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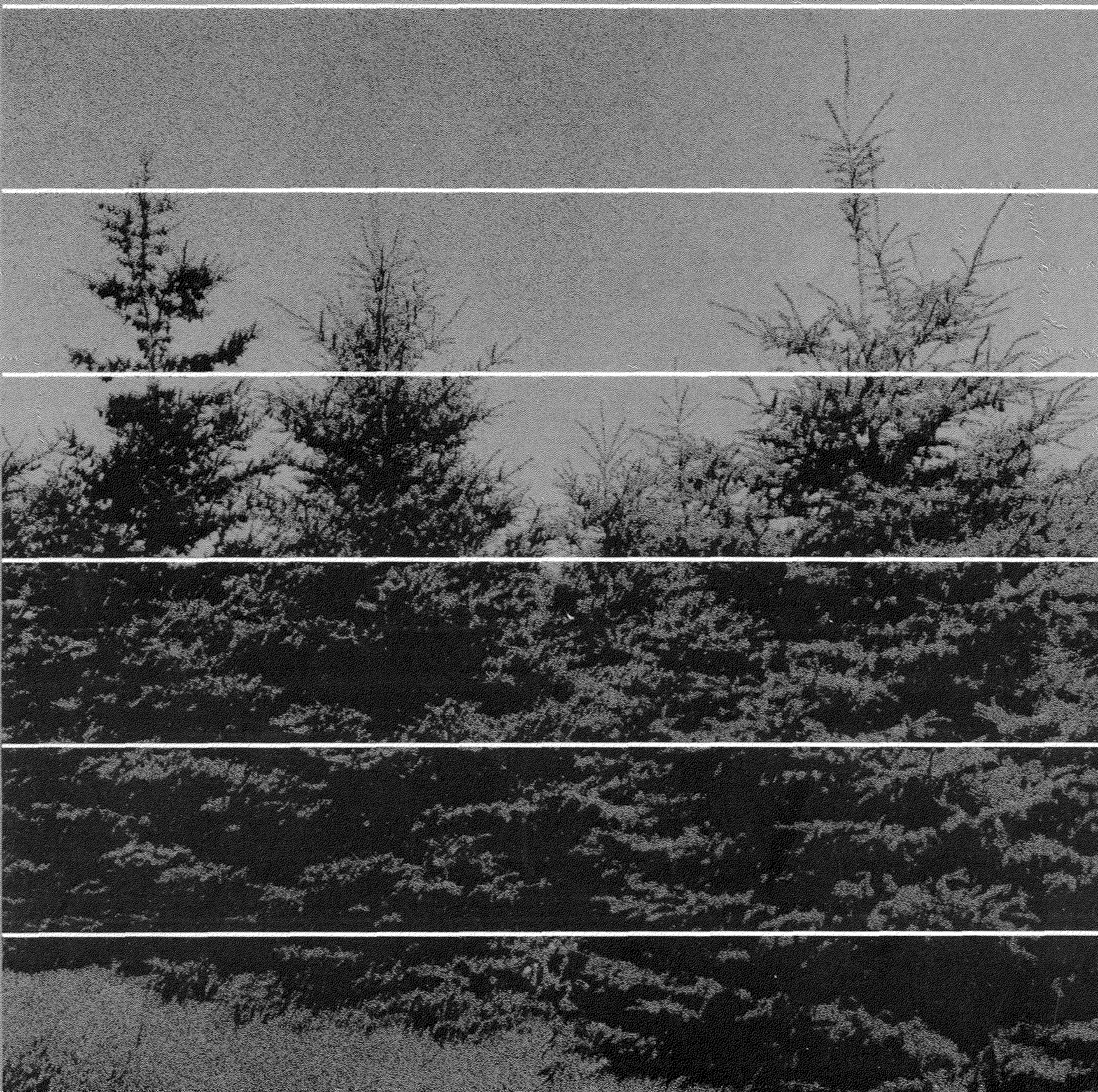

THE COSTS AND BENEFITS OF TREE IMPROVEMENT PROGRAMS

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Résumé en français

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ABSTRACT

The report reviews information relating to costs and benefits of tree improvement programs in North America, discusses a model for evaluating benefits from tree improvement, and considers the costs of increasing yields by genetic and cultural methods.

Evidence is presented indicating that (1) the costs of producing genetically superior seed are more than offset by 2 - 5% increases in yield of merchantable timber, and (2) the use of genotypes with superior wood qualities can profoundly affect mill profits.

It was calculated (taking into account interest, inflation, stumpage rate, establishment cost, management cost, yield and site class) that for white spruce (*Picea glauca* (Moench) Voss) in eastern Canada:

1. the added cost of producing enough improved seed in seed production areas to plant 1 acre at 8 x 8 feet spacing is about 43c. If the use of these superior genotypes results in a 15% increase in yield this investment generates a discounted profit of $4.74 to $11.91 depending upon site class.
2. if $1,500,000 (including interest) are invested in white spruce research over a 15 year period, and this research leads to a 15% increase in yield, this investment generates a potential benefit of about $832,000 per annum in the context of a 100,000 acre per annum planting program. The added cost of producing the seed in seed production areas for such a program would be about $23,000 per annum.

These benefit estimates are conservative. It is recommended that tree improvement and silviculture programs be closely coordinated to achieve maximum yield and crop security.

RÉSUMÉ

Rapport d'informations sur les coûts et revenus concernant l'amélioration des arbres nord-américains. Les auteurs ont mis au point une méthode d'évaluation des revenus, qu'ils présentent, et ils analysent ce qu'il en coûte pour augmenter le rendement au moyen de la génétique et par la sylviculture.

On a prouvé que le coût de production de graines génétiquement supérieures était moindre par 2 à 5 p. 100 que l'augmentation de revenus produite par le rendement accru en bois d'oeuvre obtenu; on sait aussi que l'emploi de génotypes à bois de meilleure qualité peut augmenter de beaucoup les profits de la scierie.

Voici ce que l'on a calculé à propos de l'Épinette blanche (*Picea glauca*) dans l'est du Canada (prenant en considération les intérêts, l'inflation, les droits de coupe, les coûts d'établissement et d'aménagement, le rendement et la classe de fertilité):

1. Il en coûte 43 cents de plus pour produire suffisamment de graines génétiquement supérieures qui serviront à planter un acre de semis espacés de 8 en 8 pieds. Si l'utilisation de telles graines produit un rendement de 15 p. 100 meilleur, le profit net sera $4.74 à $11.91 selon la classe de fertilité.
2. Incluant les intérêts, si l'on investit $1,500,000 dans la recherche sur l'Épinette blanche, répartis sur 15 ans, et si à la suite de telles recherches, le rendement est accru de 15 p. 100, les revenus potentiels s'établiront à $832,000 l'an par 100,000 acres plantés chaque année. Les frais supplémentaires qu'entraîne la production des graines supérieures dans ce cas monteraient à environ $23,000 par an.

De telles estimations de profits sont conservatrices. Et les auteurs insistent sur le fait qu'il faut associer les programmes d'amélioration des arbres avec les autres méthodes sylvicoles pour obtenir un rendement maximal et l'assurance de bonnes récoltes.

CONTENTS

INTRODUCTION

This report considers the costs and benefits of tree improvement programs in North America to discover whether or not the returns from such programs are worthwhile. The report reviews the information in the literature, discusses a model for white spruce (*Picea glauca* (Moench) Voss) yield improvement in eastern Canada, and considers the advantages of genetic improvement in the broad national context.

Inevitably such a report impinges on costs and benefits of tree planting and culture as a whole; tree improvement cannot be considered in isolation. It is likely that some will disagree with some basic assumptions used in the white spruce model concerning stumpage rates, interest rates, management costs, and establishment costs. The authors have avoided using arbitrary figures; the data used are either from the literature or averages of figures supplied by practising foresters and forest economists. These figures are perhaps more applicable to eastern provinces, and Ontario in particular, than to other parts of Canada. Many of the concepts, however, are of general application.

In the model the assumption is made that money used in the establishment and maintenance of plantations carries compound interest (like any other investment) over the rotation. Trees are essential to the nation's economy and well being, and it could be argued that the investment is an unavoidable expenditure and should not carry interest. Also it could be argued that the cost of tree establishment simply reduces the profit from sale of the previous crop, and so interest should not be charged over the following rotation. The authors feel that this is begging the question, and the fact must be faced that the investor has a choice, particularly when he is dealing with his own property; he can invest in planting trees and maintaining them or invest in some other enterprise. In view of this, the authors have charged interest on the investment in tree planting and culture.

Throughout the paper the term "tree improvement" refers to the production of trees with superior, genetically controlled attributes, covering the whole research and development spectrum. The term is often used by others in a more restricted sense, but the broader meaning is used in the present report to avoid repeated qualification of statements.

