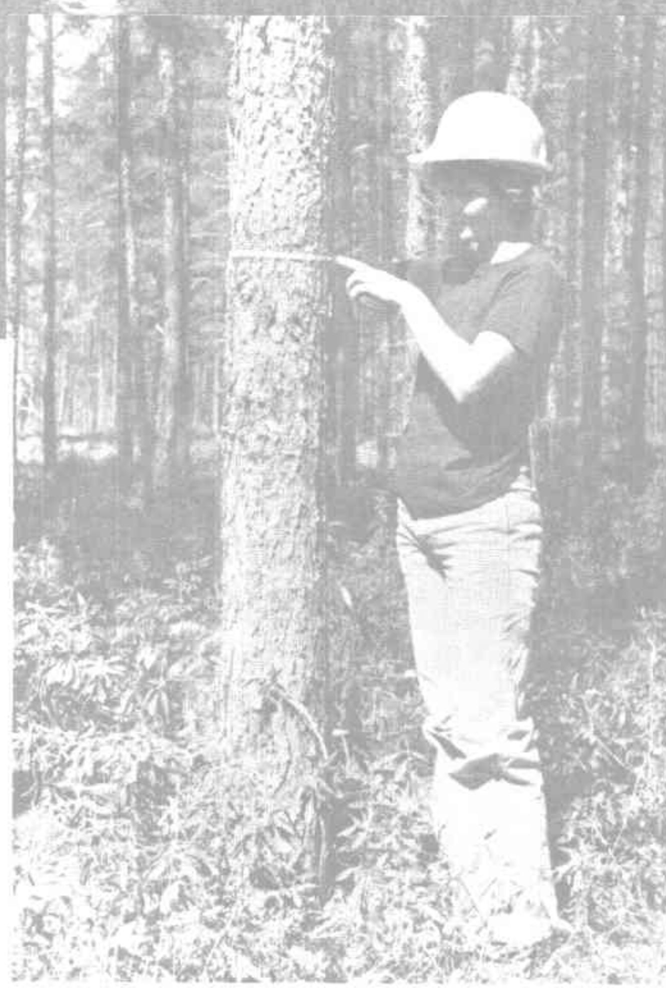
Proceedings of the fifteenth meeting of the Canadian Tree Improvement Association: Part 2

Comptes rendus de la quinzième conférence de l'Association canadienne pour l'amélioration des arbres: partie 2



Petawawa Forest Experiment Station
Chalk River, August 18-22, 1975

Station d'expérimentation
forestière de Petawawa
Chalk River, du 18 au 22 août 1975

LE PORTRAIT EN TETE

Peuplement semencier de pin gris près du Réservoir Baskatong, Québec, aménagé conjointement par la Compagnie Internationale de Papier du Canada, le Ministère des Terres et Forêts du Québec et le Service Forestier Canadien. Une éclaircie commerciale sur trois cent acres accroîtra la production de semences en prévision de la récolte qui se fera par une coupe totale sur une superficie donnée du peuplement. Les arbres-plus sélectionnés (médaillon) serviront de matérial de base pour un verger à graines de semis et des crosiements futurs.

THE COVER PICTURE

Jack Pine seed production area near Reservoir Baskatong, Québec, developed in cooperation between Canadian International Paper Company, Ministére des Terres et Forêts, and the Canadian Forestry Service. Three hundred acres were thinned commercially to encourage seed production in advance of periodic seed collection by felling. Plus trees were selected (insert) as the foundation for a seedling seed orchard and advanced - generation breeding.

ACKNOWLEDGMENT

We wish to thank M. Yves Lamontagne and Drs. Armand Corriveau and Gilles Vallée for translation of English abstracts into French résumés.

Editor

PROCEEDINGS OF THE FIFTEENTH MEETING OF THE CANADIAN TREE IMPROVEMENT ASSOCIATION

PART 2

A. SEMINAR: APPLIED GENETICS IN FOREST MANAGEMENT
Papers and discussion held August 20, 1975

B. 12TH LAKE STATES FOREST TREE IMPROVEMENT CONFERENCE
Abstracts of papers given August 19 and 21, 1975

HELD JOINTLY WITH THE
LAKE STATES FOREST TREE IMPROVEMENT CONFERENCE
AND
CANADIAN INSTITUTE OF FORESTRY WORKING GROUP 7

PETAWAWA FOREST EXPERIMENT STATION
CHALK RIVER, ONTARIO
AUGUST 18-22, 1975

Part 1 Minutes and Members' Reports. Distributed to Association members and available to others on request.

Part 2 Seminar: Applied Genetics in Forest Management. Distributed worldwide to persons and organizations actively engaged or interested in forest genetics and tree improvement.

Produced by the Canadian Forestry Service.
Department of the Environment, for the
Canadian Tree Improvement Association
Ottawa, 1976

Editor: E. K. Morgenstern

COMPTES-RENDUS DE LA

QUINZIÈME CONFÉRENCE DE L'ASSOCIATION CANADIENNE POUR

L'AMÉLIORATION DES ARBRES

PARTIE 2

A. SEMINAR: LA GÉNÉTIQUE APPLIQUÉE A L'AMÉNAGEMENT DES FORÊTS
Articles et discussion tenu le 20 août, 1975

B. 12 IÈME LAKE STATES FOREST TREE IMPROVEMENT CONFERENCE
Résumés des articles donnés le 19 et 21 août, 1975

TENU CONJOINTEMENT AVEC LA

LAKE STATES FOREST TREE IMPROVEMENT CONFERENCE
ET
LE GROUPE DE TRAVAIL NO 7 DE L'INSTITUT FORESTIER DU CANADA

STATION D'EXPÉRIMENTATION
FORESTIÈRE DE PETAWAWA
CHALK RIVER, ONTARIO
DU 18 AU 22 AOÛT, 1975

1re partie — Procès-verbaux et rapports de membres. Distribués aux membres de l'Association. Distribution au public sur demande.

2e partie — Séminar: la génétique appliquée à l'amenagement des forêts. Distribué à l'échelle mondiale aux personnes et organisations activement engagées ou interessées dans la génétique forestière et l'amélioration des arbres.

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Ottawa, 1976

Redacteur: E. K. Morgenstern

PROCEEDINGS OF THE FIFTEENTH MEETING OF

THE CANADIAN TREE IMPROVEMENT ASSOCIATION

With the compliments of the Association

Enquiries may be addressed to the authors or to Mr. J.C. Heaman, Executive Secretary, C.T.I.A., Research Division, British Columbia Forest Service, Victoria, B.C., Canada.

The Sixteenth Meeting of the Association will be held in Winnipeg, Manitoba, June 1977, in conjunction with the Canadian Botanical Association and the Genetics Society of Canada. The theme of the C.T.I.A. symposium will be "The Contribution of Forest Genetics to the Quality of the Environment". Canadian and foreign visitors will be welcome. Further information will be distributed in fall, 1976, to all members and to others on request.

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COMPTES RENDUS DE LA QUINZIÈME CONFÉRENCE DE

L'ASSOCIATION CANADIENNE POUR L'AMÉLIORATION DES ARBRES

Gracieuseté de L'Association

Les demandes de renseignements peuvent être adressées aux auteurs ou encore à M. J.C. Heaman, secrétaire du Conseil de la direction, A.C.A.A., Research Division, British Columbia Forest Service, Victoria, C.-B., Canada.

La seizième conférence de l'Association aura lieu à Winnipeg, Manitoba, en juin 1977, conjointement avec l'Association canadienne de botanique et la Société de génétique du Canada. Le thème du colloque de la A.C.A.A. sera le suivant: "La contribution de la génétique des forêts à la qualité de l'environnement". Les visiteurs canadiens et autres seront les bienvenus. De plus amples reseignements seront communiqués à l'automne 1976 aux membres et autres personnes qui en feront la demande.

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SEMINAR: APPLIED GENETICS IN FOREST MANAGEMENT

12TH LAKE STATES TREE FOREST IMPROVEMENT CONFERENCE

ABSTRACTS OF PAPERS

GENERAL INTRODUCTION

E.K. Morgenstern

Canadian Forestry Service
Petawawa Forest Experiment Station
Chalk River, Ontario

I am privileged to open this Seminar on Applied Genetics in Forest Management on behalf of the Canadian Tree Improvement Association. The objectives of the Association are, briefly, to promote discussion and active participation in all phases of tree improvement by scientists, forest managers, and administrators from the scientific and technical to the policy making level. These objectives have been pursued in recent years by sponsoring a series of discussions including one on red pine breeding in 1964, a spruce symposium in 1968, a general review of tree breeding and silviculture in Canada in 1970, on gene conservation in 1971, and hybridization in 1973. This year we have planned a program designed to be of immediate interest to forest managers. The papers were prepared under two subject headings: Breeding Activities and Seed Production, and are directed particularly at practical applications in forest management.

The sessions were organized with the assistance of Dr. J.P. van Buijtenen who is Principal Geneticist of the Texas Forest Service and Scientific Advisor to the Western Gulf Forest Tree Improvement Program, which joins many organizations. Dr. van Buijtenen has considerable experience in the transfer of scientific findings to practitioners and the organization of meetings such as this. He is also Chairman of our morning session on Breeding Activities. The second session, on Seed Production, is chaired by Monsieur Yves Lamontagne of Ministère des Terres et Forêt, Québec. M. Lamontagne is in charge of the breeding program centred at Berthierville in southern Quebec, and is working very closely with many forest managers and knows their problems.

I believe we are all familiar with the role of the management forester in a tree improvement program - his impact can be very great. The extent to which he is willing to become involved in selection and management of seed production areas, selection of plus trees, is critical to the success of silvicultural programs. He is responsible for a large forest area and a sizable regeneration program. Typical management units in northern Ontario, for example, encompass a land area of 1,000 square miles (approx. 260,000 ha). The unit forester may be responsible for an annual planting program on about 1,000 acres (400 ha), in addition to site preparation and direct seeding on an even larger area. He has the opportunity to practice tree improvement on a big scale. Unfortunately the experience with our species is limited - and so are funds and facilities and for the same reasons geneticists and foresters together must learn to use these great opportunities effectively and efficiently.

Again, this is not easy because species, silviculture and scale of operations differ so much from countries with more advanced programs that we cannot apply their procedures here. This is particularly true for Canada and to a lesser degree for the northern United States. It is clear, therefore, that we must develop methods adapted to our particular conditions. As I said, this development requires the common efforts of the geneticist and forest manager. So let us continue our sessions today in this atmosphere of learning and discussion, all of us working together toward the common goal of applying genetics to forest management.

