume gains were reduced proportionately when the quantity of improved seed did not meet planting requirements in the earlier years of orchard development. Second generation gain was estimated as described above with the assumptions of no change in heritability and phenotypic standard deviation. These assumptions appeared reasonable for traits with low heritability (Lush, 1970) such as height and volume (Campbell *et al.*, 1986).

Economies of scale will be realized from harvesting larger trees at rotation (Dobie *et al.*, 1975; Jackson and McQuilan, 1979). Additional economies are gained by harvesting more volume from a given hectare. Through running the firm's forest planning model with higher per hectare volume estimates and a larger average tree size, a constant factor was determined by which one could multiply the gain in volume to predict the gain in value. Because the value factor determined by the firm is proprietary we chose to use a factor of 1.5 to illustrate the effect of the economies and quality improvements that will accompany the gains from tree improvement[10]). We assume that a 10 percent gain in volume of a given stand will increase its value by 15 percent due to lower processing costs and the higher valued products it can produce. Because a capital gain will be realized from these increased values we reduce the values received by 27 percent, the current capital gains tax rate.

The forest plan projects the period in which each unit is to be regenerated. The tree improvement alternative being evaluated determines seed orchard yields and the gain inherent from that seed for each period. We assign the projected gain to each planting unit unless the orchard cannot produce enough seed to meet all requirements. In this case some units will not be planted with improved seed, and will not contribute to the tree improvement benefit stream. Stands regenerated with improved seed are credited with a benefit fifty years after planting. This benefit will equal the product of baseline value ($ 52,600/ha), percent volume gain, volume-to-value factor (1.5), and capital gain tax adjustment (0.73). A hectare planted with seed yielding a 10 percent volume gain will be credited with a benefit of ($ 52,600 × 0.10 × 1.5 × 0.73 =) $ 5,760 at harvest time. This value is discounted to today to determine its discounted benefit. Total discounted benefit for each alternative is the sum of the discounted benefit received each year for the given alternative.

## Results

*Non-Orchard Options*

The first branch given in *Figure 1*, the use of woods-run seed, represents current seed collection practice. Seed is collected from the appropriate seed zone, with the criterion of "easiest to obtain" dominating its collection. This is the basis from which tree improvement alternatives are measured. The gains attributable to tree improvement are for gains exceeding this base. If the net present value for tree improvement options are positive, then tree improvement is more attractive financially than planting woods-run seedlings.

### Option 1: Seed Collected From Tested Trees

A non-orchard tree improvement alternative is to restrict seed collection to trees shown to be superior by progeny test results. Testing selected trees would normally be done only if a more intensive tree improvement program was to be implemented. Once this testing has been done, however, its costs are sunk. If at this point, the net value of seed orchard establishment does not exceed the net value

*Table 2.* — Discounted collection cost, opportunity cost, total costs, benefits, and net present value over a range of discount tates for the collection of seed in wild stands from progeny tested parent trees [1]).

| Disc Rate | Collection[2]) Cost | Opportunity[3]) Cost | Total[4]) Cost | Discounted[5]) Benefit | Net Pre-[6]) sent Value |
|---|---|---|---|---|---|
| 3% | 5.46 | -15.02 | -9.56 | 520.94 | 530.50 |
| 4% | 4.50 | 27.81 | 32.31 | 259.73 | 227.42 |
| 5% | 3.79 | 50.87 | 54.65 | 132.89 | 78.23 |
| 6% | 3.25 | 62.66 | 65.91 | 69.58 | 3.68 |
| 7% | 2.83 | 68.05 | 70.88 | 37.20 | -33.68 |
| 8% | 2.50 | 69.81 | 72.31 | 20.25 | -52.05 |
| 9% | 2.23 | 69.53 | 71.76 | 11.21 | -60.55 |
| 10% | 2.02 | 68.12 | 70.14 | 6.30 | -63.84 |

[1]) All cost and benefit figures are in thousands of dollars.

[2]) Collecting cost is the present value of 56 years of collection at a cost of $ 202.50 per year after taxes ($ 375 before taxes).

[3]) Opportunity cost = (($ 13,050 $(1 + i)^{-5}$ — $ 67,900 $(1 + i)^{-56}$) × 12 × 0.73) where "i" is the discount rate, "12" is the number of hectares reserved for the tested parents, and "0.73" is the adjustment factor for capital gain tates.