The terms "improved genotype" or "superior genotype" are also used in the broad sense and include any genotype with a performance better than another genotype where this better performance is genetically controlled. The terms obviously include trees obtained by selection of genetically superior individuals within populations and subsequent breeding. They also, however, include provenances which, when grown on a particular site, have performances superior to the local provenance (or any other tested genotype) provided this superiority is genetically controlled; the better provenances are genetically superior with respect to the populations with which they are being compared on particular sites.

LITERATURE REVIEW

Several reports in the literature discuss the economics of tree improvement programs, and the majority of authors conclude that these programs are a good investment; several demonstrate that even small increases in yield due to tree improvement result in considerable increases in the merchantable value of planted forests (Perry and Wang 1958; Marler 1963; Cole 1963; Lundgren and King 1965; Pitcher 1966; Bouvarel 1966; Zobel 1966; Davis 1967, 1969; Hopkins 1968; Swofford 1968; Bergman 1968, 1969). These papers mainly refer to the costs and benefits of seed orchards and do not account for the cost of research in developing varieties. There is no distinct division between research and development. Some research programs (tree selection and breeding in clonal or seedling orchards) yield usable seed directly and are part of the applied tree improvement program, i.e. there is an overlap between research, development and implementation. Basic research (e.g. studies of heritability and variation) does not yield seed directly but provides essential information; if such basic studies result in seed zone designation and seed transfer rules they enable the best seed to be selected.

In most reports little account is taken of the value of increasing tree crop security and improving stem form and timber quality, and not all allow for interest on the money invested or the effects of inflation. It is difficult to get a clear picture of the economics of tree improvement programs in terms of hard cash.

A method commonly used to assess the cost and benefit of a tree improvement program is to compare the cost of the seed with the value of the increase in timber yield. Davis (1967) developed a model for estimating seed production costs of loblolly pine (*Pinus taeda* L.) in orchards in the southern U.S.A. and compared these costs with economic potential. He estimated that improved seed costs $7.00 - $20.00 per pound compared with $3.00 - $7.00 per pound for ordinary commercial seed. Direct seeding in the forest costs about $5.00 - $12.00 per acre depending on rate of seed application. Davis indicated that for a planted acre (with a seed cost of about $1.00 per acre) a yield increase of slightly less than 1 cord per acre at rotation (or its dollar equivalent in quality increase) justifies the investment in the improved seed. Loblolly pine yields 25 - 40 cords per acre at 30 years of age, and the yield gain would need to be about 2.5 - 4% over current yields from unimproved seed. Perry and Wang (1958) calculated that expenditure of $19.00 per pound on seed (at 1958 dollar values) on southern pine plantations in the U.S.A. was justified by a 2% increase in yield at an age of 25 years. Increases in yield of this order or more can be expected from tree improvement programs.

Lundgren and King (1965) analyzed costs and benefits of both long-term and short-term tree improvement programs for red pine (*Pinus resinosa* Ait.) and jack pine (*P. banksiana* Lamb.). They expressed the increase in yield as apparent increase in site index (resulting from an increase in total height at the age of 50 years). They concluded that for rates of return of 4 - 6% the gain in site index needed to justify either short-term or long-term improvement programs for either species should be attained without difficulty.

Davis (1969) studied the effects of tree improvement on harvesting costs and daily profits from pulp mills, using the pine programs of south-eastern U.S.A. as an example. He pointed out that harvesting accounts for 60 - 70% of the total cost of wood delivered at the mill site, and increases in harvesting efficiency will be two or three times as effective in reducing costs as the same percent increase in stumpage yields. If greater stem uniformity can be achieved by tree improvement or other means this will greatly increase the efficiency with which trees can be harvested by mechanical means. He defined raw material quality as the physical or chemical attributes of the material which affect the production cost and the value of the final product. The quality of raw material influences both yield of product per unit volume of wood, and the time required to process a certain quantity of the wood. He calculated that in a paper mill producing 500 metric tons of paper daily, if yield of paper per unit of wood input was increased by 5% and the processing time reduced by 5%, costs at the mill would be reduced by 2.4 - 7%, and the daily profits increased by 15 - 41%. Relatively small improvements in the quality of the raw material can have profound effects on mill profits, and such improvements can be achieved by tree improvement programs (Harris 1969) as well as by better cultural techniques.

Swofford (1968) analyzed costs and benefits of the tree improvement program of the National Forests in Alabama. The value of the program was expressed as the percentage of value increase in the forest stand due to the tree improvement program. Future costs and benefits (which occurred at different times during the life of the project) were discounted to the year the program started. Costs included expenditure on tree selection, orchard establishment, orchard management and progeny testing; expected benefits included rotation age reduction, timber quality gain and timber volume gain. Longleaf pine (*Pinus palustris* Miller), loblolly pine, and slash pine (*P. echinata* Miller) were studied and the increases in values of the forest stands due to the tree improvement program were 14%, 18%, and 19% respectively for these species, with mean increase in value of 15.5%. The analysis clearly demonstrated the wisdom of investing in tree improvement in this particular forestry program.

The seed production costs in loblolly pine orchards have been analysed by Bergman (1968). He took into account costs of tree selection, progeny testing, scion collection, orchard establishment and management, capital expenditures on buildings and machinery; he used an interest rate of 7% per annum, and computed benefits for two site classes, two rotations and two tree spacings, with various stumpage prices. He calculated that at a stumpage rate of $5.00 per cord, and a seed crop of 20 lb per acre per year, an increase in timber yield of 3 - 6% would justify seed production costs. Increases of 15 - 20% are quite possible with this species. Bergman emphasized the importance of using heavy cone producers in seed orchards, as variations in seed productivity greatly affect costs and profits.

All the information in the literature cited, therefore, indicates that production of improved seed is profitable and justifiable. Unfortunately no information has been published for Canada where plantation forestry and tree improvement are relatively new. A model for the evaluation of white spruce yield increases which can be achieved by population selection is given in the following section. It is based upon available information.

A COST AND BENEFIT MODEL FOR WHITE SPRUCE IMPROVEMENT IN CANADA

Gains from using selected provenances

Before discussing the cost and benefit model it is necessary to consider what increases in yield we can expect from genetic selection of white spruce. Nienstaedt (1969) described the interim results from provenance trials of white spruce seedlings from twenty nine sources in the United States and Canada, field-planted at fourteen locations across northern United States and Canada, from latitudes 42° to 48° north extending from North Dakota to New Brunswick. The trials were planted from 1960 to 1962 as 2 + 0 or 2 + 2 stock, so they are still young. Trees from seed collected in the Beachburg area in Ontario grew particularly well at all locations with height growth 35% better than average. In New Brunswick these trees were 25% taller than average and 23% taller than a New Brunswick provenance. Other provenances from Ontario and Quebec also performed consistently well. These trials are still in their early stages but Nienstaedt refers to 29-year old tests of white spruce in northern Wisconsin (where the climate is cold) in which trees from Douglas, Ont. (near Beachburg) maintained a 22% height growth advantage over the trial average and 16% advantage over local white spruce. He suggested that even data from 5-year old trees may be reliable for predicting the adult performance of this species.

In Canada there is a series of white spruce provenance trials at present aged from 8 - 15 years which consist of trees from 89 seed sources

(Teich 1970). Trials are at 15 locations distributed from Fredericton, N.B., to Fort Frances in western Ontario. On average the best provenance at each location had 22% better height growth than the average, and the local provenance was only 3% better than average. The provenance from Peterborough, Ont., not only grew consistently taller (mean 17%) than average at all locations, but on average was also 14% taller than the local populations. The survival of this provenance was also greater (5%). These plantings are still young, but together with Nienstaedt's findings they indicate that considerable increases in height growth can be achieved by selecting white spruce genotypes.

The translation of research results of this type to field practice is essentially a process of successive approximations. Early results can provide guidelines but prescriptions based on them will have a higher element of risk than for prescriptions based on older trials. We can be more certain that the right selections have been made after one or two tree crops have been successfully grown and harvested -- but we cannot wait this long to provide seed for an increasing planting program. We could play it safe and use local populations which are probably well adapted, but the yield from these local populations is less than that from selected introductions for this species. Substantial gains in yield could be obtained from selection, testing and breeding within local populations, but again this takes time. It is therefore necessary to rely upon results from relatively young trials of white spruce provenances for current guidance on choice of provenance. Later results may modify this choice.

Gains from selections within a provenance

There is very little information about the improvement in growth which can be achieved by propagating white spruce selected for superior growth within a particular provenance. Thirty-two white spruce were selected in Michigan for vigor, height growth, form, needle length and branch characteristics (Jeffers 1969). After four seasons the progenies from the two fastest growing parents had 63% more height growth in 1 year (1967) than the average; progenies from the five fastest growing parents grew 21% better than average. Teich (1970) reports that in Canadian plantings, aged 19 years, the tallest progeny from twelve selected white spruce plus trees was 16% taller than average. These plantings are still young and of limited extent, but they demonstrate the gain which can be achieved by selecting within a provenance, quite apart from the gains of selecting the right population as a seed source. Heritability of height growth in white spruce may be as high as 91% (Holst and Teich 1969).