BREEDING STRATEGY

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ABSTRACT

The development of breeding strategy is of paramount importance before breeding is begun in any given species. The purpose of improvement, degree and pattern of variation, and species biology are primary factors to be considered. The breeding method is then chosen, and selection, hybridization and mutation breeding are discussed here. Selection is well adapted to the characteristics of many species and is most commonly applied. The potential of hybridization has not been fully realized but must usually be combined with some form of selection. The use of special research environments, such as growth chambers, greenhouses and nurseries can give useful partial answers and direction to tree improvement in species where little basic information is available.

RÉSUMÉ

Le développement des techniques d'amélioration est d'une importance capitale avant le début des travaux sur une espèce donnée. Le but de l'amélioration, le degré et le type de variation ainsi que la biologie de l'espèce sont des facteurs primordiaux à considérer. Le choix de la technique d'amélioration est aussi un autre aspect important dont il faut tenir compte. Il est donc question ici de la sélection, de l'hybridation et des mutations. La technique de sélection s'adapte bien aux caractéristiques de plusieurs espèces et est le plus souvent employée. Le potentiel de l'hybridation n'a pas été entièrement exploité. Cependant, elle doit généralement être associée à une forme quelconque de sélection. L'utilisation de milieux spéciaux pour la recherche comme les chambres de croissance, les serres et les pépinières, peuvent fournir des réponses partielles mais utiles sur l'orientation des programmes d'amélioration pour les espèces pour lesquelles peu d'information de base est disponible.

INTRODUCTION

Some of the major forestry problems in Canada are problems of our modern industrialized society. Growing populations and dwindling forest areas are creating increasing demands on forest lands both for economic needs and for improvement of environmental quality, particularly in the southern, most accessible and productive areas. Fortunately, forest values can be sustained and improved by good management which aims at:

(1) Enhancement of productivity by
   (i) improvement of the inherent or genetic potential of the trees themselves and mass propagation of such improved trees;

   (ii) improvement of the environment of the trees by adopting refined regeneration techniques, improving drainage, use of fertilizers, adoption of good cultural practices and providing effective protection against fires, insects and diseases.

(2) Improvement of utilization by the use of improved harvesting, transportation and industrial processing of forest products.

Genetic improvement of trees aims to find, create and mass produce genetically superior trees which have the desired attributes and would be adapted to the environment (both climate and soil) of the site where they are intended to be grown. Such trees will not only produce more wood and fibre but will also include healthy trees with high amenity values in urban environments, trees that make effective shelter belts, improved wildlife habitats and watersheds, and provide the special aesthetic qualities for which man longs when returning to forests.

However, such ambitious goals will never be reached unless carefully planned programs are developed, using all available information and new research results as they become available. A carefully developed strategy must be the first step in any breeding program. This paper, which is the first in the seminar, explains how this strategy is developed.

BENEFITS OF GENETIC TREE IMPROVEMENT

Genetic improvement of forest trees plays a crucial role in forest management because of its contribution to enhanced productivity, supplementing the benefits derived from site improvement and amelioration of environmental quality. The major benefits of tree improvement are listed below.

Enhanced Productivity

1. Although the local population of a species is adapted to its environment, the purpose of breeding is to identify or create populations which are superior to the local population. The increased productivity of improved types of trees often far outweighs the increased cost of genetically improved seed. The most recent analysis of white spruce in Canada is a good example of expected benefits. Carlisle and Teich (1971) have estimated an additional cost of $1/ha ($0.43/ac.) for production of genetically superior seed. Cooperative research in Canada and U.S.A. over the last two decades has demonstrated the possibility of a 15% increase in wood and fibre production of white spruce by using randomly selected seed of superior provenances from southeastern Ontario. This would result in a discounted profit of $12-30/ha ($5-12/ac.), depending upon site. There is also a possibility of an additional improvement of 16-17% in height and 25% in d.b.h. at the age of 20 years by single-tree selection of 10% of the best trees in the superior provenances (Teich and Khalil 1973).

2. Some improvements, like those in disease and insect resistance and some wood and fibre qualities, depend upon breeding to a large extent.

3. When genetic improvement is achieved it continues into future generations, providing a perpetual source of superior seed without the need for recurring expenditure on its production.

Supplementing the Benefits of Site Improvement Practices

4. It is often possible to identify strains of trees which are better suited to unfavourable sites or show better response to expensive site improvement practices than their average counterparts.

Amelioration of Environmental Quality

5. Wood and fibre for pulp manufacture can be genetically improved so that reduced quantities of chemicals would be required in industrial processing for pulp manufacture and the input of industrial waste into the environment would be reduced.

6. Similarly the input of harmful insecticides into the environment can be reduced by using trees which are resistant to insects due to genetic qualities.

7. The quality of life in industrial urban communities can be improved by developing pollution and salt tolerant strains of trees and ornamental trees.

BASIC INFORMATION NEEDED TO DEVELOP BREEDING STRATEGY

The following information is necessary to develop a tree improvement strategy:

(1) the purpose of improvement;
(2) the degree and pattern of variation; and
(3) the biology of the species.

These three categories will be discussed more fully below.

The purpose of improvement must be carefully considered and clearly stated since it influences the breeding methods used in many ways. Examples could be: production of lumber, pulp or both; production of saw logs or veneer logs; increased quantity or quality of pulp; development of resistance to diseases. Theoretically many options are available but in practice satisfactory progress can only be made if the program concentrates on a small number of tree characters. These should be characters which are economically important and lend themselves to improvement through a combination of breeding and silviculture. If some characters are easily modified in manufacturing, breeding may be superfluous. The choice may not be easy, and before a clear picture emerges the closest team work is required of specialists in wood utilization, silviculture, economics and management, forest protection, and genetics.

The degree and pattern of genetic variation determines the level of improvement possible and how it is best achieved. For example, when plus-tree selection is carried out, the best genotypes are selected and accumulated for seed production in seed orchards (Morgenstern et al. 1975). It is very helpful if past studies have established the degree of variation indicated by distribution curves of certain tree characters (Trimble and Seegrist 1970). It is then easier to set selection standards. In general, the diversity of environment in the natural range of the species and mode of pollination determine the degree of variation within the species. Heterogeneous environment, cross-pollination and interspecific hybridization increase variation and vice versa. Furthermore, patterns of genetic variation follow patterns of environmental variation. Continuous environmental change produces continuous (or clinal) variation and discontinuous environmental change produces discontinous (or ecotypic) variation. Such patterns are detected in provenance studies and indicate how selection may be carried out efficiently. For example, if variation is largely discontinuous, then differences among stands within regions will be large and selection should be concentrated within the best stands.

Finally, the biology of the species must be taken into account (van Buijtenen 1975). This includes such aspects as:

1. Whether the flowers are unisexual or bisexual.

2. Whether the species is monoecious or dioecious.

3. Mode of pollination: by self-pollination or cross-pollination by wind or insects.

4. Grafting and rooting ability of scions and branch cuttings.

5. Age to sexual maturity.

6. Effectiveness of controlled pollination.

7. Presence or absence of the genes for the desired trait in the species, such as disease resistance.

8. Composition of genetic variance (mainly additive or is non-additive variance also important?)

9. The convenience with which artificial regeneration is possible.

These aspects are all important because they determine which breeding methods can be most effectively applied.

BREEDING METHODS

Some of the most common breeding methods applied are selection, hybridization, and mutation breeding combined with utilization of polyploidy.

Selection

Selection is the most common method used in conifers and forestry in general. The basic condition needed is the presence of a substantial amount of genetic variation for the traits of key importance in the breeding program. Selection is promising in forest trees because these are still wild species with a great deal of variability. Since most forest species are cross-pollinating, selected trees can be accumulated in seed orchards for effective seed production. The specific selection methods to be used, whether individual-tree or family selection or a combination of both, have been discussed elsewhere (Shelbourne 1969, van Buijtenen 1975).

Hybridization

The usual procedure of hybridization of annual crop plants is to develop several homozygous pure lines by repeated selfing and to cross two such pure lines. Hybrid vigor is the main advantage in such hybridization. Unfortunately, hybridization between pure lines is not possible with forest trees due to long periods to sexual maturity. Hybridization of forest trees is possible only among existing genotypes and is conducted primarily for combining the desirable traits of both parents. Hybrid vigor is often attained. Two types of hybridization are practiced in forestry, interspecific, and intraspecific.

Interspecific hybridization usually combines the useful characters of both parent species and results in a hybrid which is intermediate in those characters and often has hybrid vigor for growth. The large amount of literature which has accumulated on interspecific hybridization has been consolidated and reviewed by several workers, for example, Wright (1962) and Nienstaedt and Teich (1972). Some of the outstanding achievements are: (1) the *Pinus rigida* x *P. taeda* L. hybrid in Korea which performs better than the parents in certain environments (Hyun 1961); (2) the *Pinus radiata* x *P. attenuata* hybrid in California which grows better in higher altitudes and colder sites than *P. radiata* (Stockwell and Righter 1946); and (3) the *Larix decidua* x *L. leptolepis* hybrid in Europe. The last one is probably the best example in forestry of a well-proven heterotic interspecific hybrid. Interspecific hybrids sometimes have reduced seed set in the F_1 generation. This apparent handicap can be overcome by backcrossing to one of the parents or by vegetative propagation. With increasing use of root-forming hormones and tissue culture techniques it should soon be possible to extend the use of interspecific hybrids to species which cannot be vegetatively propagated easily. Notwithstanding some problems encountered in interspecific hybridization, the method has much potential which has not been fully utilized by forest tree breeders (Schmitt 1975), except in the genus *Populus* where it is used together with vegetative propagation (Zsuffa 1975).

Intraspecific hybridization of forest trees is in very early stages. Nevertheless it has shown encouraging results in combining the desirable traits of both parents (Nilsson 1975, Morgenstern 1975).

Mutations and Polyploidy

Mutation breeding is not a very useful tool in tree improvement. There are two reasons which militate against its use:

(i) Most mutations are random and harmful.

(ii) Unless mutations are produced in germ cells (pollen and unfertilized egg cells) the mutated plant has to be propagated vegetatively by grafting or rooting.

Polyploidy results from mutations in which the normal chromosome set is multiplied within the nucleus without subsequent nuclear division. Polyploidys occur in nature and can also be produced artificially, usually by the use of specific chemicals, the most common of which is colchicine. Polyploidy can be induced in vegetative cells of growing tissues, which produce a tetraploid sporophyte generation. The tetraploid individuals produce diploid gametes which, on fusion with haploid gametes from ordinary individuals produce triploid individuals. Tetraploidy provides the possibility for the production of vigorous fertile forms from sterile interspecific hybrids. It also facilitates interspecific fertilization when the species are otherwise incompatible.

Tetraploids sometimes have slower growth than diploids in which case they can be used as ornamentals. Triploids tend to have faster growth and better pulping qualities than diploids (Einspahr 1972).