[4]) Total cost is the sum of discounted collection cost and discounted opportunity cost.

[5]) Discounted benefit is the present value of receiving $ 89,850 per year for fifty-six beginning fifty-two years from now.

[6]) Net present value is the result of subtracting discounted costs from discounted lenefits.

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[8]) Meizenheimer, E.: Personal communication. Silviculturist, Olympic National Forest, Olympia, WA, U.S.A. (1982).

[9]) Crown, M.: Personal communication. Seed Production Officer, British Columbia Ministry of Forests, Victoria, B.C., Canada (1981).

[10]) A ratio of 1 (value gain equals volume gain) and 2 (value gain is double volume gain) were used in sensitivity tests to determine the importance of the assumed ratio. Although the net present values and internal rate of return are affected by this ratio, the rankings of the options does not change. The internal rate of return falls by approximately 0.4 percent with the high ratio , compared to the results presented later.

of designated tree cone collection, then collection of seed from designated trees would be preferred to establishing a seed orchard.

Because of low selection intensity, we expect only the average or better selections to produce any gain, restricting cone collection to the top 60 of the 120 tested parent trees on company ownership. The calculated volume gain from seed collected from these parents is 2.6 percent. Gain is low because the designated trees are pollinated from natural stands, rather than by superior trees. Each designated tree is projected to produce 8300 seeds in each four-year planning period, which is enough seed to plant 4 ha. Two hundred and forty hectares per period can be regenerated with the resulting improved stock. The balance of the hectares will be regenerated with unimproved stock, yielding zero gain. The future benefits per four-year period from this option will be (240 ha × $ 52,600/ha × 0.026 (gain) × 1.5 (value/volume conversion ratio) × 0.73 (tax effect) =) $ 359,400. One will receive **$ 89,850 annually** starting 52 years from now (assuming a 50 year rotation and a two year lag between cone collection and seedling outplanting)[11]. This strategy is assumed to be followed for 56 years[12].

The cost of reconnaissance to determine cone crops, and the actual cone harvest cost was estimated at $ 25 per tree per period for a total per period cost of ($ 25/tree × 60 trees) = $ 1,500. These costs are presented in *Table 2* over a range of discount rates.

In addition to the explicit cone harvest cost, there is the opportunity cost of reserving for each designated tree, a 0.2 ha island of trees for pollinating the designated seed tree and to prevent its blowdown. The average age of the selected trees is 45 years. If this option is chosen, the trees will be harvested after 56 years when they will be 101 years old. The opportunity cost is harvesting these trees at age 101, rather than at the planned 50-year rotation age. This opportunity cost is the value of 50-year-old trees received 5 years from now minus the value of 101 year-old trees harvested 56 years from now. Using the DFSIM model we projected a 290 $m^3$/ha harvest from a natural stand at age 50. The stumpage price HAYNES *et al.* (1980) projected for 1985 is $ 45/$m^3$ leading to a value of (290 $m^3$/ha × $ 45/$m^3$ =) $ 13,050/ha. Using the DFSIM model we projected a yield of 865 $m^3$/ha at age 101 and a projected price of $ 78.50/ha to produce a stumpage value of $ 67,900/ha. The opportunity cost for delaying the harvest of the designated trees and their islands, by discount rate, is given in *Table 2.* Also given are the discounted benefits and net present values for this option. These results are plotted on *Figure 2.* The internal rate of return for this option is about 6.1 percent. Its net present value evaluated with a five-percent discount rate is $ 78,200.

Collecting seed from tested parent trees could be viewed as an interim method of seed collection, available until parent trees are harvested, while waiting for production from a seed orchard. The costs and benefits are calculated for each cone collection until parent trees are removed during the regular harvesting cycle. The cost of this strategy is the $ 25 per tree for cone collection. The benefit from this strategy is enough seed for planting 4 ha yielding a future value of (4 ha × $ 52,600/ha × 0.026 (gain) × 1.5 (value/volume conversion ratio) × 0.73 (tax effect) =) $ 5,990. This value will be received 52 years after the cone harvest. The discounted value of each cone harvest is compared to its present cost in *Table 3.* From *Table 3* one can see that this practice has an internal rate of return of about 12.5 percent; thus, cone collection from tested trees is a desirable interim practice even if it is an inferior long term option.