The gains from selecting the best provenance and within-provenance selections described above refer to height growth; if the plantations are managed well and the trees continue to increase in height and diameter up to harvest, the gains in volume should be considerably more. Yield tables illustrate that a small increase in height growth greatly increases volume yield.

Flushing and dormancy are also genetically controlled in white spruce; if trees are selected for both late flushing and rapid growth, it will increase both crop security and yield simultaneously (Nienstaedt and King 1969).

Apart from the study of wood densities of different white spruce provenances by Jones (1958), very little is known about the variation and heritability of wood characteristics of white spruce. Wood characteristics (such as specific gravity, tracheid length and thickness, and proportion of summer wood) which affect pulp quality are known to be genetically controlled, with relatively high (ca. 80%) narrow and broad sense heritabilities, in other coniferous species (Harris 1969; McElwee 1963; Goggans 1962; Dadswell and Wardrop 1959). White spruce is very variable and there is every reason to believe that it will respond to selection and breeding for timber characteristics. Even small gains in wood quality greatly affect mill profits, as mentioned earlier.

Although we still know little about the variability of white spruce and the heritability of attributes of economic importance, the evidence strongly suggests that it will respond well to selection of the best provenance and further within-provenance selection and breeding.

A cost-benefit model for white spruce plantation yield improvement

A model was constructed to estimate the value of different percent increases in yield in white spruce plantations taking into account as many sources of cost and benefit as possible. The model applies to increases in yield achieved by any means, cultural or genetic. In the present report, however, the model was used to answer the restricted question "Is the value of the increase in yield we can expect from using selected provenances of white spruce in Ontario more or less than the investment in the production of seed in seed production areas?"

The model is a means of estimating the value of the yield increase due to using a superior provenance. The cost of research leading to the designation of the superior provenance is not included.

No attempt is made to compare the value of yield increases arising from the use of superior genotypes obtained by within-provenance selection and breeding with the costs of seed production in clonal seed orchards. Too little information is available from this approach about the gains we can expect and the costs involved.

Although we are not yet in a position to state precisely what gain in yield at harvest we can expect from selection of the right white spruce seed source, it will probably be at least 20% more than trees grown from unselected seed. For the purposes of the present discussion we shall assume that a 15% increase in yield is possible from selection of the right seed source for this very variable species. This does not include the additional gains which will be achieved from subsequent selection and breeding within provenances, nor does it include increases in quality.

The basis of the model is the white spruce yield tables constructed by Stiell and Berry (1967) from plantations at Petawawa Forest Experiment Station in Ontario (See Appendix III).

THE MODEL

A. INPUT

1. Site index classes. The site index classes (the dominant tree heights in feet at the age of 40 years) in the present white spruce example height range is 40 - 70 feet. These represent the growth of a particular group of white spruce genotypes on sites of different fertility. In this example, the growth of these unimproved genotypes is the reference point for comparisons of profit and yield. If an improved genotype is used, the growth on the various sites will be different from that of the unimproved genotypes, and the site index classes will change. For simplicity the site index classes only refer to the unimproved genotypes.

2. Tree spacing. Tree spacings were 4 x 4, 5 x 5, 6 x 6, 7 x 7 and 8 x 8 feet. The effects of spacing on establishment costs, economic rotation and yield were incorporated in the model.

3. Increment and standing crop. Current annual increment (cu ft/acre per annum) and merchantable volume of standing crop for the unimproved white spruce were taken from yield tables (Stiell and Berry 1967). Data are only available for trees up to 40 years old and this was slightly less than the maximum computed economic rotation of 48 years. It was therefore necessary to extrapolate current annual increment a little (up to 8 years) beyond the recorded data, assuming that at the age of 48 years the age-growth relationships of the white spruce stands are still linear. The evidence from natural stands of white spruce on a range of sites in Canada (Kirby 1962) suggests that at the age of 50 the age-growth curve is well below the point of inflexion.

4. Interest rate. A compound interest rate of 6% per annum was used. This is lower than the current bank rate (6.5 - 7%), but in the long run 6% is likely to be nearer the mean rate. Any interest rate can be used in the model to compound costs to the harvest age and discount profits from harvest age to the time of planting.

5. Stumpage value. Stumpage values (dollars per cubic feet of standing timber) vary greatly from one locality to another, with different land tenure systems, and the type of product (pulp or saw-timber). It is also apparent that some stumpage rates are lower than the true values. Any stumpage rate can be used in the model, but in this example the rate used was $7.00 per cord, or 8.2c per cubic foot as used by Love and Williams (1968), which is the mean stumpage rate for spruce in central North America computed by Lewis and James (1961). This stumpage rate was increased annually by inflation at 2%. For comparison a stumpage rate of 3.7c per cubic foot was also used in the model as this is a rate commonly in use on

Crown lands in Ontario. In the present example it was assumed that the plantations produce mainly pulp wood but also some saw-logs from the larger trees. The model does not apply to stands grown mainly for saw-timber; in such stands the stumpage rate varies with tree size and this would have to be accounted for in computing economic rotation.

6. Inflation rate. The effect of inflation on stumpage rates was taken as 2% per annum following Love and Williams (1968); the same rate was applied to management costs. This is lower than the current inflation rate of 3.5 - 4.5% per annum, but is probably realistic in the long term. In fact, increases in stumpage rates have lagged behind inflation for the past 10 years. Any inflation rate can be used in the model.

7. Establishment costs. These costs, like stumpage values, vary with the site, the technique used (seeding or planting), tree spacing, tree species, site preparation and many other factors. In the present example the establishment costs are based on those for Ontario (W.W. Wahl, personal communication). It was assumed that a certain amount of site preparation was necessary, planting (2 + 2 trees) rather than seeding was used, and there were few failures. Costs used were site preparation $11.00 per acre, plant production 1.90c per plant, cost of planting 4.25c per plant. The total planting costs at the different tree spacings were calculated as the product of number of trees per acre and mean cost of establishment per tree (6.15c). For the closer spacings this cost estimate is a little high, as cost of planting per tree is likely to decrease with more trees per acre.

For the model, it was assumed that the forest land has no alternative use so the interest on the value of the land was not taken into account. Cost of forest land varies; Love and Williams (1968) suggested a mean value of $12.20 per acre in Ontario. The 6% interest on $12.20 per acre is 73c per annum. This is equivalent to rent and could be incorporated in the model if necessary.

8. Management costs. The annual costs of management (protection, road maintenance, cleaning, non-commercial thinning) were taken as $1.00 per acre initially, increasing at 2% per annum to allow for inflation. Interest at 6% was charged over the economic rotation. This applies to plantations where intensive management is not used. It is less than the total management cost of $2.21 per acre per annum used by Love and Williams (1968), which was based on cost of management of privately owned forests in the southern U.S.A. where management is more intensive than is likely in Canada. The yield tables used as the basis of the model referred to stands with a low management intensity. The $1.00 per acre management cost does not include pruning costs; pruning would not be essential if pulp production were the main aim. This cost of $1.00 per acre is probably still too high. In the absence of any better figures, however, it is retained, in keeping with the general policy of the report to give conservative estimates of profits and other benefits. The effects of varying management and other costs will be discussed in a later report.

The effects of variations in management costs on sites with different site class indices are not included. It is assumed that the management refers to a large area of white spruce plantations consisting of even-aged stands, the stands being of different ages, so that total management costs are similar from one year to another; for any particular stand the management costs would vary considerably at different times in the rotation. Any value for management cost can be used in the model.

9. Improvement in yield of merchantable timber. Levels of improvement in yield of merchantable timber used in the model were 0, 5, 10, 15, 20 and 25%; the 0 level is the yield of unimproved white spruce based on yield tables (Stiell and Berry 1967). Improvements in yield of 5 - 10% can be expected from most tree improvement programs. White spruce is, however, a variable species which lends itself to improvement by selection and breeding; as mentioned earlier, the available evidence (Teich 1970) indicates that we can expect gains in height growth of 15 - 20% (and more in terms of volume) compared with both local provenances and provenances selected at random, just by selecting the best provenance.

B. OUTPUT

10. Economic rotation. The economic rotation in years was calculated as the age at which the cost (including compound interest at 6% per annum and inflation at 2% per annum) of waiting one more year is equal to or greater than the increased value due to tree growth expected in the next year. This economic rotation is only valid for stands grown mainly for pulp; it would be different if production of saw timber were the main objective.

11. Profit or loss at harvest (net present worth). The net profit or loss (dollars per acre) was the difference between total cost (at 6% interest) and value of merchantable wood discounted to the time of planting, i.e. it is the net present worth of the forest enterprise.