The tetraploid stage can be bypassed by treating the generative organs during flower formation, which results in the production of diploid pollen. This pollen can be used to pollinate the haploid egg cells from diploid individuals. The resulting embryo and the tree is triploid and is produced quickly, saving one generation time.

THE ROLE OF SPECIAL METHODS IN RESEARCH

A problem that often arises in the development of a breeding strategy is that very little basic information is available initially. This is the case particularly with regard to genetic variation patterns and heritability. Here the methods applied in research can make a difference whether at least partial answers can be found in a relatively short time. Results can be expedited to a considerable extent by increasing use of growth chambers and greenhouses in provenance research to discover variation patterns. Heritability estimates in nursery tests give first insights into the problems of selection in a new species. Research along these lines is needed and research managers should provide leadership by encouraging and supporting creative research in these directions.

CONCLUSIONS

The development of a suitable strategy is of crucial importance in any breeding program and requires the evaluation of information from several disciplines. The first consideration is that of the tree characters to be improved which will of necessity involve at least silviculturists, wood technologists, and economists. Secondly, genetic parameters such as variances and heritability of individual characthers have to be obtained in experiments or predicted from the experience of other closely related species with more advanced research records, to see how the characters can be improved and how much can be achieved in one breeding cycle. Thirdly, before any decision regarding methods is made, the biology of the species must be reviewed as an additional factor in determining genetic variation patterns, evaluating chances of crossing, seed production, vegetative propagation, etc. Putting this all together and including cost will usually point out several alternative solutions. Of the breeding methods discussed here - selection, hybridization, mutation and polyploidy breeding - selection is most commonly applied. Its primary advantages are a higher degree of confidence in producing adapted genotypes and the feasibility of mass producing seed in relatively simple fashion. If hybridization is used, it is usually combined with selection such as in poplars. Since each species offers unique problems and opportunities, an open mind is needed in all cases.

LITERATURE CITED

Carlisle, A. and A.H. Teich. 1971. The costs and benefits of tree improvement programs. Can. For. Serv. Pub. 1302. 34 pp.

Einspahr, D.W. 1972. Forest tree improvement and the pulp and paper industry. TAPPI 55 (12): 1660 - 1669.

Hyun, S.K. 1961. Mass production of control-pollinated seed of conifers. Proc. 5th World For. Congr., Vol. 2: 787 - 792.

Nilsson, B. 1975. Recent results of interprovenance crosses in Sweden and the implications of breeding. Pages 3 - 16 in Proc. Fourteenth Meet. Can. Tree Improv. Assoc., Part 2.

Nienstaedt, Hans and A.H. Teich. 1972. Genetics of white spruce. U.S. Forest Serv. Res. Pap. WO-15. 24 pp.

Morgenstern, E.K. 1975. Early results of provenance hybridization in black spruce. Pages 27 - 37 in Proc. Fourteenth Meet. Can. Tree Improv. Assoc., Part 2.

Morgenstern, E.K., M.J. Holst, A.H. Teich, and C.W. Yeatman. 1975. Plus-tree selection: review and outlook. Can. For. Serv. Pub. 1347. 72 pp.

Schmitt, D.M. 1975. Interspecific hybridization in forest trees: potential not realized. Pages 57 - 66 in Proc. Fourteenth Meet. Can. Tree Improv. Assoc., Part 2.

Shelbourne, C.J.A. 1969. Tree breeding methods. N.Z. Forest Serv. Tech. Pap. 55. 43 pp.

Stockwell, P. and F.I. Righter. 1946. *Pinus*: the fertile species hybrid between Knobcone and Monterey Pines. Madrono 8: 157 - 160.

Teich, A.H. and M.A.K. Khalil. 1973. Predicting potential increase in volume growth by progeny testing white spruce plus trees. Bi-Monthly Res. Notes 29: 27 - 28.

Trimble, George R., Jr., and Donald W. Seegrist. 1970. Distribution of diameter growth rates and clear stem lengths as a basis for selecting superior phenotypes. U.S. Forest Serv. Res. Pap. NE-160. 11 pp.

van Buijtenen, J.P. 1975. Advanced generation breeding. Pages 63 - 72 in Proc. Thirteenth South. For. Tree Improv. Conf.

Wright, Jonathan W. 1962. Genetics of forest tree improvement. FAO Forestry and Forest Products Studies No. 16. 399 pp.

Zsuffa, L. 1975. A summary review of interspecific breeding in the genus *Populus*. Pages 107 - 123 in Proc. Fourteenth Meet. Can. Tree Improv. Assoc., Part 2.

ADAPTIVE VARIATION - MANIFESTATIONS IN TREE SPECIES AND USES IN FOREST MANAGEMENT AND TREE IMPROVEMENT

Hans Nienstaedt

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ABSTRACT

Adaptive variation and the genetic system that maintains adaptive fitness are described. It is emphasized that optimum fitness and genetic flexibility are opposing demands on the plant populations and have led to a compromise between fitness to existing environments and the capacity for further change. Using as examples phenological and edaphic adaptation, patterns of variation are discussed. Clinal variation is described and the importance of adequate sampling stressed in establishing discontinous, ecotypic variation patterns. Variation patterns are character specific and may be highly complex depending on the pattern of the environmental variation - clines within clines, clines within ecotypes and ecotypes within clines must exist within north temperate tree populations. The breeding system and the factors determining the sizes of breeding groups are important aspects of the genetic system and must be considered in planning by foresters and tree breeders alike.

Uses of knowledge regarding adaptive variation are considered in three areas of endeavor: (1) seed collection and distribution, and germplasm preservation policies, (2) regeneration of natural stands, (3) tree improvement planning and implementation.

RÉSUMÉ

L'auteur décrit la variation adaptative et le système génétique qui maintient l'aptitude à l'adaptation. Il souligne que dans les populations de plantes, la meilleure aptitude à l'adaptation et la flexibilité génétique sont des caractères opposés et qu'elles ont mené à un compromis entre l'aptitude à s'adapter aux environnements existants et la capacité de changer de nouveau. En prenant comme exemples l'adaptation phénologique et l'adaptation édaphique, il discute des modèles de variation. La variation clinale est décrite et on souligne l'importance d'un bon échantillonnage dans l'établissement de modèles de variation écotypique discontinue. Les modèles de variation sont caractérisés et spécifiques et peuvent être très complexes selon les modèles de variation de l'environnement: à l'intérieur des populations d'abres du nord de la zone tempérée il doit sûrement exister des clines à l'intérieur de clines, des clines à l'intérieur d'écotypes et des écotypes à l'intérieur de clines. Les systèmes d'amélioration et les facteurs déterminant la grandeur des groupes d'amélioration sont des aspects importants du système génétique et les forestiers, tout comme ceux qui travaillent à l'amélioration des arbres, doivent en tenir compte dans leurs planifications.

L'auteur traite de trois domaines où utiliser les connaissances sur la variation adaptative: (1) la récolte et la distribution des graines et la politique de conservation des sources de gènes, (2) la régénération des peuplements naturels, (3) la planification et l'exécution des travaux d'amélioration des arbres.

Widely distributed north temperate tree species encounter many different environmental conditions over their ranges. Photoperiod, temperature-related factors, precipitation, soil p^H and nutrients, competition with other plant species, disease, insect and fire occurrence vary and exert selection pressures to which the tree populations must adapt in order to survive.

Environments are not static, but show long-term and short-term changes. Populations must be capable of adjusting to the environments and remain competitive with other species in the plant community as the changes occur, and new sites become available for settlement.

Teleologically speaking, species have solved this problem in one of two ways. They have evolved "buffered" genotypes that are broadly adapted and can "cope" with a variety of environments - or they have evolved narrowly adapted types with fitness for specific environments and with genetic flexibility permitting rapid production of variants that can "handle" the changing environments.

This paper will discuss these adaptive strategies, will describe some examples of adaptive variation and variation patterns, and will consider how this information must be put to use in forest management and tree improvement.

ADAPTIVE STRATEGIES

The selective forces of the environment "directing" the evolution of adapted types will tend to restrict genetic variation by favoring progeny of optimum fitness. Flexibility, on the other hand, requires a potential for the continuous production of variant progeny that fit new environments. Mather (1943) has pointed out that these opposing demands on the plant population have led to a compromise between fitness to existing environments and the capacity for further adaptive change.

It can be no surprise, that the majority of north temperate species have maintained these contrasting characteristics to a high degree. Without flexibility they would not have been able to reoccupy the areas gradually freed from the ice during the warm-up of the past millennia. At the same time, without fitness they could not have continued to occupy the territories in which they were already established, but where the ecosystem and competition was changing.

As our knowledge has increased, we have come to realize that the majority of the northern tree species have evolved a very high degree of fitness, showing specific adaptation even to local climatic variation. Some species, however, have developed "well-buffered" phenotypes with a wide reaction range. For example, red pine (*Pinus resinosa* Ait.) encounters a substantial environmental variation over its range, yet is among the genetically least variable conifer species in the North. Other species with specific fitness but genetic flexibility, also include highly "buffered" strains adapted to a variety of environmental conditions. In white spruce (*Picea glauca* (Moench) Voss), the southeastern Ontario provenance shows superior growth in many environments in northeastern United States and adjacent Canada (Nienstaedt and Teich 1972).

GENETIC BASIS FOR ADAPTIVE VARIATION

Genetic analyses of the adaptive characteristics that differentiate tree populations have not been attempted. Nevertheless, it is possible to make a number of pertinent statements regarding the genetics of the characteristics involved, and about the genetic system that operates to maintain the essential genic flexibility.

Characteristics that may be of adaptive value are complex in nature and must be assumed to be under additive genetic control (several interacting genes in control). This is not to say that some simply inherited characteristics may not be of adaptive value. Rather, it implies polygenic control of important factors such as germination requirements, phenological responses, growth rates, stem and crown form, fruiting, and resistance to climatic extremes, diseases, and pests.

How many controlling genes are involved is not known. Data from other species suggest that the number may be relatively small. In an herbaceous species studied by Clausen and Hiesey (1958), only 3 of 19 characters were controlled by more than 10 genes. Two of these - leaf length and stem length - were related to vigor. Nine characters were controlled by 4 to 6 genes and the rest by 1, 2, or 3 genes.

Our understanding of the interaction between the genotypes and the environment is still very limited. In studies in which the interaction has been statistically significant, responses have been of three types: (1) Some have demonstrated a systematic reversal of the ranking of the populations in response to different climatic gradients. (2) In others, the ranking has remained the same but the magnitude of response has changed - superiority has been proportionally greater on increasingly better sites. (3) In yet another type of studies, interactions between genotypes and environments have not been systematic. In this last type, it has been impossible to find biologically meaningful explanations for the statistically significant interactions. Finally, some materials under study have shown non-significant interactions (Wright 1973).