### *First Generation Options*

Two first-generation options were chosen for evaluation. One option is an in-place seedling seed orchard, established concurrently with progeny tests. A clonal orchard option was also evaluated.

### Option 2: The Seedling Seed Orchard

Selection, based on mid-parent values from progeny tests, of the 30 most vigorous families in a four-year-old 8000-tree, seedling seed orchard resulted in a projected volume gain of 9.8 percent at a selection intensity of 12.5 percent.

The discounted cash flow results for this option are presented in *Figure 1.* The net present value of this option, (evaluated with a five-percent real discount factor) is $ 2,017,000 and its internal rate of return is 7.6 percent.

### Option 3: A Clonal Seed Orchard

The seedling seed orchard option was chosen in part because at the time of orchard establishment, graft incompatibility was a known problem. The development of graft compatible rootstock has alleviated this problem; hence, a clonal orchard is now feasible. The main advantage of a clonal orchard is that only the top parents are established in the orchard rather than the randomly crossed individuals currently in the seedling seed orchard. Establishing the top 50 parents would produce an average volume gain of 12.5 percent in seed from the clonal orchard versus 9.8 percent from the seedling orchard. The disadvantage of this strategy is the cost of orchard establishment, and the longer wait until improved seed is available.

*Table 3.* — Discounted benefits, discounted costs and net present value realized each time a cone harvest is made from a progeny tested parent tree.

| Disc Rate | Discounted[1] Benefit | Discounted[2] Cost | Net Present[3] Value |
|---|---|---|---|
| 3% | $1,287.93 | $13.50 | $1,274.43 |
| 4% | 779.28 | 13.50 | 765.78 |
| 5% | 473.79 | 13.50 | 460.29 |
| 6% | 289.42 | 13.50 | 275.92 |
| 7% | 177.61 | 13.50 | 164.11 |
| 8% | 109.49 | 13.50 | 95.99 |
| 9% | 67.80 | 13.50 | 54.35 |
| 10% | 42.17 | 13.50 | 28.67 |
| 11% | 26.34 | 13.50 | 12.84 |
| 12% | 16.52 | 13.50 | 3.02 |
| 13% | 10.41 | 13.50 | -3.09 |
| 14% | 6.58 | 13.50 | -6.92 |

[1] Discounted benefit is the present value of receiving $ 5,990.00 fifty-two years from now.

[2] Discounted cost is the after tax cost to harvest a cone crop from a progeny tested parent tree. Because this analysis is in the time frame of when the harvest is made, cost requires no discounting.

[3] Net present value is discounted benefit minus discounted cost.

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[11] Although we project only one collectable cone crop per four year period we calculate our economic costs and values as though we had cone crops on one quarter of the trees each year. This approach is taken because we do not know in which of the four years the cone crop will be.

[12] The forest planning model projects regeneration needs in four-year periods. A fifty-six year planning horizon is the closest multiple of four that will provide a final harvest of the designated trees at about age 100 which is the planned time for a second rotation to occur.