12. Increase in profit or decrease in loss (change in net present worth). Increases in profit (or decreases in loss) due to increases in yield were calculated as the differences between discounted net profits (or losses) for the different increased yields and those for unimproved white spruce. In other words this parameter is the change in net present worth due to the increase in yield.

13. Internal rate of return. The rate of return is the interest rate at which an investor would have to borrow money to invest in establishment and management in order to break even. This is similar to the method used by Marty and Rindt (1966) to calculate internal rate of return, which they defined as "the interest rate that makes the present worth zero for a particular cost and future added value".

The model flow chart and Fortran program are given in Appendices 1 and II respectively. The calculations were carried out with a PDP-8 computer with a 4,000 word core memory and an ancillary 32,000 word disc memory.

The summarized results are given in Table 1. These results differ slightly from those informally reported earlier (Carlisle and Teich 1970) due to subsequent modifications and refinements of the model and program.

DISCUSSION OF MODEL

It is apparent that:

1. The discounted profit at harvest (column 7) is greatly affected by the tree spacing (column 2) and the site index class (column 1), and a net profit only occurs on the best site classes (60 and 70) and the wider tree spacings of 6 x 6 to 8 x 8 feet. No information is available for yield at 9 x 9 feet spacing; the figures in Table 1 suggest that the discounted profit at 9 x 9 feet spacing would be even greater than at 8 x 8 feet.

2. Although the economic rotation (38 - 48 years) (column 5) is slightly affected by site class and tree spacing, it is not appreciably affected by increasing yield on a particular site at a particular spacing. If the rotation were to be calculated as the age at which trees reach a particular size (instead of the age at which the cost of waiting another year is equal to or greater than the increased value) smaller changes in yield would affect rotation.

3. If yield on the site with a site index of 70 and trees at 8 x 8 feet spacing is increased by 15%, the value of this increase discounted to planting time (column 8) is $11.90 per acre; it increases profit from $8.42 per acre to $21.17 per acre, i.e. a profit increase of 150%. On the poorest site (site index class 40) where there is a net loss at harvest (column 7), the 15% increase in yield reduces the loss by $4.74 to $5.97 per acre, depending upon the spacing used. If the yield can be increased by genetic selection, tree improvement pays even when the total forest investment results in a net loss; a decrease in loss is as much a gain as an increase in profit where there is an over-riding reason for this total forest investment.

At a given spacing, the increase in profit (or reduction in loss) is greater on better sites than on poor sites, and for a particular site class the profit increase (and loss reduction) is more at closer spacings than at wider spacings.

4. The rate of return (column 9) varies from 6.3 - 6.9% on the best site (index 70) at 8 x 8 feet; where there is a net loss on a poorest site (index 40) at 8 x 8 feet this rate of return varies from 3.9 - 4.4%. To illustrate what the rate of return means, on site class 40 at 8 x 8 spacing with a 15% increment improvement there is a net loss, and the rate of return is 4.2%. This means that to break even the investment should carry an interest rate of 4.2% instead of the 6.0% used in the model. If the investment must carry an interest rate of 6.0% the investor will lose money when he sells on the stump. The profit is markedly influenced by even small changes in the chargeable compound interest; it needs a large change in profit or loss to influence the rate of return by 1%.

Table 1. The profits (and losses) and rates of return for white spruce planted at different spacings on different sites for various percent increases in yield. Interest 6% per annum, inflation 2% per annum, establishment costs 6.15c per tree + $11 per acre land preparation, management cost $1.00 per acre per annum, stumpage 8.2c per cu ft merchantable timber. Current annual increment from Stiell and Berry (1967).

(1) Site class (Height in ft at 40 years)	(2) Spacing (ft)	(3) Current annual increment (cu ft per acre)	(4) Yield at harvest	(5) Economic rotation age (years)	(6) Improvement in yield (%)	(7) Profit (or loss) at harvest, discounted to planting date ($/acre)	(8) Increase in profit (discounted) due to yield improvement ($/acre)	(9) Rate of return on money invested (%)
70	8 x 8	199	4850	42	0	8.42	----	6.3
					5	12.38	3.96	6.4
					10	16.35	7.93	6.5
					15	20.32	11.90	6.7
					20	24.28	15.86	6.8
					25	28.25	19.83	6.9
	7 x 7	198	4814	41	0	- 0.69	----	5.9
					5	3.40	4.09	6.1
					10	7.50	8.19	6.2
					15	11.59	12.28	6.3
					20	15.68	16.37	6.4
					25	19.77	20.46	6.6
	6 x 6	200	4802	40	0	-15.71	----	5.5
					5	-11.47	4.24	5.6
					10	- 7.22	8.48	5.7
					15	- 2.97	12.73	5.9
					20	1.29	16.99	6.0
					25	5.54	21.24	6.1
	5 x 5	201	5010	40	0	-42.25	----	4.9
					5	-37.83	4.42	5.0
					10	-33.40	8.85	5.1
					15	-28.97	13.28	5.2
					20	-24.55	17.70	5.4
					25	-20.12	22.13	5.5
	4 x 4	195	4689	38	0	-96.50	----	3.8
					5	-92.03	4.47	4.0
					10	-87.56	8.94	4.2
					15	-83.08	13.42	4.3
					20	-78.60	17.90	4.4
					25	-74.11	22.39	4.5

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
60	8 x 8	164	3948	43	0	- 8.97	----	5.6
					5	- 5.87	3.11	5.7
					10	- 2.76	6.21	5.8
					15	0.35	9.32	6.0
					20	3.46	12.43	6.1
					25	6.56	15.53	6.2
	7 x 7	170	4138	43	0	-17.79	----	5.3
					5	-14.54	3.25	5.4
					10	-11.28	6.51	5.6
					15	- 8.02	9.77	5.7
					20	- 4.77	13.02	5.8
					25	- 1.51	16.28	5.9
	6 x 6	170	4140	42	0	-33.24	----	4.9
					5	-29.85	3.39	5.0
					10	-26.47	6.77	5.1
					15	-23.08	10.16	5.2
					20	-19.69	13.55	5.4
					25	-16.31	16.93	5.5
	5 x 5	167	4006	40	0	-59.99	----	4.2
					5	-56.45	3.54	4.4
					10	-52.91	7.08	4.5
					15	-49.37	10.62	4.6
					20	-45.83	14.16	4.7
					25	-42.30	17.69	4.9
	4 x 4	165	3939	39	0	-113.88	----	3.3
					5	-110.27	3.61	3.4
					10	-106.65	7.23	3.5
					15	-103.04	10.84	3.7
					20	- 99.42	14.46	3.8
					25	- 95.79	18.09	4.0

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
50	8 x 8	132	3176	45	0	-25.20	----	4.8
					5	-22.89	2.31	4.9
					10	-20.57	4.63	5.0
					15	-18.26	6.94	5.2
					20	-15.94	9.26	5.3
					25	-13.63	11.57	5.4
	7 x 7	136	3193	44	0	-34.76	----	4.5
					5	-32.34	2.42	4.6
					10	-29.92	4.84	4.8
					15	-27.50	7.26	4.9
					20	-25.08	9.68	5.0
					25	-22.65	12.11	5.1
	6 x 6	146	3556	45	0	-49.70	----	4.2
					5	-47.11	2.59	4.3
					10	-44.52	5.18	4.5
					15	-41.93	7.77	4.6
					20	-39.34	10.36	4.7
					25	-36.75	12.95	4.8
	5 x 5	157	3792	45	0	-76.48	----	3.8
					5	-73.72	2.76	3.9
					10	-70.96	5.52	4.0
					15	-68.19	8.29	4.1
					20	-65.43	11.05	4.2
					25	-62.67	13.81	4.3
	4 x 4	154	3724	44	0	-130.82	----	2.9
					5	-128.00	2.82	3.0
					10	-125.18	5.64	3.2
					15	-122.36	8.46	3.3
					20	-119.54	11.28	3.4
					25	-116.72	14.10	3.5

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
40	8 x 8	104	2432	48	0	-40.42	----	3.9
					5	-38.84	1.58	4.0
					10	-37.26	3.16	4.1
					15	-35.68	4.74	4.2
					20	-34.10	6.32	4.3
					25	-32.53	7.89	4.4
	7 x 7	111	2586	48	0	-50.23	----	3.7
					5	-48.55	1.68	3.8
					10	-46.87	3.36	3.9
					15	-45.19	5.04	4.0
					20	-43.51	6.72	4.1
					25	-41.84	8.39	4.3
	6 x 6	116	2728	48	0	-66.62	----	3.4
					5	-64.85	1.77	3.5
					10	-63.07	3.55	3.6
					15	-61.30	5.32	3.7
					20	-59.53	7.09	3.8
					25	-57.76	8.86	3.9
	5 x 5	127	2973	48	0	-93.66	----	3.0
					5	-91.72	1.94	3.1
					10	-89.79	3.86	3.3
					15	-87.87	5.79	3.4
					20	-85.93	7.73	3.5
					25	-84.00	9.66	3.6
	4 x 4	125	2951	47	0	-147.93	----	2.3
					5	-145.94	1.99	2.4
					10	-143.95	3.98	2.5
					15	-141.96	5.97	2.6
					20	-139.97	7.96	2.7
					25	-137.98	9.95	2.8

Column 7 is synonymous with net present worth.
" 9 " " " internal rate of return.