Trees in the studies in which it has been possible to interpret interactions have in most cases been young. It is probably reasonable to expect that with age response patterns will surface that will permit more meaningful biological interpretations. Also, as the trees grow older and year-to-year effects have less of an impact, reliable information for more individual characters should become available. One can expect that some characters will be little influenced by the environment and, therefore, show very little interaction, while others will show highly significant interaction.

Correlations between many characteristics are highly significant, but have not been genetically analyzed. It is, therefore, not possible to say whether correlations result from genetic linkage (controlling genes located on the same chromosome) or arise at the physiological level. Answers to this question must be found if tree breeders are to use adaptive variation efficiently in tree improvement.

The genetic system that maintains fitness and facilitates evolution of the populations involves: (1) The genetic controls just described. (2) The chromosomal system which establishes the rate of gene segregation and recombination. (3) The breeding system (whether obligate outcrossing, inbreeding or apomictic, etc.). (4) The factors determining the sizes of breeding groups (Heslop-Harrison 1964). The genetic systems cannot be discussed in detail here, but some general examples and explanations may be helpful.

A high recombination index gives flexibility and provides for future adaptive changes; it is achieved at the cost of gene combinations favoring the prevailing environment. In comparison, a low recombination index preserves adapted genotypes at the cost of future adaptive potential. The recombination index has been assumed to be high for forest trees; this may be correct for many species, but not for the widely distributed conifers (Stern and Roche 1974).

Outcrossing (cross-pollination) promotes variability, while inbreeding (selfing) reduces variability. However, over a succession of generations a high index of recombination and outcrossing and a low index and selfing are alternative means to the same end, i.e., genetic stability (Heslop-Harrison 1964).

Outcrossing in cross-pollinated populations is not an all-or-none effect as is the case in the obligate self-pollinator. The degree of inbreeding and the flow of variation will depend on the size and distribution of the breeding group. Isolation of populations hinders gene flow, and will favor discontinous variation patterns, while continuous variation patterns may develop where populations are continuous and barriers to the gene flow at a minimum. Isolation may be spatial, resulting from actual physiographic factors and the ecological habitat that controls population density, or it may result from limited pollen transport or phenological isolation of flowering.

The genetic system, including the genic controls, maintains the adaptive variation that keeps the species competitive in stable and changing environments. In the following, examples of adaptive variation and the distributional patterns of such variation will be discussed.

ADAPTIVE VARIATION

Clinal Variation

To illustrate some typical patterns of variation, let us consider the time of flushing in some North American species. The pattern of flushing of sugar maple (*Acer saccharum* Marsh) (Kriebel 1957), yellow birch (*Betula alleghaniensis* Britton) (Clausen and Garrett 1969), and eastern white pine (*Pinus strobus* L.) (Mergen 1963) is essentially the same. In tests at intermediate latitudes within the ranges of the species, northern collections will start growth first; they are followed gradually by more southerly seed sources until the most southerly trees finally terminate the array. In one such test, a four-week period separated yellow birches from Québec and Tennessee.

Black walnut (*Juglans nigra* L.) (Bey et al. 1971a, 1971b), yellow poplar (*Liriodendron tulipifera* L.) (Sluder 1960, Farmer et al. 1967), sweetgum (*Liquidambar styraciflua* L.) (Winstead 1968), Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco (Read and Sprackling, in press), and American sycamore (*Platanus occidentalis* L.) (Schmitt and Webb 1971) show the reverse trend - trees from the southern sources initiate growth first. As yet the difference between the two groups of species has not been adequately explained.

The site - as a result of the interaction between genotype and environment - can have a profound effect on results. Testing eastern white pine at Manistique, Michigan revealed no meaningful pattern of height growth variation, but the results of tests in northern Minnesota were the reverse of those in southern Michigan (King and Nienstaedt 1969).

Sampling conditions profoundly influence interpretation of results. A few samples from widely scattered populations over the range of a species might suggest discontinuous variation, while sampling of the populations in between might reveal that the variation is continuous. Of the examples mentioned, the yellow birch, black walnut and sugar maple tests represent the more complete sampling of the species distribution. They clearly show that the variation is continuous or clinal. This is perhaps the most common variation pattern in north temperate trees.

The spring temperature (accumulated degree days) is the main factor that controls the flushing response from year to year. Spring frost is undoubtedly the selective force because frost injury reduces the trees' competitive ability. Late flushing is, therefore, a selective advantage enabling the trees to avoid damage in most years.

Local topography and air currents can have great impact on local temperature patterns and as a result, tree species may show local adaptive variation. This was demonstrated in a study of bud flushing in Sitka spruce (*Picea sitchensis* (Bong.) Carr) (Burley 1966a, 1966b). Burley, in order to explain the results, divided 47 provenances into nine groups. Five groups showed the expected north-south flushing pattern. Exceptions were the two most southerly sources from California where spring frosts are rare. Burley suggests that in this group, there has been little selection for late flushing.

One Alaskan groups showed a 10-day spread in flushing and consisted of two early provenances from mild coastal climates and two late flushing provenances adapted to regions exposed to flows of cold air from inland ice fields. The remaining groups showed similar variation to local climates.

Clinal variation has been demonstrated in practically all species studied. Date of growth cessation and the related fall coloring and leaf drop, and characteristics such as specific gravity, fibre length, needle dry weight, and resistance to climatic extremes such as drought and winter desiccation, all may show clinal variation.

If environmental factors exerting the selection pressure follow a gradient, the resulting variation patterns are likely to be clinal unless major breaks in the species distribution occur.

On the other hand, if the environmental factor exerting the selection pressure is discontinuous, resulting variance will also be discontinuous, i.e., ecotypic.

Ecotypic Variation

It is difficult to demonstrate ecotypic variation convincingly. Much described ecotypic variation is the result of inadequte sampling and is biologically meaningless. The identification of such variation requires both the demonstration of discontinuity in the variation pattern in the population sample, and in the environmental factor responsible for the biological response.

Stern and Roche (1974) have pointed out that clinal and ecotypic variation do not differ qualitatively, but reflect adaptive strategies of the populations, which depend on the pattern of the environment and the genetic system of the species.

Ecotypic variation in forest trees has most convincingly been described with regard to variation to different soil types. Teich and Holst (1974) have suggested the existence of a white spruce ecotype adapted to calcareous soils. Resistance to salt of a population of *Pinus taeda* L. has been described by Land (1967) (cited by Stern and Roche 1974), and rooting characteristics related to soil types have been described by Habeck (1958) in northern white cedar (*Thuja occidentalis* L.) and by Schmidt-Vogt (1971) in red alder (*Alnus glutinosa* L. Gaertn.).

Complex Patterns of Variation

Sitka spruce was mentioned as an example of genetic adaptation to local environmental variation. A number of additional points should be made to show the complexity that adaptive variation may attain.

The variation pattern is character specific and may not be the same for different characteristics. For example, in sugar maple injury from high insolation shows one pattern of variation, while the time of flushing and fall colouration shows a different one.

Environmental factors do not operate independently in controlling responses. As an example, early fall frost is the selective force that affects growth. The actual mechanism that triggers cessation of growth is photoperiod. However, in all species there is considerable scatter around the regression line if the date of growth cessation is plotted over photoperiod. This may indicate that factors other than photoperiod also affect the date; Morgenstern (1969) considered temperature the most important secondary factor in *Picea mariana* (Mill.) B.S.P.

As suggested by the Sitka spruce example, regional and local patterns of the environment are not simple gradients. Local topographic conditions can greatly modify large scale climatic trends; edaphic conditions can be superimposed on a climatic gradient. Different climatic factors such as photoperiod, temperature, and precipitation may each show a particular variation pattern. If the environmental factor exerts a selective pressure or acts as a controlling mechanism of a growth response, a corresponding pattern of adaptive variation may have evolved. It follows that we eventually may be able to identify, for our tree species, clines within clines, clines within ecotypes, and ecotypes within clines. Such complex patterns have been described for herbaceous plants. With adequate sampling, they may be found in tree species as well.

USES OF ADAPTIVE VARIATION IN FOREST MANAGEMENT AND TREE IMPROVEMENT

In the past, knowledge pertaining to adaptive variation has primarily been used for selection of outstanding provenances for reforestation purposes and for use in tree improvement programs. How else can such information contribute to decision making in forest management and tree improvement?

It is of crucial importance in three areas of endeavor: (1) seed collection and distribution, and germplasm preservation policies; (2) regeneration of natural stands; (3) tree improvement planning and implementation.

Seed Collection, Distribution, and Germplasm Preservation

Seed collection practices have improved markedly during the last few decades. It is doubtful that any reputable department of natural resources today would fail to maintain some record of origin throughout the seed collection and nursery operations. However, it may be equally doubtful that the collections in fact represent populations or that they sample populations adequately. In many cases, the collections represent only a portion of the population, or worse, they include too few trees or include seed from trees most of which are related. In the future specific seed collection directives must be developed for each major species. They should be based on knowledge of adaptive variation including the genetic system and should stress adequate sampling of populations for each species.

Planting seed from a "wrong" source within an existing population may result in a direct loss of growth and in a loss on a second count as well. The planted stand may constitute an inferior genotype that in the long run may lower the adaptive quality in adjacent naturally reproduced stands.

In 1971 the Committee on Forest Tree Breeding in Canada devoted the better part of a meeting to a Symposium on the Conservation of Forest Gene Resources. The Proceedings included a statement on Conservation of Forest Genes. It addresses itself to *in situ* preservation of exceptionally valuable tree populations including both populations "of special interest in tree improvement" and those recognized as "endangered". *Ex situ* conservation in tree improvement collections and seed banks is also recognized. A working party was created to work on the problem.

To be effective, this working party or any similar group must apply not only all existing knowledge regarding the adaptive variation of the species involved, but also information regarding the genetic systems that control the perpetuation and evolution of the gene pools making up the populations.

Regeneration of Natural Stands

Maini (1971) has estimated that by the year 2000, 4% or at the most 5% of the productive forest land in Canada will be in man-made forests. Similar values, undoubtedly, will apply to large areas of the U.S.A., although some regions will have a much higher percentage. The important point is that natural regeneration will continue to play a major role in North American forestry for many years. The success of natural regeneration is usually measured entirely on the basis of the stocking of the future stand; no consideration is given to the genetic make-up. Often the seed trees have been of inferior phenotypes (probably of poor genotype as well) left as remnants after clear-cutting. Furthermore, it is not unlikely that spacing of trees has favored selfing on the one hand and future possibilities for inbreeding on the other, because each seed tree has seeded relatively large areas. Discussing gene conservation in natural stands following logging, Yeatman (1971) listed the following mandatory requirements: (1) The population should be adequately maintained. (2) New generations should be derived from an adequate number of parental trees. (3) Only natural regeneration or seed of local origin should be used. Yeatman purposely did not try to define what an adequate number of parental trees or what a population is. Only by using available knowledge regarding the adaptive variation and the genetic system as it applies to each individual species and situation, can the pertinent values be established. My point is that Yeatman's mandatory requirements should be considered whenever stands are being regenerated naturally.