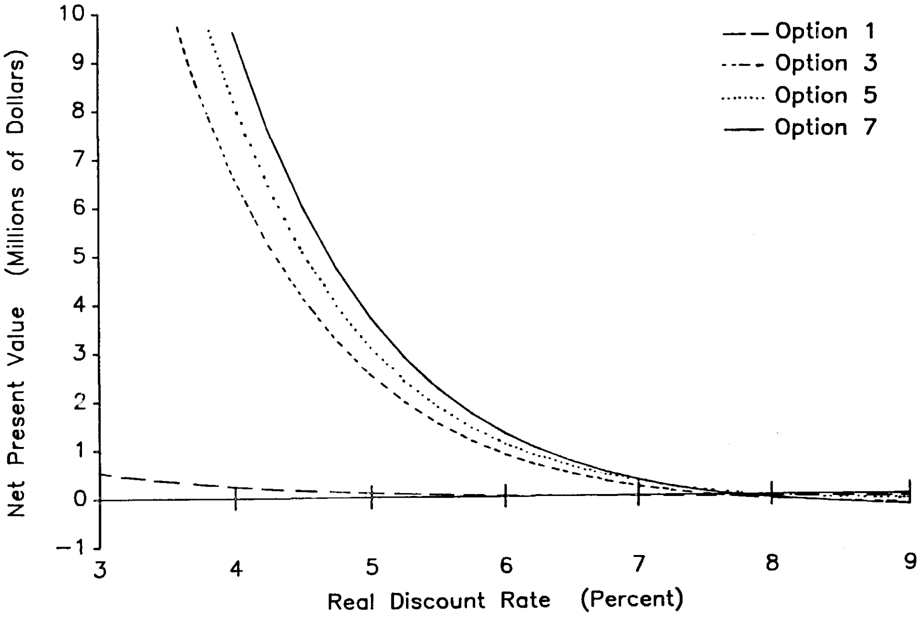

*Figure 2.* — Net present value versus discount rate for the best non-orchard alternative (Option 1), the best first generation alternative (Option 3), the best second generation alternative (Option 5), and the best first plus second generation alternative (Option 7).

(The longer wait is because the seedling seed orchard is already four years old; hence, will begin seed production sooner than an orchard which is yet to be established).

Discounted cash flow results, presented in *Figure 1,* show this option has a net present value of $ 2,510,000, and internal rate of return is 7.6 percent.

By comparing the net present value and internal rate of return between Option 2 and Option 3, we see that Option 3 has a higher net present value and equal internal rate of return so we say Option 3 dominates Option 2. A plot of net present value versus discount rate (net present value profile) for Option 3 is given in *Figure 2.*

### *Second Generation Options*

Because higher genetic gains can be achieved from clonal orchards and because use of clonal orchards allows for management of clones that may be increasingly more desirable as forest genetics research progresses, only clonal orchards are considered for second generation options. The selection population is 150 full-sib families generated by crossing the 150 best progeny-tested parents from the first generation. Projected volume gains of 9 percent for selection among parents, 9 percent for selection of the best 30 full-sib families, and 4 percent for the best 1 or 2 individuals in the best 30 families summed to a projected gain of 22 percent.

Two clonal options were designed for analysis. A primary difference between orchards was their establishment dates.

### Option 4: Orchard Option A

Orchard option A follows the traditional establishment pattern. An orchard is established when 15-year progeny test information identifies the 50 best clones. The results of the discounted cash flow analysis are presented in *Figure 1.* This option has a net present value of $ 1,508,000 and internal rate of return of 7.1 percent.

### Option 5: Orchard Option B

To compress the time lag when waiting for second generation improved trees, one could establish the orchard at an earlier date. To establish the orchard earlier one must rely on younger progeny tests for evidence of superiority. Additional timber value at the end of the rotation is the goal of improvement. The younger the test data, the less confidence one has in choosing trees that will be best at rotation age. We felt that an orchard could be established on the information provided by 10-year old progeny tests. To compensate for errors that may result from data based on younger tests, extra clones would be established in the orchard. Ten was arbitrarily chosen as the number of extra clones although further analyses could be used to explore optimizing the trade-off of establishing additional clones to compensate for making decisions with less information. After 5 years, when the fifteen-year test data were available, the poorest ten clones would be rogued yielding an orchard with the same clonal make up as Orchard Option A. Baring major changes in family rankings between ages 10 and 15, projected genetic gains should be the same for both options. Orchard Option B, however, will be five years old when Orchard Option A is planted.

The benefit of Orchard Option B is receiving improved seed five years sooner. The extra cost is that of establishing extra clones in the orchard which will be removed before orchard seed production. The results of the discounted cash flow are given in *Figure 1.* Option 5's net present value is $ 3,065,000 and its internal rate of return is 7.8 percent. From *Figure 1* we see that Option 5 dominates Option 4. Its net present value profile is plotted on *Figure 2* as it is the best second generation alternative.

### *First Plus Second Generation Options*

Rather than relying solely on first generation or second generation improvement, many tree breeding programs will follow first generation improvement with second generation improvement.

The first plus second generation options evaluated here are the four combinations of the first and second generation options evaluated previously. The first generation orchard is phased out as the second generation orchard meets the seed production goals. No benefits for the first generation accrue beyond this point.