With a stumpage rate of 3.7c there was a net loss even on the best sites with wider spacings and increased increments.

The increase in profit (or decrease in loss) per acre due to any improvement of the tree genotype is the value per acre of the improvement discounted to planting time. It is in fact a minimal value or gain. If this improvement is achieved by genetic means there will also be an improvement in crop security and possibly an increase in quality which will increase mill profits; the timber could yield more pulp per unit volume of timber processed and be cheaper to process (Davis 1969).

The model was designed to give conservative estimates of profits, and some sources of gain are excluded. For example, the calculated potential yields of white spruce (Love and Williams 1968) are appreciably higher than those used in the model; also if yield per acre is increased, harvesting costs per cunit will be decreased. In addition the authors think that their estimate of management costs may still be high for the type of plantation management appropriate to Canadian conditions. The gain of 15% in growth which can be expected from using genetically improved white spruce seed is conservative in that the research results refer to height growth; the gain in volume is likely to be more (Teich 1970). The total value of the gains may well be considerably more than estimated; the estimates of increases in profit in the present report are the least one can expect.

Given the estimate of profit increase due to an increase in yield, the manager has to decide the most efficient and economic way of achieving it. He can achieve it by genetic or cultural means, or both. In the case of white spruce, which is a variable species, there is evidence that an increase in yield of 15% will not be too difficult to achieve by genetic selection. In the case of a uniform species which is less responsive to improvement by selection (e.g. red pine) this would be less easy to achieve, and a mainly silvicultural approach would perhaps be preferable. The manager needs to know the genetic characteristics of the species before he can make an objective decision about the best ways of increasing yield.

If the manager decides to use the genetic approach he will need an estimate of costs of implementation in relation to the minimal increase in profit he can expect. In the case of the present white spruce model the increases in profit arising from a 15% increase in yield are $11.90, $9.32, $6.94 and $4.74 per acre with an 8 x 8 feet spacing for sites with indices of 70, 60, 50 and 40 respectively. Not many sites to be planted will be as good as 70, so a median value of $8.32 per acre is used in the present example. Pitcher (1966) has estimated that the total cost (allowing for interest) of production of white spruce seed in seed production areas is $43.00 per pound of seed. The price of unimproved white spruce seed at present is about $16.00 per pound so the increase in cost is $27.00 per lb. Estimates of how many trees 1 lb. of white spruce seed produces vary from 43,000 to 173,550. In accordance with the general aim to give conservative estimates of benefits, the lowest estimate (43,000 trees per pound) was used (Stoeckler and Jones 1957); in fact modern nursery practice will probably enable many more 2 + 2 trees than this to be grown from 1 lb. of seed.

One pound of white spruce seed will therefore produce enough transplants to plant at least 63 acres at an 8 x 8 feet spacing (680 trees per acre); the increase in cost ($27.00 per pound) of producing the improved seed on seed production areas is therefore about 43c for each acre to be planted. For an expenditure of 43c per acre at the time of planting the manager can expect a discounted increase in profit of about $11.90 - $4.74 (median $8.32) if all goes well and his plantations do not fail. It would be difficult to find a cultural practice which could achieve this 15% increase in yield for so little expenditure.

The gain in timber yield and increase in crop security achieved by selecting the right provenance is only the start and further within-provenances selection and breeding should considerably increase this gain in successive breeding cycles.

So far the discussion has been mainly concerned with costs of seed production in relation to increases in profits when the trees are sold on the stump; no account has been taken of the cost of research which provided the knowledge about which tree genotype to select in order to increase yield. The assessment of costs and benefits of research is made difficult by the fact that few research programs leading to a particular result can be considered in isolation; most research programs utilize knowledge from other programs. Also there are very few figures available for total costs of research programs, and it is often difficult to assess benefits quantitatively.

In the case of white spruce improvement we already know what research programs lasting 8 - 15 years can give some idea about which provenances are better than others on particular sites, with height growths 15% or more better than average and about 14% more better than those of local provenances. There is some evidence that juvenile superiority tends to persist (Nienstaedt 1969; Teich 1970). Such a 15 year program at Petawawa Forest Experiment Station cost a total of $775,000 including interest; the results apply to a limited range of sites. If, however, a study of growth and hardiness of white spruce provenances from the species' entire range were studied on a wide range of sites where the species is of economic importance this would probably cost about $1,500,000 (including interest) over a 15 year period with present day and foreseeable costs. The present white spruce planting program in Canada is 50,000 acres per annum; on the basis of Cayford and Bickerstaff's (1968) prediction that man-made forests will reach 10,000,000 acres by 1985, the white spruce planting program should average about 147,000 acres/annum in Canada over this period if the proportion of species currently being planted or seeded remains about the same. However, to be conservative we shall assume a future white spruce planting program of 100,000 acres per annum; most of this will probably be planted rather than seeded. If the 15 year long tree improvement research program costing $1,500,000 produces results which increase yield by 15% (and this seems quite likely), the discounted profit at 8 x 8 feet spacing is $11.90 - $4.74 per acre depending upon site. Using the median value of $8.32 per acre as an approximation, in a 100,000 acre per annum planting program with 8 x 8 feet tree spacing the potential benefit is $832,000 per annum; obviously this will vary with the frequency of the sites with particular indices.

There is, however, the additional cost of implementation of the research results, i.e. the seed production and collection costs. Using the figures for white spruce transplants produced per pound of seed given by Stoeckler and Jones (1957), if the seed production areas produced 2.4 lb. of seed annually, it would need 666 acres of white spruce seed production areas to produce the 1600 lb. of seed needed to provide trees for a 100,000 acre per annum planting program (8 x 8 feet spacing). Rudolf (1959) estimated that 10 acres of white spruce seed production areas are needed to produce one million seedlings per year. If we use this figure to calculate the seed production area needed to supply a 100,000 acre planting program, we get a very similar answer (680 acres). Pitcher (1966) estimated that white spruce seed production areas cost about $35.00 per acre per annum to operate, including interest; then the cost of establishing and maintaining 666 acres of seed production areas is about $23,000 per annum.

These figures indicate that for a research investment of $1,500,000 and an annual expenditure of about $23,000 on seed production a potential economic benefit of about $832,000 per annum will be generated. This is a good return on the research investment, even in the limited context of seed sowing to sale on the stump.

Before such a return can become a reality, the knowledge gained from research must be put into practice.

THE PHASES FROM SEED SOWING TO FINAL FOREST PRODUCT

The information in the literature largely relates cost of tree improvement to the value of standing timber, but the culture, management and sale of trees is only one phase in the sequence of events from sowing to the final product. There are three principle phases (Table 2) and each of these incurs its own costs and produces its own benefits. It is preferable to consider the costs of tree improvement in relation to all three phases rather than to any one.

The profits or losses arising from the first phase (tree establishment and culture up to sale on the stump) depend upon the site, mean annual increment, establishment costs, cultural method used and stumpage rates, as well as interest rates and inflation. The white spruce model described earlier suggests that a net profit can be obtained from this phase at wider spacings on good sites at a stumpage rate of 8.2c per cu ft. At a lower stumpage rate of 3.7c there is a net loss even on good sites. The increase in increment achieved by using improved genetic material is beneficial whether there is a profit or a loss, as a decrease in loss is valuable where a loss is unavoidable. A net loss in this first phase is acceptable if the organization executing this phase does so on account of a social obligation to maintain a tree cover in order to support industry, protect watersheds or create recreation facilities. It is also acceptable if the organization is also involved in the second and third phases (Table 2) which carry their own profits which may be large enough to offset the loss in the first phase; this applies to major companies which grow trees, process

Table 2.

Phase	I	<u>Tree establishment and culture</u> (long term)
		Seed production and collection Sowing Raising of plants in nursery Site clearance Planting Weeding Replacement of failures Fertilization Pruning Pre-commercial thinning Commercial thinning Sale at stump
Phase	II	<u>Harvesting, transport and conversion to lumber or pulp</u> (short term)
		Harvesting Transport Storage Conversion to lumber or pulp Sale of lumber or pulp
Phase	III	<u>Manufacture of consumer goods</u>* (short term)
		Conversion to consumer goods Advertising Sale of consumer goods

*In this sense consumer goods mean goods sold to the public (other than lumber), including housing, newsprint, etc.

wood and produce consumer goods. A private investor involved only in the first phase could not carry such a loss; increasing yield by using genetically superior trees and improved cultural methods, and only planting on fertile, accessible sites would all be essential to stay in business.