Tree Improvement Programs

Information on adaptive variation and the genetic system that maintains adaptation of populations is basic to the planning and implementation of a breeding program. Some of the most important points to consider will be discussed here.

1. Fitness to the natural environments and to the environments imposed by man is not one and the same thing.

For example, the establishment of natural reproduction of a tolerant species under an overstory will be basically different from planting of the species in a clearcut. Management of species such as black spruce (*Picea mariana*) or tamarack (*Larix laricina* (Du Roi) K. Koch) probably would be on upland sites, while natural reproduction often is confined to bog sites. Site preparation and maintenance through the use of herbicides may constitute major modifications of the environment.

The responses of genotypes to such modified environments cannot now be predicted. Therefore, testing and selection for advanced generation breeding must be in typical management situations. Furthermore, since the lead time in a breeding program must be at least ten years or longer, tests must be conducted under conditions typical of future management practices insofar as possible.

2. Adaptive variation will determine the source of breeding material, and will set the limit for the breeding zone.

Breeding materials should be selected within the populations that perform best in the region of management. The best populations may be either local or they may come from outside the region. They may come from a somewhat milder climate as in black walnut (Bey et al 1971a and 1971b) or from a broadly adapted provenance such as the southeastern Ontario white spruce provenance. Without reliable provenance information, breeding material should be selected from local populations.

Each seed orchard will produce populations with adaptive limitations that depend on the parent material in the orchard. The limits may or may not coincide with the region in which the parents are selected. Ultimately, the limit must be established through testing.

3. It may be possible to broaden adaptation through the hybridization of genotypes with different adaptive characteristics.

Zobel (1971) suggested broadening adaptation by crossing genotypes selected in stands far apart. This undoubtedly could involve hybridization of genotypes with different (and unknown) adaptive characteristics. At present, we have no way of predicting the results of such crossing, hence we can do no actual planning of how to best achieve a specific goal.

Several pertinent studies are in progress. Until these studies yield results to guide in planning, available knowledge about adaptative variation should be used to select base material for tree improvement. Geneticists should be conservative in mixing ortets representing different adaptive strains, and should carefully test the adaptive ability of the new genotypes.

4. In breeding programs, it is essential that a broad genetic base be established.

Naturally regenerated stands will predominate North American forestry for years to come, but in some areas the genetic material included in the tree improvement programs will soon constitute the only reliable genetic material. Artificial regeneration directly or through pollen contamination will have had its impact on the naturally occurring genotypes. Well-documented parent trees of a broad genetic base must, therefore, be included in the programs from the start.

Zobel (1971) addresses himself to this question. He recommends an initial base of 300 clones, one ortet selected per stand, in stands 40 or more acres in size, and several to hundreds of miles apart. This approach will make possible genetic combinations never found in nature and insure "a broad adaptability". For long-term programs, he recommends a continuous effort to broaden the genetic base.

These recommendations certainly seem reasonable, but are they correct? Is it necessary to limit the sample to a single tree per 40 acres? Is a distance between samples of "hundreds of miles" perhaps too great? Is the initial base of 300 clones large enough, and what is a continuous broadening of the genetic base? Our answers to these questions need to be more precise; they must be based on a thorough knowledge of the adaptive variation and genetic systems within our major species.

5. The magnitude of the adaptive variation of populations relative to the variation among trees within a population determines the selection scheme.

Where the variation in adaptive characteristics is large and the patterns of variation well defined, initial selection should give priority to seeking out well adapted populations. On the other hand, large variation among progenies relative to variation in adaptive characteristic of population dictates large scale testing of selections of individual trees. Such trees should be selected within local populations over a relatively large region (several thousands of square miles).

6. The factors of the genetic system, particularly the factors determining the size of breeding groups, influence seed orchard design and and management.

A high degree of self-compatibility and pronounced inbreeding depression could result in very low quality seed from orchards in early years when pollen is in short supply. Possible solutions would be: (1) Release of additional pollen in the orchards. (2) Delay of seed collection until pollen supply is adequate, or seed collection from the clones of low self-compatibility only. (3) Rigorous culling of seedling populations before field planting.

The degree of self-compatibility determines the arrangement of clones and families within the orchards, and has resulted in designs that minimize the chance of selfing.

Flowering of all the material in an orchard must be synchronized. It may be necessary to discard otherwise high quality clones if time of flowering is out of phase with the rest of the parents.

Isolation zones surrounding orchards have been decided arbitrarily on the basis of very limited information. We need specific, detailed information on which to establish the width of isolation zones surrounding the orchards.

IN SUMMARY

I have tried to stress the two important aspects of adaptive variation: (1) The adaptive responses to the selection force of the environments. (2) The genetic systems that permit populations to maintain adaptation, yet evolve new adaptive types capable of competing in changing environments. It is pointed out that adaptation is a compromise between fitness to existing environments and the capacity for further change.

The view is expressed that contrary to past practices, both adaptive variation *per se*, as well as the genetic systems of species and populations, should be taken into consideration when: 1) policies for seed collection, distribution and germplasm preservation are planned; 2) when silvicultural schemes for natural regeneration are developed; and 3) when tree improvement programs are planned.

LITERATURE CITED

Bey, Calvin F., N.L. Hawker, and P.L. Roth. 1971a. Variations in growth and form in young plantation black walnut trees. Pages 120 - 127 in Proc. Eleventh South. For. Tree Improv. Conf.

Bey, Calvin F., J.R. Toliver, and P.L. Roth. 1971b. Early growth of black walnut trees from twenty seed sources. U.S. For. Serv. Res. Note NC-105. 4 pp.

Burley, J. 1966a. Genetic variation in seedling development of Sitka spruce, *Picea sitchensis* (Bong.) Carr. Forestry 39: 68 - 94.

Burley, J. 1966b. Provenance variation in growth of seedling apices of Sitka spruce. For. Sci. 12: 170 - 175.

Clausen, J. and W.M. Hiesey. 1958. Experimental studies on the nature of species. IV. Genetic structure of ecological races. Carneg. Instn. Wash. Pub. 615.

Clausen, K.E. and P.W. Garrett. 1969. Progress in birch genetics and tree improvement. Pages 86 - 94 in Birch Symposium Proceedings. U.S. Forest Serv., Northeastern For. Exp. Sta.

Farmer, R.E., Jr., T.E. Russell, and R.M. Krinard. 1967. Sixth-year results from a yellow poplar provenance test. Pages 65 - 68 in Proc. Ninth South. For. Tree Improv. Conf.

Habeck, J.R. 1958. White cedar ecotypes in Wisconsin. Ecology 39: 457 - 463.

Heslop-Harrison, J. 1964. Forty years of genecology. Advances Ecol. Res. 2: 159 - 247.

King, J.P. and Hans Nienstaedt. 1969. Variation of eastern white pine seed sources planted in the Lake States. Silvae Genet. 18: 83 - 86.

Kriebel, H.B. 1957. Patterns of genetic variation in sugar maple. Ohio Agric. Exp. Sta. Res. Bull. 791. 56 pp.

Land, S.B. 1967. Intraspecific variation in sea-water tolerance of loblolly pine (*Pinus taeda* L.). M.S. Thesis, North Carolina State Univ., Raleigh, N.C.

Maini, J.S. 1971. Conservation of forest gene resources in Canada: an ecological perspective. Pages 43 - 50 in Proc. Thirteenth Meet. Comm. For. Tree Breed. Can., Part 2.

Mather, K. 1943. Polygenic inheritance and natural selection. Biol. Rev. 18: 32 - 64.

Mergen, F. 1963. Ecotypic variation in *Pinus strobus* L. Ecology 44: 716 - 727.

Morgenstern, E.K. 1969. Genetic variation in seedlings of *Picea mariana* (Mill.) B.S.P. I. Correlation with ecological factors. Silvae Genetica 18: 151 - 161.

Nienstaedt, Hans and Abraham Teich. 1972. The genetics of white spruce. U.S. Forest Serv. Res. Pap. WO-15. 24 pp.

Read, Ralph A. and John A. Sprackling. In press. Ten-year performance of Douglas fir. In Proc. Twelfth Lake States For. Tree Improv. Conf.

Schmidt-Vogt, H. 1971. Wachstum und Wurzelentwicklung von Schwarzerlen verschiedener Herkunft. Allg. Forst-u. Jagdztg. 142: 149 - 155.

Schmitt, D.M. and C.D. Webb. 1971. Georgia sycamore seed sources in Mississippi plantings. Site adaptability a key factor. Pages 113 - 119 in Proc. Eleventh Conf. South. For. Tree Improvement.

Sluder, E.R. 1960. Early results from a geographic seed source study of yellow poplar. U.S. Forest Serv., Southeastern For. Exp. Sta., Res. Note 150. 2 pp.

Stern, Klaus and Laurence Roche. 1974. Genetics of forest ecosystems. Springer-Verlag, New York-Heidelberg-Berlin. 330 pp.

Teich, A.H. and M.J. Holst. 1974. White spruce limestone ecotypes. For. Chron. 50: 110 - 111.

Winstead, J.E. 1968. Ecotypic differentiation in *Liquidambar styraciflua* L. Ph.D. Thesis, University of Texas. 138 pp.

Wright, Jonathan W. 1973. Genotype-environment interaction in North Central United States. For. Sci. 19: 113 - 123.

Yeatman, C.W. 1971. Gene conservation in relation to forestry practice. Pages 19 - 24 in Proc. Thirteenth Meet. Comm. For. Tree Breed. Can., Part 2.

Zobel, Bruce. 1971. Gene preservation by means of a tree improvement program. Pages 13 - 17 in Proc. Thirteenth Meet. Comm. For. Tree Breed. Can., Part 2.

PLUS-TREE SELECTION IN BRITISH COLUMBIA

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ABSTRACT

Two plus-tree selection programs developed by the Research Division of the British Columbia Forest Service are discussed. The first of the programs developed for coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) is a strict phenotypic selection program. Untested ramets of plus trees thus selected are established in seed orchards for seed production. The second program developed for interior spruces (white spruce, *Picea glauca* (Moench) Voss and Engelmann spruce, *P. engelmannii* Parry) employs a much more relaxed selection standard followed by open pollinated progeny trials. Advantages and disadvantages of both programs are discussed. Evaluation and recommendations are given based on experience gained during execution of the programs.