It is tempting to assume that the best two-generation strategy is the best first generation option followed with the best second generation option. The value of the clonal first generation option, *vis-a-vis* the seedling option, is in receiving higher gains over a long period. If a second generation is pursued, however, it may be wiser to retain the first generation seedling seed orchard until the higher gains from a second generation are realized. To correctly evaluate the interactions of these options one must evaluate each of the four possible strategies.

Option 6: Seedling Seed Orchard Followed With Orchard A

Option 6 has a net present value of $ 2,862,000 (*Figure 1*) and internal rate of return of 7.4 percent.

Option 7: Seedling Seed Orchard Option Followed With Orchard B

Option 7 has a net present value of $ 3,683,000 (*Figure 1*) and internal rate of return of 7.7 percent.

Option 8: Clonal Seed Orchard Followed With Orchard A

Option 8 has a net present value of $ 3,054, 000 (*Figure 1*) and internal rate of return of 7.4 precent.

Option 9: Clonal Seed Orchard Followed With Orchard B

Option 9 has a net present value of $ 3,601,000 (*Figure 1*) and internal rate of return of 7.6 percent.

Through comparing the net present value and internal rate of return among these first plus second generation alternatives, Option 7 is identified as the superior alternative. Its net present value profile is plotted on *Figure 2.*

## Discussion

The alternatives evaluated for this Douglas-fir tree improvement program are given in *Figure 1*. The net present value profiles of the non-seed orchard alternative (Option 1), the best first generation alternative (Option 3), the best second generation alternative (Option 5), and the best combined generation alternative (Option 7), are plotted on *Figure 2. Figure 2* identifies Option 7 as the dominating alternative. All options considered were internally cost-efficient due to the marginal analyses performed. Option 7 is cost- efficient and dominates all other alternatives.

Given the assumptions and statistical uncertainty underlying all estimates one may question whether there is an important difference among alternatives. It is likely that a firm willing to accept an investment such as Option 7 would also accept Option 3 if Option 7 was unavailable. In this sense both Option 3 and Option 7 are suitable investments, but each alternative is mutually exclusive so one must choose only one of the alternatives. A more important question is whether the ranking of the alternatives would change if better assumptions or estimates were available. Thomson (1983) addresses this issue and concludes it is likely Option 7 would still dominate the other alternatives even if the analyses were rerun using some different estimates because changes in estimates will effect all alternatives similarly.

For the specific alternatives analyzed here, tree improvement should follow this scenario: 1) collect seed from tested wild trees as available, 2) retain the current seedling seed orchard, and 3) proceed with second generation work establishing an orchard when 10-year progeny test data is analyzed. Not only does this program meet the criteria that benefits exceed costs (for real discount rates of 7.8 percent or less), but the profitability of this strategy exceeds that available from the other alternatives.

Although a specific tree improvement program is analyzed in this paper, the methodology is general and could be used to evaluate other programs. It demonstrates how one can lay out a series of mutually exclusive tree improvement alternatives which encompass a variety of timing and genetic gain options, determine the costs and benefits accruing to each strategy, and choose the alternative with the highest Net Present Value. In today's environment of increasing financial scrutiny of timber management practices, the analysis allows the tree improvement staff to develop a program that can be attractive to executives who have authority for allocation of funds.

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# Composition of bud Exudate of Populus × interamericana Clones as a Guide to Clonal Identification

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## Abstract

Capillary column gas chromatographic analysis of bud exudate enabled the *Populus × interamericana* van Broekhuizen clones 'Barn', 'Beaupré', 'Boelare', 'Donk', 'Hunnegem', 'Raspalje', 'Rap' and 'Unal' to be distinguished.

*Key words: Populus × interamericana*, Clonal identification, bud exudate, GC/MS.

## Zusammenfassung

Kapillar-Gaschromatographie/Massenspektroskopie der Knospen-Exkrete von *Populus × interamericana* erlaubt die Unterscheidung der Klone 'Barn', 'Beaupré', 'Boelare', 'Donk', 'Hunnegem', 'Raspalje', 'Rap' und 'Unal'.