It is difficult to find realistic figures for the value of timber by the time it becomes the final product, but Love and Williams (1968) recently summed up the situation: "... the costs to society of raw material production may be relatively unimportant when compared to the benefits of industrial development made possible by the availability of the raw material. In the case of pulp and paper where the value of the final product may be \$140.00 per ton, the cost of producing the cord and a half of wood (127.5 cu ft solid) required -- \$10.00 to \$15.00 depending upon the interest rate used -- may be unimportant considering the derived benefits". In their example the value of the final product is \$140/127.5 = \$1.10 per cu ft of wood, which is considerably more than the stumpage rate we used, 3.7 - 8.8c per cu ft. The costs of research, development and implementation should be considered in relation to figures such as these rather than compared with sales at stump. Unfortunately reliable data upon which to base such comparisons are not available and we can only use sale at stump as our point of reference. All benefits calculated on the latter basis can only be regarded as minimal; in fact they will be much greater.

WAYS OF INCREASING YIELD

Tree improvement is only one way of increasing timber yield; considerable gains can be obtained from improved cultural, harvesting and conversion techniques. For example, increases in yield of 25 - 50% (or even more) have been recorded following forest fertilization (Strand and Miller 1969; Steinbrenner 1969). Conversion of trees to lumber can involve losses of almost half the stem material (Kerbes and McIntosh 1969), and even a small improvement in technique could lead to considerable gains. A major part (60 - 70%) of the cost of a forest operation is in harvesting (Davis 1969), and improvement in methods could reduce this cost and increase the proportion of material recovered. There is a good case for increasing investment in research in all these fields. The gains from improvement of these cultural, harvesting and conversion methods are large in comparison with the 10 - 20% yield gain from tree improvement programs, but gains from silviculture, harvesting, conversion and tree improvement are all interdependent. In so far as these gains refer to plantations, gains from silviculture, harvesting and conversion can only be achieved if the trees are adapted and survive. Furthermore even if the trees survive, gains from improved silvicultural techniques can only be optimized if the tree genotypes have a high growth potential and produce the right type of material; it would be as senseless to lavish expensive care on a poor type of tree as it would be for a farmer to give costly, high grade feed to a low grade cow.

Canadian foresters would be very pleased if they were able to get mean annual increments of 200 - 220 cu ft per acre. In New Zealand, Chile, Australia and the Union of South Africa it is not unusual to get a mean annual increment of 350 cu ft (true volume) per acre with exotic radiata pine (*Pinus radiata* D. Don) on a 25 year rotation in favorable areas, and in one zone in Chile the increment is 400 cu ft per acre per annum (Scott 1960). Thomson (1969) reports that radiata pine being logged in one part of New Zealand (Kaingaroa) at ages of 39 - 41 years consistently yield 11,000 to 11,500 cu ft per acre irrespective of site and stocking; mean annual increments of 270 and 300 cu ft per acre are being obtained from untended stands on sites regarded as marginal or submarginal for this species. If Canada is to compete in the world markets with countries possessing forests growing at this rate, every means must be used to get maximum growth and quality as economically as possible.

The value of any innovation must be assessed in the context of what expenditure in research was involved, how much it will cost to put the new knowledge into practice, and how long the benefit will persist. Genetics and tree improvement research is expensive to carry out, but not a great deal more so than any other research involving planting, maintenance and measurement of the trees over a rotation. The development stage of tree improvement (i.e. seed production and collection on a commercial scale) involves expenditure, the magnitude of which depends upon seed yield and whether clonal orchards (where establishment costs are relatively high), seedling orchards or seed production areas are used. The use of improved trees in a timber production program has the valuable attribute that it only involves expenditure at one time in the seed production → tree growth → timber sale sequence, and once the trees are improved the benefit persists into subsequent generations. The costs of genetics and improvement programs are frequently increased by loss of seed sources and lack of program continuity. The cost of any research and development program is greatly influenced by the period of time between program initiation and the implementation of results. This period is often increased by the destruction of seed sources used in experiments. A superior genotype is designated after long term trial but sometimes the researcher cannot go back to the seed source and collect seed for extended field trials and operational forestry. Instead he must establish a clonal seed orchard from the material in his experiments and wait 10 - 20 years before he can collect useful quantities of seed. Interest compounded over such a period is considerable. It would be most valuable if seed sources used in provenance trials could be preserved until the researcher has some idea which are the most promising genotypes, at least 15 years. Libby, Stettler and Seitz (1969) state that "... between 50 and 75% of the research information potentially available from forest genetics research has been lost due to personnel changes, administrative inconsistencies, and damage due to the occurrence of some low-probability disaster". We may not be able to do a great deal about unforeseen disasters, but clearly there is a need for stability in the administration of this type of research so that the greatest benefit can be obtained from long term research.

Cultural practices such as fertilization, thinning, pruning and weeding often have to be implemented more than once in a rotation. For example, yield can be increased by 25 - 50% by the addition of urea, but the effects may only last 7 - 8 years and the treatment may have to be repeated several times. The cost of aerial application of urea is about $9 - $17 per acre (Steinbrenner 1969; Swan 1969), and if this is repeated three or four times to maintain the increased growth the cost approaches half the establishment cost, quite apart from the cost of research leading to the new practice. It is more realistic to look at the costs of putting research findings into practice on a basis of per cent gain in yield achieved per unit of money invested in its execution. It seems likely that if this is done the relatively small (e.g. 10 - 20%) gains from tree breeding (which cost comparatively little to implement) will compare very favorably with larger gains from improved cultural practices (which are often costly to implement).

The value added (sale value less costs of materials, fuel, power and processing) by the logging, pulp and paper, sawmills, and wood and paper using industries rose from 2.85 billion dollars in 1965 to 3.25 billion dollars in 1968; total wood and paper exports were 2.30 billion dollars (20% of total domestic exports from Canada) in 1965 and 2.59 billion dollars (20% of total domestic exports) in 1968 (Michael R.C. Massie, personal communication; Anon. 1964, 1965, 1966, 1968). In 1965 the forest industries identified above contributed 6% of the gross domestic product (J.E. Marshall, personal communication). Most of the forest is natural and in 1965 man-made forests in Canada accounted for only 1,852,000 acres. In 1965 forests were being planted in Canada at a rate of 183,000 acres per year and this is on the increase; it has been estimated that by 1985 more than 10 million acres will have been planted (Cayford and Bickerstaff 1968). Man-made forests are clearly going to play an increasingly important role in Canada's forest industry. Natural regeneration is not always reliable and the risk of failure in getting the right kind of tree onto a specific site is often high. The area so far planted or seeded by man is small compared with the total area of productive forest. Plantations can produce timber of the right kind in uniform stands within reach of the mills, and in which full use can be made of modern harvesting technology. It is essential that the trees in these man-made forests are well adapted and grow rapidly. This cannot be achieved by any one means, whether it be tree improvement or silviculture. The two must work in cooperation in order to achieve the most efficient methods of establishment and culture.

CONCLUSIONS

1. There is good evidence that the costs of producing genetically superior seed are more than offset by small increases in yield of 2% to 5%.
2. The increase in yield (15%) which can be expected by using superior provenances of white spruce, results in substantial economic gains. An increase in discounted profit of $4.74 - $11.90 depending upon site (median value $8.32 per acre) can be expected from the use of improved seed produced in seed production areas established in superior provenances at an added cost of about 43c per acre to be planted.
3. In the context of a 100,000 acres per annum white spruce planting program, an investment in white spruce improvement research of $1,500,000 (including 6% interest) over a 15-year period and an annual expenditure of $23,310 on seed production and collection generate a potential economic benefit of approximately $832,000 per annum (median value); this latter value will depend upon the frequency and area of the different types of site.
4. Yields can be increased by improvement in both genetic constitution and cultural methods; neither can achieve maximum yields on their own.
5. The cost of using improved genetic material is only incurred once (at seed production) in the timber production sequence, and the benefit is carried over into future generations.
6. Once the research is completed, the additional costs of producing seed which will result in trees with faster growth in plantations are small (e.g. 43c per acre) compared with costs of some cultural techniques (e.g. use of fertilizers) aimed at increasing growth.

7. Tree improvement programs not only produce trees which grow faster and are well adapted; they can also produce trees with superior timber quality which can considerably increase mill profits by increasing yield of product per unit volume of timber handled, and by reducing processing costs.
8. There is a need for stable administration of genetics and improvement programs to reduce the considerable expense incurred by loss of research results arising from lack of program continuity and by destruction of seed sources.
9. Plantations will play an increasingly important role in Canada's forest economy. If Canada is to compete in the world markets with countries capable of tree growth rates of up to 400 cu ft per acre per annum, yields of species used in Canada's plantations must be increased by all economic means, genetic and cultural.
10. Improvement can be a paying proposition, particularly in the case of a variable species such as white spruce.