RÉSUMÉ

L'auteur présente deux programmes de sélection des arbres plus menés par la Division de la recherche du Service forestier de la Colombie britannique. Le premier programme qui concerne le Douglas taxifolié de la région côtière (*Pseudotsuga menziesii* (Mirb.) Franco) est un programme strict de sélection phénotypique. Les ramets non testés provenant des arbres plus ainsi sélectionnés sont plantés dans des vergers à graines pour la production de graines. Le deuxième programme, concernant les épinettes des régions intérieures (épinette blanche, *Picea glauca* (Moench) Voss et épinette d'Engelman, *P. engelmannii* Parry), est réalisé selon des normes de sélection beaucoup moins sévères. Cette sélection est suivie de tests sur des descendances obtenues par pollinisation libre. L'auteur discute des avantages et des inconvénients des deux programmes. Une évaluation et des recommandations sont faites, suite à l'expérience acquise durant l'exécution des programmes.

DOUGLAS-FIR PLUS-TREE SELECTION PROGRAM

Introduction

This program was developed by the British Columbia Forest Service under the supervision of Dr. A. Orr-Ewing of the Research Division.

The initial program was developed to alleviate acute seed shortages of high elevation Douglas-fir on Vancouver Island. Apparently, coastal Douglas-fir above 1,500 feet (450 m) elevation produces infrequent seed crops. According to the original plan a seed orchard was to be established using 20 plus-tree clones. Soon, however, this plan was expanded to include a much larger number of plus trees from the whole of the coastal range of Douglas-fir.

The expanded program required cooperation with others as the amount of work involved was beyond the capabilities of the Forest Service. These cooperators included the forest industry, the University of British Columbia and the federal Canadian Forestry Service. Together with the B.C. Forest Service they formed a "Plus Tree Board". They contributed by selecting plus trees and some even established clone banks and seed orchards of their own.

Plus-Tree Selection

All cooperators used the selection methods and standards developed by the B.C. Forest Service. The first step in the selection process was the choice of stands. Preference was given to stands close to rotation age growing on the best sites. Stand selection was based on forest cover maps, aerial photographs, and information obtained from foresters.

Upon finding the right stand, a crew of two or three cruisers covered the whole stand examining, marking, and recording all potential candidates. Age, height, and diameter at breast height were recorded for all candidates and the three nearest dominant trees. At the end of the cruise all candidates were re-evaluated and the best candidates were accepted and registered. All plus trees were visited by the forester in charge of plus-tree registry to ensure a reasonable uniformity of standards. Each registered tree received a registration number and a registration card, and was permanently marked and mapped.

Selection standards for the Douglas-fir program were high. The working plan for the program used the Swedish program as a guide (Plym Forshell 1964) and the following points were listed for the assessment of good phenotypes (Heaman 1967):

1. Rapid height and diameter growth.

2. Resistance to diseases and pests. Should not show repeated mechanical injuries.

3. Narrow crown, no double leaders.

4. Straight stem, minimum taper, good natural pruning.

5. Short light branches, right angles (or nearly so) to the stem. No internodal branches.

6. Thin bark.

7. Good cone production.

Soon it became evident that trees meeting all the above requirements were very rare and the standards had to be relaxed to some extent. Greatest weight was put on height superiority and stem form, followed by the other criteria.

Scion material was collected from each tree and established in clone banks and seed orchards. The Cowichan Lake Forest Experiment Station of the B.C. Forest Service serves as a clone bank for all registered plus trees. Scion material for seed orchards is supplied from this clone bank for the cooperators who require it.

The foregoing is a short summary of the British Columbia Douglas-fir plus-tree selection program. More detailed information was given by Heaman (1967). My main reason for discussing this program here is so that a comparison can be made between this and the following program.

INTERIOR SPRUCE PLUS-TREE SELECTION PROGRAM

Introduction

White and Engelmann spruce are the two most important commercial species in the interior of British Columbia. It is estimated that 40 - 50 million spruce seedlings will have to be planted annually by 1985. Thus, it is quite logical that interior spruces were next in line for improvement.

The spruces in British Columbia cause nightmares for taxonomists. The two particularly important species were originally described as *Picea glauca*, white spruce, and *P. engelmannii*, Engelmann spruce. Generally it was considered that Engelmann spruce grew at high elevations (above 1,300 m) while white spruce occurred at lower elevations. However, Garman (1957) indicated that intermediates between the two species occupied large areas of British Columbia. Taylor (1959) proposed that this closer relationship be recognized by designating white spruce as *Picea glauca* subsp. *glauca*, and Engelmann spruce as *P. glauca* subsp. *engelmannii*. Roche (1969), who was employed by the B.C. Forest Service to study the geographic variation in interior spruces, suggested that the two species "...are the extreme forms of a clinal pattern of variation". The problem is further complicated by hybridization between white spruce and Sitka spruce

(*Picea sitchensis* (Bong.) Carr.) which form hybrid swarms in the western part of British Columbia. These hybrid swarms still need further investigation as their extent is not yet clearly established. Based on personal observation I believe that the problem is even more acute due to naturally occurring black and white spruce hybrids in certain parts of British Columbia.

These difficulties cause problems when discussing selection programs of individual species, and therefore I refer to the program in general terms. We do not classify a plus tree as to species.

Plus-Tree Selection

The plus-tree selection program was developed in 1967 and implementations began in 1968.

In developing the program we had to take many factors into account. It is well known that plus-tree selection would be most effective in stands of about harvesting age. Unfortunately, most of the best spruce stands encountered in interior British Columbia are overmature. Also the stands are quite dense and comparison of trees is difficult. A further restriction was the limited personnel available and the fact that both cone and scion material had to be collected during a short time.

Taking all these factors into consideration, we decided to adopt the tree improvement scheme recommended by Silen (1966) for Douglas-fir with some modifications.

According to our plan, the interior of British Columbia was divided into selection units within which we consider seed transfer acceptable. Within each unit we will select between 100 - 200 trees. The selection criteria are not nearly as strict as those used in the Douglas-fir program. A tree is selected after a visual comparison of the trees in a certain area. The major criteria used are:

1. Height and diameter superiority in comparison to neighbors.

2. If height and diameter differences are negligible, straightness of stem and appearance will be considered.

3. Third priority is given to branching characteristics; fine branches, and horizontal branching habits are desirable traits.

4. If all previous traits are more or less equal, fecundity is the deciding factor. Heavier cone production is more desirable.

5. Trees should be at least one mile apart to prevent possible inbreeding.

In practice, a crew of two (the geneticist and his assistant) drive in on a forest access road in the particular selection unit and note outstanding spruce trees. Returning on the same road these trees are evaluated on the basis of the points listed and those judged acceptable are selected. The selected trees are measured for height and diameter at breast height and described as to branching characteristics, stem characteristics, natural pruning and other traits. Associated species and lesser vegetation are also recorded along with the elevation above sea level. The tree is painted, labelled, and photographed and its position is marked on the map.

Provision is made to collect scions and cones from each of the selected trees. This is done with the aid of a .22 calibre rifle. Scions are grafted onto potted rootstocks in the greenhouse. Most of our grafting is done in the spring. Grafts are usually grown in pots for two years before outplanting in the clone bank.

Cones are collected from late August to mid-September. We aim for a minimum of 150 cones but in light cone years some trees fall short of this number especially if the squirrels get to the tree first. Open pollinated seedlings, grown for three years in the nursery are outplanted in replicated trials at several sites within the selection unit. Initial height measurements at planting will be followed by height measurements at three years in the field. Further measurements will be carried out as required.

Roguing of undesirable families can begin following the first growing season of the open pollinated seedlings in the nursery. Some families exhibit poor germination and the parents of these families can be eliminated on this characteristic alone. In our experience a number of families had less than 10 per cent germination although only filled seeds were sown and all seeds were stratified. These families originated from the western part of the province where Sitka spruce introgression is suspected. Although we have not yet established the reason for poor germination - environmental factors such as insufficient seed ripening due to short growing seasons could also be involved - we would recommend against including these families in the seed orchard just to be on the safe side.

To date we have completed plus tree selection in three selection units (Fig. 1):

1. Prince George Selection Unit extending between longitudes 122° 00' - 123° 00' W and latitudes 52° 45' - 54° 10'N. A total of 177 plus trees was selected in 1968. Cones were collected the same year. Scions were obtained in the spring of 1969.

2. East Kootenay Selection Unit extending between longitudes 114° 30' - 116° 30'W and latitudes 49° 00' - 50° 45' N. A total of 132 plus trees was selected in 1969. Scions were obtained in the fall of 1969 and spring 1970. Cones were collected in the fall of 1971.

3. Smithers Selection Unit extending between longitudes 125° 00' - 127° 30'W and latitudes 53° 30' - 55° 00' N. A total of 134 plus trees was selected in 1970. Cones were collected in the same year. Scions were obtained in the spring of 1971.

There are advantages inherent in the spruce plus-tree selection program as compared to the Douglas-fir program. The cost of selection is much reduced. Each parent tree will eventually be evaluated on the basis of progeny performance but all selected material will be retained in the clone bank serving as a gene pool.

A weak point of the program is the fact that more of the outstanding phenotypes might be missed due to the less intensive cruising technique. Orr-Ewing (1967) demonstrated the strong relationship between parent and offspring in Douglas-fir. However, his study also indicated that phenotypic selection occasionally can be misleading as some trees selected as poorer parents produced better offspring than was expected and vice versa. Nevertheless, it is generally true that superior phenotypes have a higher chance of being superior genotypes. To find trees that might be overlooked we are requesting all foresters and rangers to inform us of any outstanding spruce trees in their region and we inspect all trees reported to us. I regret to say that so far only a few trees have been pointed out to us. Another method of improving coverage is presently being tested by the Reforestation Division of the Forest Service, which involves the use of the helicopter in both selection and scion collection. Hewson (1975) reports that there may be a great future in the technique. Outstanding trees can easily be located from the air and the crew can be landed for closer inspection and marking of the tree. Cones and scions can also be collected from the helicopter.

Our experience with open pollinated progenies, based on nursery measurements, indicates that some seedling families can be 2 - 3 times taller than others at the end of the second growing season. We expect that this vigorous growth will continue in the future. It seems realistic to expect a phenotypic gain of 15 - 20 per cent if only the best 30 per cent of the original families are retained. I consider that a conservative estimate.

In conclusion I feel that the lower intensity plus-tree selection developed for the interior spruces of British Columbia is quite adequate and could easily be adopted for any tree improvement program. Seed orchards could be established as soon as sufficient ramets are available from the plus trees. As soon as information is available from the open pollinated progeny trials, unwanted families can be removed from the orchard. By the time the orchard reaches the productive age many of the undesirable families have been eliminated and a considerable gain can be expected from the seed produced.