## Introduction

Chemotaxonomy has been used to assist in differentiating poplar species and identifying poplar hybrids by a number of workers. Anderson and Bowman (1979) investigated chemical composition of leaves of 17 pure species and 14 hybrids of poplar and used leaf polyphenols to verify the origin and hybridity of various clones. They also concluded that polyacrylamide gel disc electrophoretic banding patterns of peroxidase and esterase might well permit clonal identification. Kim and Chung (1974) had similarly concluded that isoperoxidase patterns would allow clones of *P. × euramericana* (Dode) Guinier to be distinguished, and Guzina (1974) also suggested that isoperoxidase patterns could be a valuable chemotaxonomic criterion for *Populus* spp. Clones have also been identified by means of serological reactions by Mottl and Sterba (1973) using immunoelectrophoresis. Other workers have assessed the use of compounds (primarily phenolic glucosides) extracted from leaves of *Populus heterophylla* L. as a taxonomic guide (Pearl and Darling, 1977). Phenolic glycosides of poplar and willow bark (Julkunen-Tiitto, 1985; 1986; Ronald *et al.*, 1973; Ronald and Steele, 1974; Steele and Ronald, 1973; Steele *et al.*, 1973) and flavonoid aglycones of poplar leaves and bud exudate (Boccone, 1975; Crawford, 1974; Jones and Seigler, 1975; Wollenweber, 1975) have also been investigated as chemotaxonomic criteria. From detailed studies of flavonoid aglycones of poplar bud exudates Wollenweber (1975) established that analysis of flavonoid aglycones of poplar bud exudate allowed species of the sections *Aigeiros* and *Tacamahaca*, together with some of their hybrids, to be separated, although analysis of flavonoid aglycones alone did not permit differentiation between different clones of a species or hybrid.

Previous work has established that the bud exudate of poplars consists of a complex mixture including aliphatic acids, substituted benzoic and phenolic acids and their esters, terpenoids and flavonoid aglycones (Chadenson *et al.*, 1971; Greenaway *et al.*, 1987; Nagy *et al.*, 1986; Papay *et al.*, 1986; Wollenweber, 1975; Wollenweber and Egger, 1971; Wollenweber and Weber, 1973). We have separated this complex mixture of compounds from buds of *P. × euramericana* 'Robusta' in a capillary gas-chromatographic column to produce a complex chromatogram (Greenaway *et al.*, 1987), which can be regarded as a 'fingerprint'. Preliminary work (unpublished) indicated that these 'fingerprints' could be used to differentiate between poplar species. We here report the apparent stability of bud exudate composition within a poplar clone and the use of bud exudate composition to differentiate between morphologically similar clones of *P. × interamericana* van Broekhuizen.

## Materials and Methods

### *Plant material*

Bud exudate was obtained from 25-year-old trees of a single clone of *P. × euramericana* 'Robusta' at Buckland, Oxon., U.K. and from nursery stock of the *P. × interamericana* clones 'Barn', 'Beaupré', 'Boelare', 'Donk', 'Hunnegem', 'Raspalje', 'Rap' and 'Unal' at Alice Holt Lodge, Farnham, U.K. P. × euramericana 'Robusta' is a male cultivar which arose spontaneously in a nursery near Metz in the north east of France in about 1890. The seed parent

*Table 1.* — Parental plants and origin of *P. × interamericana* clones.

| clone | female parent | male parent | source |
|---|---|---|---|
| 'Barn' | P. deltoides | P. trichocarpa | Dorschkamp[2] |
| 'Beaupré' | P. trichocarpa 'Fritzi Pauley' | P. deltoides[1] | Geraardsbergen[3] |
| 'Boelare' | P. trichocarpa 'Fritzi Pauley' | P. deltoides[1] | Geraardsbergen |
| 'Donk' | P. deltoides | P. trichocarpa | Dorschkamp |
| 'Hunnegem' | P. trichocarpa 'Fritzi Pauley' | P. deltoides[1] | Geraardsbergen |
| 'Raspalje' | P. trichocarpa 'Fritzi Pauley' | P. deltoides[1] | Geraardsbergen |
| 'Rap' | P. trichocarpa | P. deltoides | Dorschkamp |
| 'Unal' | P. trichocarpa 'Fritzi Pauley' | P. deltoides[1] | Geraardsbergen |

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[1] This was an intraspecific hybrid bred from Iowa and Missouri provenances.

[2] The Dorschkamp Research Institute for Forestry and Landscape Planting, Wageningen, The Netherlands.

[3] The Government Poplar Research Station, Geraadsbergen, Belgium.

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