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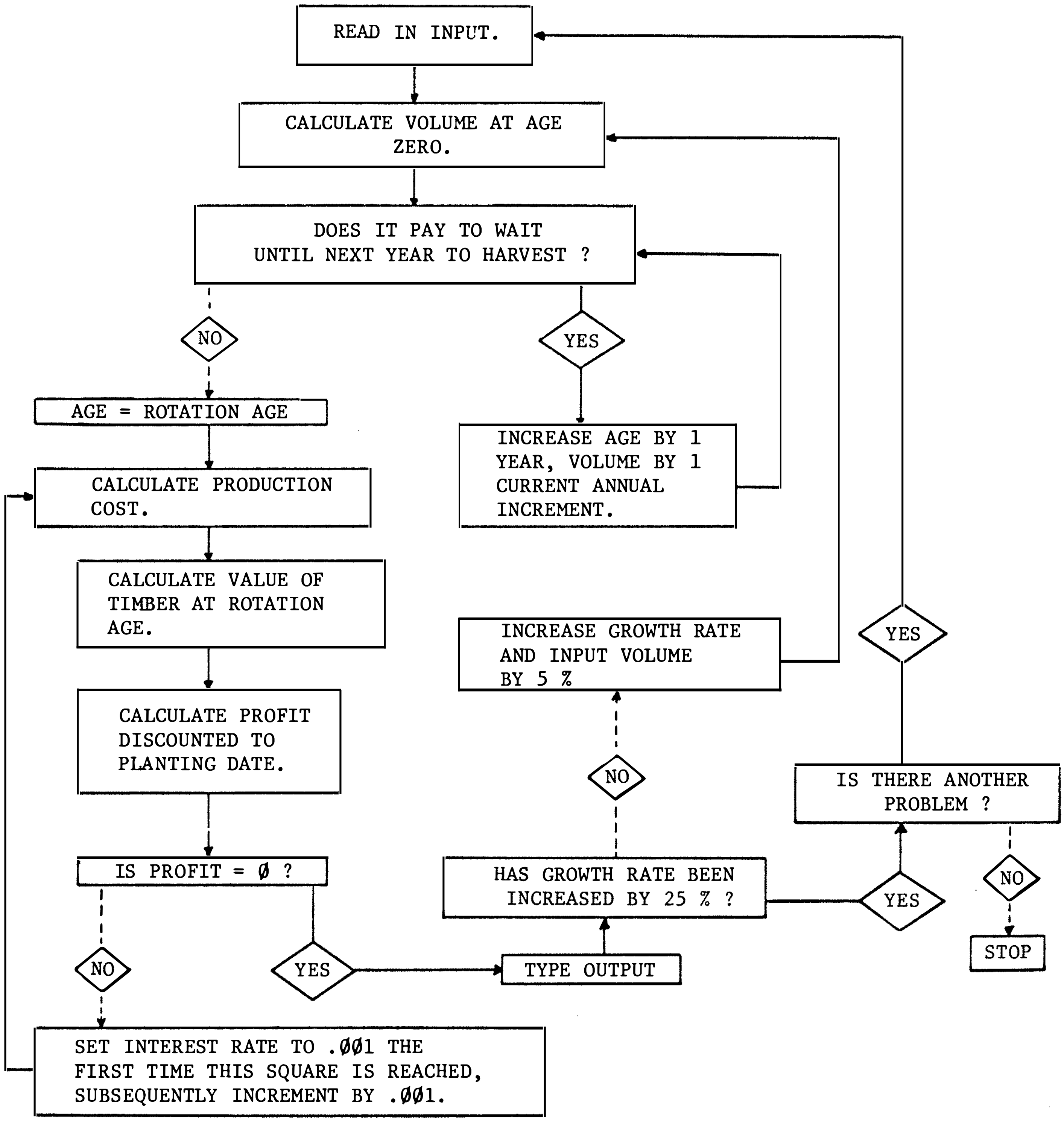
APPENDIX I

Cost and benefit model flow chart



APPENDIX II

Cost and benefit model computer program

DEFINITIONS OF VARIABLES USED IN PROGRAM

A: Input Variables.

RINT - interest rate on investment.
RATE - current annual growth rate in cubic feet / acre.
STUM - dollar value of one cubic foot of wood.
AGE - age in years for which a volume of wood / acre is known.
VOL - volume of wood (cubic feet / acre) at age.
RINF - rate of inflation.
ECST - establishment cost (dollars).
AMC - annual management cost (dollars).

B: Program Variables.

VRATE - same as RATE, but varies throughout program.
VAGE - same as AGE, but varies throughout program.
VAMC - same as AMC, but varies throughout program.
VSTUM - same as STUM, but varies throughout program.
XVOL - same as VOL, but varies throughout program.
XINT - same as RINT, but varies throughout program.

TVAL - value of standing timber at calculated age.
RET - return for waiting one year to harvest. (see flowchart notes)
COST - cost for waiting one year to harvest. (see flowchart notes)
SAMC - sum of annual management costs. (see flowchart notes)
AJ - VAMC backdated one year.
PRCST - production cost. (see flowchart notes)
PROF - profit earned by harvest discounted to date of planting.

C - counter aiding in logic manipulations - can be equal only to zero or one - permits statement 5 to be typed only once in each major (DO loop) cycle.
Y - year counter aiding in finding SAMC, during calculation of earned interest.
I - integer counter of DO loop - counts Ø to 25 by fives.
XI - floating point form of I.

FORTRAN PROGRAM FOR COST AND BENEFIT MODEL

```
C       PROGRAM CALCULATING ECONOMIC EFFECTS OF TREE
C       IMPROVEMENT IN TERMS OF PROFIT AND EARNED INTEREST.

1       READ(2,100)RINT,RATE,STUM,MAGE,VOL,RINF,ECST,AMC

        IF(RINT)200,201,201

201     AGE=MAGE
        XRINT=RINT*100.
        XRINF=RINF*100.
        WRITE(1,101)
        WRITE(1,102)XRINT,RATE,STUM,MAGE
        WRITE(1,103)
        WRITE(1,104)VOL, XRINF,ECST,AMC
        WRITE(1,105)
        WRITE(1,106)

C       DO LOOP INCREASES GROWTH RATE BY 5% IN EACH
C       CYCLE, STARTING AT CYCLE TWO.

        DO 15 I=0,25,5

C       SECTION TWO ADJUSTS VARIABLES TO INPUT , THEN
C       AGE AND VOLUME TO YEAR ZERO.

2       VRATE=RATE
        VAGE=AGE
        XVOL=VOL
        C=0.
        XI=I
        XI=1.+XI/100.
        XINT=RINT
        VSTUM=STUM
        VRATE=VRATE*XI
        XVOL=XVOL*XI
        SAMC=0.
        VAMC=AMC
        XVOL=XVOL-VRATE*VAGE
        VAGE=0.

C       SECTION THREE FINDS MOST PROFITABLE AGE, PLUS ONE
C       YEAR, AND FINDS SUM OF MANAGEMENT COSTS FROM
C       YEAR ZERO TO CALCULATED AGE.

3       TVAL=XVOL*VSTUM
        RET=VRATE*VSTUM*(1.+RINF)+TVAL*RINF
        COST=TVAL*XINT+VAMC
        SAMC=(SAMC+VAMC)*(1.+XINT)
        XVOL=XVOL+VRATE
        VAGE=VAGE+1.
        VAMC=VAMC*(1.+RINF)
        VSTUM=VSTUM*(1.+RINF)
        IF(RET-COST)4,4,3
```

```
C       SECTION FOUR BACKDATES AGE AND SUM OF MANAGEMENT
C       COSTS ONE YEAR TO MOST PROFITABLE HARVEST AGE,
C       THEN FINDS PROFIT AND BACKDATES TO YEAR ZERO.

4       VAGE=VAGE-1.
        AJ=VAMC/((1.+RINF)*(1.+XINT))
        SAMC=SAMC/(1.+XINT)-AJ
        PRCST=SAMC+ECST*EXP(ALOG(1.+XINT)*VAGE)
        PROF=(TVAL-PRCST)/EXP(ALOG(1.+XINT)*VAGE)
        XAGE=VAGE+.5
        NAGE=XAGE
        X10=PRCST
        X11=TVAL
        X12=PROF

C       REMAINING SECTION FIND VALUE OF INTEREST EARNED ON INVESTMENT.

        IF(PROF)7,14,7

7       XINT=0.

8       XINT=XINT+.01
        VAMC=AMC
        SAMC=0.
        Y=0.

9       SAMC=(SAMC+VAMC)*(1.+XINT)
        VAMC=VAMC*(1.+RINF)
        Y=Y+1.
        IF(VAGE-Y)10,10,9

10      PRCST=SAMC+ECST*EXP(ALOG(1.+XINT)*VAGE)
        PROF=(TVAL-PRCST)/EXP(ALOG(1.+XINT)*VAGE)
        IF(PROF)11,14,8

11      XINT=XINT-.001
        SAMC=0.
        Y=0.
        VAMC=AMC

12      SAMC=(SAMC+VAMC)*(1.+XINT)
        VAMC=VAMC*(1.+RINF)
        Y=Y+1.
        IF(VAGE-Y)13,13,12

13      PRCST=SAMC+ECST*EXP(ALOG(1.+XINT)*VAGE)
        PROF=(TVAL-PRCST)/EXP(ALOG(1.+XINT)*VAGE)
        IF(PROF)11,14,14

14      XINT=XINT*100.
```

```
      WRITE(1,107) I, NAGE, X10, X11, X12, XINT
15    CONTINUE
      WRITE(1,108)
      GO TO 1
100   FORMAT(F5.3,F6.1,F7.4,I3,F6.1,F5.2,F7.2,F6.2)
101   FORMAT('INTEREST-%     GROWTH RATE     STUMPAGE      AGE')
102   FORMAT(F6.2,9XF7.1,9X1H$,F7.4,6XI3/)
103   FORMAT('TIMBER VOL.    INFLATION-%     ESTAB.COST   ANN.MAN.COST')
104   FORMAT(F8.1,7XF8.2,8X1H$,F8.2,7X1H$,F7.2,//)
105   FORMAT('IMP.  ROT.   PRODUCTION     HARVEST      DISCOUNTED    EAR
     1NED')
106   FORMAT(' %     AGE    COST            VALUE         PROFIT        INT
     2EREST-%'/)
107   FORMAT(I3,3XI3,4X1H$,F9.2,3X1H$,F10.2,4X1H$,F8.2,5XF8.2/)
108   FORMAT(/////)
200   STOP
      END
```