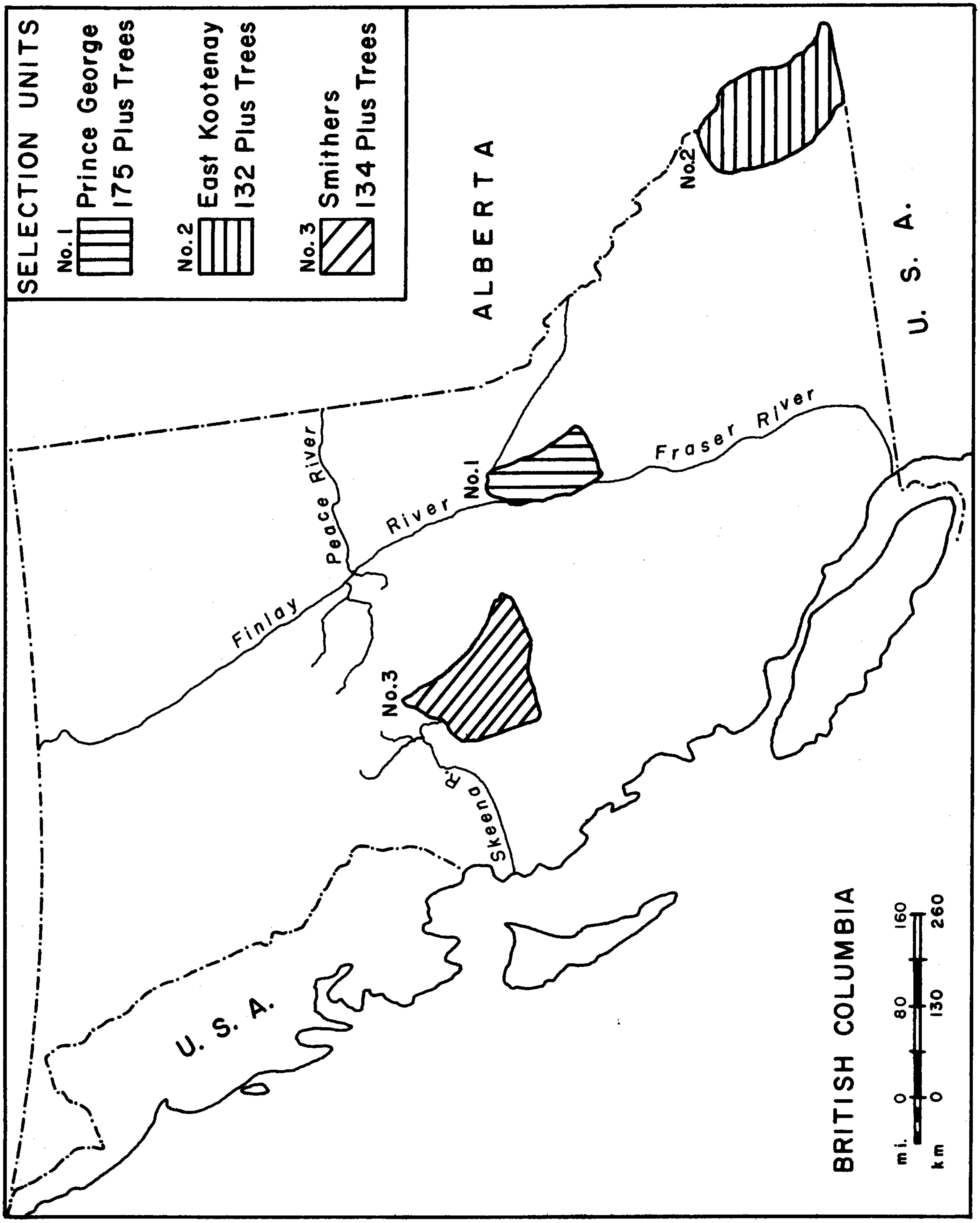

Fig. 1. Interior spruce plus-tree selection units

LITERATURE CITED

Garman, E.H. 1957. The occurrence of spruce in the interior of British Columbia. B.C. Forest Serv. Tech. Pub. T 49. 31 pp.

Heaman, J.C. 1967. A review of the plus tree selection programme for Douglas-fir in coastal British Columbia. B.C. Forest Serv. Res. Note 44. 27 pp.

Hewson, C.A. 1975. Personal communications regarding plus tree selection by the Reforestation Division, B.C. Forest Service.

Orr-Ewing, A.L. 1967. A progeny test of Douglas-fir to demonstrate the importance of selection in forest practice. B.C. Forest Serv. Res. Note 43. 29 pp.

Plym Forshell, W. 1964. Genetics in forest practice in Sweden. Unasylva 18 (2 - 3): 119 - 137.

Roche, L. 1969. A genecological study of the genus *Picea* in British Columbia. New Phytol. 68: 505 - 554.

Silen, R.R. 1966. A simple, progressive tree improvement program for Douglas-fir. U.S. Forest Serv. Res. Note PNW-45. 13 pp.

Taylor, T.M.C. 1959. The taxonomic relationship between *Picea glauca* (Moench) Voss and *P. engelmannii* Parry. Madrono 15: 111 - 115.

PROGENY TESTING IN PRACTICAL TREE IMPROVEMENT

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ABSTRACT

Good quality planting stock and good plantation care during the early years are very important. A well executed progeny test of moderately good design usually gives much more information than a poorly executed experiment of the most refined design.

Half-sib progeny tests are less expensive, and give less gain and information than full-sib progeny tests. The costs, gain and information ratios between the two types vary considerably, depending on several factors. Often, with northern conifers, half-sib tests are preferable for first-generation work and full-sib tests in more advanced breeding programs.

Progeny tests often need to contain a few hundred families. With tests that large it is desirable to compute optimum family size (often smaller than has been used in the past) and to consider carefully the effects of plot size and number of replications on efficiency; otherwise the tests may become unmanageable. A variation of the randomized complete block design is often regarded as the most practicable for large tests.

A few hints are included as to desirable measurement and analysis procedures.

ADDITIONAL KEY WORDS

Plot size, Family size, Experimental design, Plantation care.

RÉSUMÉ

Il est très important d'utiliser des plants de bonne qualité et de bien entretenir les plantations durant les premières années d'un test de descendance. Un test d'un modèle simple mais bien exécuté donne beaucoup plus de renseignements qu'un autre d'un modèle plus raffiné, mais dont l'exécution laisse à désirer.

Les tests de descendance maternelle reviennent moins cher, mais le gain obtenu est inférieur et les informations sont moins nombreuses que dans les tests de descendance biparentale. Les rapports coût, gain et quantité d'informations entre ces deux types de test de descendance varient considérablement et dépendent de plusieurs facteurs. Pour les conifères des régions nordiques, il est préférable d'utiliser le test de descendance maternelle pour les vergers à graines de première génération et le test de descendance biparentale s'il s'agit de programmes d'amélioration plus avancés.

Les tests de descendance doivent souvent contenir quelques centaines de familles. Pour les tests d'une telle grandeur, il est souhaitable de bien estimer le nombre optimal d'individus par famille (souvent plus petit que le nombre utilisé dans le passé) et de bien considérer l'effet que peuvent avoir la dimension des parcelles et le nombre de répétitions sur l'efficacité du test; sinon, les tests deviennent difficilement réalisables. Pour les grands tests, on considère les différentes variantes du dispositif à blocs complets avec distribution des répétitions au hasard comme les types les plus satisfaisants.

L'auteur fait quelques suggestions concernant les méthodes de mesure et d'analyse les plus avantageuses.

INTRODUCTION

A progeny test is a plantation containing the offspring of many different trees. Usually the offspring's identities are maintained by parent so that it is possible to tell the female parent or the male and female parents of every tree in the plantation. Not too many years ago a progeny test was regarded primarily as a scientific research procedure designed to demonstrate the presence of genetic differences within a species or obtain theoretical data on heritability. That time is past, and progeny testing is now regarded as an integral part of nearly every tree breeding project whether applied or theoretical. Thus progeny tests have become common. They have also become large. Many include the offspring of several hundred different trees and occupy many acres. In the most active breeding projects, two or three large progeny tests may be initiated each year.

In this paper I shall cover briefly some of the planting aspects such as type of nursery stock, spacing, care before and after planting, etc. However, those vary considerably by species and are usually covered adequately in manuals on nursery and plantation technique. Hence most of the paper will be concerned with questions of design.

ESTABLISHMENT AND EARLY CARE

The best single measure of the ability of a progeny test to produce useful data on genetic differences is the size of the Least Significant Difference (= LSD) in growth rate among seedlots. The size of the LSD is governed partly by experimental design, but much more by the quality of planting stock and of early care. In experiments established during the past 15 years, the ones with 95+% survival and with good weed control (at least on strips) are the ones in which the LSD is 8 - 15% of the mean; they are also the ones which are growing most rapidly and will give the earliest results. There are many such plantations. There are also other plantations established with non-uniform planting stock, on mediocre or poor sites, or given haphazard post-planting care. In them, growth is not so good and the $LSD_{.05}$ is as high as 50% of the mean; they can generate little useful data.

I cannot stress this point too much. Analysis of repeated sets of measurements of a large number of Michigan plantations indicates that the LSD as a per cent of the mean changes very little with time. First-year mortality can be replaced but the process is difficult and the replacements rarely perform the same as the original trees. Lack of weed control at the start can be corrected later to make the plantation look good but if the plantation is uneven at the start it will remain uneven. It is best to adopt a philosophy of "Do it right the first time--mistakes cannot be corrected in a manner to yield top-notch results."

In Finland, greenhouse culture of tree seedlings has been developed to a very high degree. The Finns are also experts in growing cuttings and seedlings in rolls so that young plants can be field planted with almost no root disturbance. Their culture methods are such as to result in vigorous seedlings in a short time at a reasonable cost. Also, equally important from the progeny test standpoint, their culture methods result in planting stock of great uniformity and in high-precision test plantations. In northeastern United States and southeastern Canada, greenhouse and container-grown seedlings are often larger but more variable than bare root stock grown outdoors in well maintained nursery beds. Thus, in our region, it is often cheaper and more satisfactory to use seedlings or transplants grown outdoors.

Ideally, the site selected for a progeny test should be open, as uniform as possible, and of average or slightly above-average quality for the species concerned. Its shape and size are of lesser consequence. If only small patches of suitable land are available, it is preferable to establish several small plantations on good sites than one large plantation on a less good site. Few off-site plantations have yielded useful information.

Many progeny tests will at some time be converted to seed orchards or breeding arboreta. This should be borne in mind when choosing the initial spacing. In Michigan we have commonly used an 8x8-foot spacing, which has been satisfactory as regards stand development and the quality of data gathered on differences in growth rate, insect resistance, branch size, etc. But now, particularly with red and eastern white pines (*Pinus resinosa* Ait. and *P. strobus* L.), we face a dilemma that the plantations need to be thinned to preserve full crown development and high fruiting capacity several years before heavy flowering starts. We would prefer to delay thinning as long as possible, in order to insure the highest possible correlation between performance at time of thinning and at maturity. However, this could only be done if the initial spacing had been wider. For several of our species 10x10-foot or even 12x12-foot initial spacings would be desirable.