APPENDIX III

Yield table for unmanaged white spruce plantations (Site Index Class 40)(Stiell & Berry 1967)

Age from planting (years)	Dominant height (ft.)	Planted spacing (ft.)	Trees per acre	Mean d.b.h. (ins.)	Basal area (sq.ft./ac.)	Volume: Total (cu.ft./ac.)	Volume: Merchantable (cu.ft./ac.)
20	17	4 x 4	2695	2.1	65	396	....
		5 x 5	1742	2.4	54	307	....
		6 x 6	1210	2.7	48	241	....
		7 x 7	889	2.9	41	189	....
		8 x 8	681	3.2	38	148	....
25	23	4 x 4	2540	2.5	86	852	366
		5 x 5	1735	2.9	80	730	314
		6 x 6	1210	3.2	68	625	288
		7 x 7	889	3.5	60	543	261
		8 x 8	681	3.9	56	478	239
30	28	4 x 4	2365	2.9	109	1381	870
		5 x 5	1695	3.3	100	1226	772
		6 x 6	1210	3.6	86	1084	705
		7 x 7	889	4.0	77	965	647
		8 x 8	681	4.4	72	870	600
35	34	4 x 4	2150	3.4	135	1933	1450
		5 x 5	1630	3.8	129	1762	1322
		6 x 6	1190	4.2	114	1583	1219
		7 x 7	885	4.6	102	1429	1143
		8 x 8	680	5.0	92	1302	1081
40	40	4 x 4	1920	4.0	167	2563	2076
		5 x 5	1540	4.3	156	2386	1957
		6 x 6	1150	4.7	138	2169	1800
		7 x 7	865	5.2	127	1975	1698
		8 x 8	675	5.6	115	1818	1600

APPENDIX III (continued)

Yield table for unmanaged white spruce plantations (Site Index Class 50)(Stiell & Berry 1967)

Age from planting (years)	Dominant height (ft.)	Planted spacing (ft.)	Trees per acre	Mean d.b.h. (ins.)	Basal area (sq.ft./ac.)	Volume	
						Total (cu.ft./ac.)	Merchantable (cu.ft./ac.)
20	21	4 x 4	2605	2.4	81	727	182
		5 x 5	1740	2.7	70	612	153
		6 x 6	1210	3.0	59	518	150
		7 x 7	889	3.3	52	445	142
		8 x 8	681	3.6	48	386	135
25	28	4 x 4	2365	2.9	109	1381	870
		5 x 5	1695	3.3	100	1226	772
		6 x 6	1210	3.6	86	1084	705
		7 x 7	889	4.0	77	965	647
		8 x 8	681	4.4	72	870	600
30	36	4 x 4	2075	3.6	147	2096	1614
		5 x 5	1600	3.9	133	1922	1499
		6 x 6	1180	4.4	125	1733	1386
		7 x 7	885	4.8	112	1573	1290
		8 x 8	680	5.2	100	1435	1220
35	43	4 x 4	1805	4.2	173	2851	2338
		5 x 5	1480	4.5	163	2676	2221
		6 x 6	1110	5.0	151	2437	2096
		7 x 7	850	5.5	140	2238	1969
		8 x 8	665	6.0	130	2061	1855
40	50	4 x 4	1535	5.0	209	3657	3108
		5 x 5	1330	5.2	196	3496	3007
		6 x 6	1015	5.7	180	3211	2826
		7 x 7	800	6.2	168	2976	2649
		8 x 8	635	6.7	156	2765	2516

APPENDIX III (continued)

Yield table for unmanaged white spruce plantations (Site Index Class 60)(Stiell & Berry 1967)

Age from planting (years)	Dominant height (ft.)	Planted spacing (ft.)	Trees per acre	Mean d.b.h. (ins.)	Basal area (sq.ft./ac.)	Volume	
						Total (cu.ft./ac.)	Merchantable (cu.ft./ac.)
20	25	4 x 4	2470	2.7	99	1093	601
		5 x 5	1720	3.0	84	952	524
		6 x 6	1210	3.4	76	830	473
		7 x 7	889	3.7	67	732	432
		8 x 8	681	4.1	63	654	399
25	34	4 x 4	2150	3.4	135	1933	1450
		5 x 5	1630	3.8	129	1762	1322
		6 x 6	1190	4.2	114	1583	1219
		7 x 7	885	4.6	102	1429	1143
		8 x 8	680	5.0	92	1302	1081
30	43	4 x 4	1805	4.2	173	2851	2338
		5 x 5	1480	4.5	163	2676	2221
		6 x 6	1110	5.0	151	2437	2096
		7 x 7	850	5.5	140	2238	1969
		8 x 8	665	6.0	130	2061	1855
35	51	4 x 4	1500	5.1	213	3814	3280
		5 x 5	1300	5.3	199	3643	3169
		6 x 6	1000	5.8	183	3354	2952
		7 x 7	795	6.3	172	3119	2776
		8 x 8	630	6.8	159	2896	2635
40	60	4 x 4	1155	6.2	243	4717	4104
		5 x 5	1030	6.4	230	4553	4006
		6 x 6	840	6.9	218	4270	3800
		7 x 7	700	7.3	204	4031	3628
		8 x 8	580	7.7	187	3798	3456

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APPENDIX III (continued)

Yield table for unmanaged white spruce plantations (Site Index Class 70)(Stiell & Berry 1967)

Age from planting (years)	Dominant height (ft.)	Planted spacing (ft.)	Trees per acre	Mean d.b.h. (ins.)	Basal area (sq.ft./ac.)	Volume	
						Total (cu.ft./ac.)	Merchantable (cu.ft./ac.)
20	30	4 x 4	2295	3.1	119	1533	1058
		5 x 5	1680	3.4	106	1375	949
		6 x 6	1210	3.8	96	1223	868
		7 x 7	889	4.2	85	1092	797
		8 x 8	681	4.6	78	988	751
25	40	4 x 4	1920	4.0	167	2563	2076
		5 x 5	1540	4.3	156	2386	1957
		6 x 6	1150	4.7	138	2169	1800
		7 x 7	865	5.2	127	1975	1698
		8 x 8	675	5.6	115	1818	1600
30	50	4 x 4	1535	5.0	209	3657	3108
		5 x 5	1330	5.2	196	3496	3007
		6 x 6	1015	5.7	180	3211	2826
		7 x 7	800	6.2	168	2976	2649
		8 x 8	635	6.7	156	2765	2434
35	60	4 x 4	1155	6.2	243	4717	4104
		5 x 5	1030	6.4	230	4553	4006
		6 x 6	840	6.9	218	4270	3800
		7 x 7	700	7.3	204	4031	3628
		8 x 8	580	7.7	187	3798	3456
40	70	4 x 4	845	7.5	259	5707	5079
		5 x 5	780	7.7	252	5567	5010
		6 x 6	680	8.0	237	5335	4802
		7 x 7	580	8.4	223	5072	4616
		8 x 8	515	8.6	207	4892	4452