As for alignment, it is very desirable that the trees be planted in straight lines in both directions. Good alignment can be obtained rather easily in any of several ways and pays off many times over when measuring a plantation in future years.

HALF-SIB OR FULL-SIB PROGENY TESTS

A half-sib family consists of all seedlings having one parent -- usually the seed parent -- in common. In a half-sib progeny test the seed is usually open pollinated. A full-sib family consists of all seedlings having both male and female parents in common, and resulting from controlled pollination.

The best half-sib family is one which results from pollination of the genetically best female parent with pollen of a number of male parents, presumably average. The best full-sib family is one which results from the pollination of the genetically best female parent with the genetically best male parent. Therefore, it is theoretically possible to achieve twice as much gain from practicing selection within a full-sib as within a half-sib progeny test.

This theoretical expectation is strictly true only when the open pollination is completely at random and when half-sib and full-sib progeny tests include the same number of parents. Those conditions are almost never met. The mathematics of comparative gains from the two types of progeny tests involve several factors and are too complex to be considered in detail here. Briefly, though, the situation can be summarized by saying that possible gain from a full-sib progeny test is usually 25 to 75% greater than the gain from a half-sib progeny test of similar size. The full 100% increase in gain has been achieved in a few cases where parents chosen on the basis of half-sib data were then crossed artificially with each other in a limited number of combinations.

Costs also vary between the two types of experiments. To produce a full-sib progeny test it is necessary to practice controlled pollination, which involves climbing, bagging and careful records. The costs of doing this are low for many birches and poplars, moderate for many pines and spruces, and extremely high for some trees such as sugar maple, walnuts and oaks. They are lower when pollinating small trees growing in plantations than when pollinating large scattered wild trees Thus, half-sib progeny tests are often preferred for first-generation work and full-sib progeny tests for second-or third-generation work.

SIZE OF PROGENY TESTS

The goals of progeny tests are to determine the amount of genetic variability among individual trees in a population, to determine which parents produce the best offspring and thus provide an opportunity to select the best parents or the best families, and to furnish a sound foundation for second and third-generation breeding work. The first goal can be accomplished with an experiment including the offspring of 25 - 50 different trees. The second and third goals cannot be accomplished without much larger experiments including the offspring of several hundred different parents. Otherwise genetic gain is lowered because there is too little opportunity to practice rigorous selection. Or, if the progeny test is reduced to the best 5 or 10 of 100 families, future tree breeders will not have a broad enough genetic base to obtain further improvement. This planning for future tree generations is important because a great deal of second-generation breeding work is already underway.

I mention this aspect of size because it affects nearly all aspects of design. Consider, for example, a test which includes the offspring of 300 different female trees, with 100 trees per family and with the seedlings planted on a 10x10 foot spacing. That test will occupy about 70 acres and at best will present certain difficulties in planting, measurement, thinning, etc. Thus, simplicity of design becomes an important feature.

There are two partial solutions to the problem of this size. One is to divide one very large progeny test into two or three smaller experiments which are more manageable. This is common practice. The second is to eliminate half or two-thirds of the families on the basis of nursery data prior to field planting. There is now a considerable body of data about the size of the correlation between juvenile and mature performance and in general such data indicate that selection based upon measurements made at age 2 or 3 can be effective. As long as the correlation is positive, even though not high, this procedure is preferable to starting with a smaller amount of material.

OPTIMUM FAMILY SIZE

The concept of optimum family size, as developed by Robertson (quoted in Falconer 1960) is important to consider at this point. In a half-sib progeny test, 25% and 75% of the total genetic variance is due to differences among and within families respectively. The greatest gain results when one practices combined selection, keeping the best individual trees in the best families. Planting a few trees of each of very many families maximizes gain from between-family selection; this procedure gives good information about the total amount of genetic variation but weak information about the genetic quality of any single family. Planting many trees of each of a few families maximizes gain from within-family selection; it gives weak information about the total amount of genetic variation but strong information about the genetic quality of single families.

However, the goal is maximum total gain from both types of selection combined and this goal can be achieved best by intermediate family size, using the formula developed by Robertson. His formula, as applicable to a half-sib progeny test is:

$$\text{Optimum half-sib} = .56 \sqrt{T/Nh^2}$$

where T, N and h^2 are the total number of trees in progeny test, number of families to be retained as parents of the next generation (choice determined by inbreeding considerations), and the single-tree heritability of the trait being improved, respectively.

Using this formula, optimum family size for a half-sib progeny test to be thinned to 10 families is as shown in the following tabulation.

Total number (= T) of trees to be planted in progeny test	Optimum family size if $h^2 = .1$	Optimum family size if $h^2 = .5$
	Trees per family	
5,000 trees	40	18
20,000 trees	80	36

For a full-sib progeny test, where differences among individual trees within families account for only 50% of the total genetic variance and there is less opportunity for gain from within-family selection, optimum number of trees per family is smaller than for a half-sib progeny test. Also, if more families were to be retained as parents of the next generation, optimum number of trees per family would be smaller.

It should be noted that these optimum family sizes are not for a single plantation but for an entire progeny test. Assume that $h^2 = .1$ and a progeny test of 20,000 trees total size is to be planted in four different areas for insurance purposes. With an optimum family size of 80 trees per family, there should be only 20 trees per family at each location.

The numbers given above are much smaller than the family sizes used in most past experiments. Evidently a general increase in number of families tested and a general decrease in the number of trees per family would be beneficial.

CHOICE OF EXPERIMENTAL DESIGN

Progeny tests should be replicated. That is, each family should be planted at different places within a plantation and in different plantations. Otherwise it is impossible to tell whether the superior growth of a particular family is due to its genotype or the site on which it is planted.

The "randomized complete block" design is simplest from the standpoint of installation and analysis. Therefore it is the most commonly used. In this design each family is represented by a single plot within each block and the families are randomly located within the blocks. In the case of unequal numbers of trees per family, every family can be planted in block 1, every family having enough trees for two plots in block 2, every family having enough trees for three plots in block 3, etc. When establishing such a randomized complete block plantation it is best to pack the n-tree plot bundles (n being the number of trees per plot) in such a way that the plots included in any block can be planted in any sequence and mapped later. That saves much time and results in better survival and growth than planting the trees in prescribed locations.

Statisticians have devised other, more sophisticated designs which give greater statistical precision than the randomized complete block design. These more sophisticated designs are commonly used in experiments with crop plants, but are much less successful with trees. They are relatively inflexible, requiring definite numbers of families and blocks per plantation; they are totally unsuited to experiments with unequal numbers of trees per family, as is commonly the case. They require a high degree of statistical competency to install and analyze. That is no problem in a crop plant experiment analyzed the same year it is sown by the same person who sowed it; it can be a serious problem in a tree experiment analyzed 20 years later by someone who had nothing to do with its design. Trees are planted as seedlings which are bulky and much more difficult to arrange in a prescribed order than the seeds used in crop plant experiments.

Thus, I believe that the randomized complete block design, modified if necessary to accomodate situations in which there are unequal numbers of trees per family, will continue as the most widely used design. Actually there are statistical procedures (relatively straightforward but too complex to describe here) by which it can be made to yield data equal to that of the most sophisticated lattice or incomplete block design. Also, there are relatively simple statistical procedures by which to analyze the data when necessary to omit certain families from certain blocks.

PLOT SIZE AND SHAPE

Statistical precision is greater for small-plot, much replicated progeny tests than for experiments containing a few large plots per family. Calculations based on empirical data gathered in Michigan and North Carolina indicate that the amount of information gained per tree planted is 15 - 20% less for 4-tree than for 1-tree plots, and 80 - 90% less for 100-tree than for 1-tree plots. If the calculations are based on information gathered per dollar spent, optimum plot size turns out to vary from three to six trees per plot. Shape does not matter particularly in plots of this size. Also, small-plot experiments are most amenable to the type of thinning which results in the greatest genetic improvement of a progeny test to be used as a seed orchard or breeding arboretum. In such a thinning, all trees of the poorest families and the poorest trees of the best families are removed. After a thinning of this type the remaining trees are much more evenly distributed with small than with large plots.

It is true that in a small-plot experiment, each tree is growing in competition with trees of different families and that there may be an accentuation of growth-rate differences if fast- and slow-growing families happen to be planted adjacent to each other. This is not serious until crown closure, and becomes less serious as a plantation is thinned to remove the poorest families. This problem is not lessened to any extent, although statistical efficiency is reduced considerably, by the use of intermediate-sized plots containing 8 to 36 trees. The problem can be avoided only by the use of large plots containing at least 7 x 7 = 49 trees (and preferably 11 x 11 = 121 trees). With plot sizes that large, statistical efficiency becomes extremely low.

NUMBERS OF REPLICATIONS PER PLANTATION AND OF PLANTATIONS PER PROGENY TEST

For many situations, optimum family size varies from 18 to 80 trees per family, and optimum plot size varies from 3 to 6 trees per plot. Dividing one by the other, one finds that there should be between 6 and 25 replications per progeny test. Should these be planted in 1, 2 or 3 different plantations?

At this point I would like to mention the concept of plantation-genotype interaction, or the fact that family A may grow better than family B at site 1, but worse than B at site 2. Some interaction always occurs. Hence, if everything is included in a single large plantation, estimates of average family performance may be in error by 5 - 10%. Also, with one large plantation there is no insurance against loss.

If there are two moderately large plantations, one can measure the size and statistical significance of the plantation-genotype interaction but cannot interpret it in such a manner as to forecast on which sites to plant family A, family B, etc. To do that it is necessary to plant every family on several different sites. Only in that way is it possible to learn the exact site factor responsible for the superior growth of particular families. Without learning that, one can only recommend on the basis of average site performance.

Actually the best procedure from the statistical standpoint is to make a separate plantation of every replication. That procedure provides maximum insurance against loss, the best estimates of average performance over a variety of site conditions, and the maximum possibility of interpreting any interactions which may be present in such a way that they can be made the basis of practical planting recommendations.

However, the logistics of establishing and managing numerous small plantations are formidable. Hence a good compromise solution is to establish three to five moderate sized plantations, each containing a few replications. Data on average performance are nearly as good as with numerous small plantations. There is little opportunity to interpret many interactions, but that has proved to be an extremely difficult task and may often be neglected.

These remarks apply to progeny tests covering a single region such as northern Wisconsin-northern Michigan or Michigan's Lower Peninsula. Numerous data showed pronounced and interpretable interactions between those regions. Hence, a progeny test to cover all of Michigan should include 3 - 5 plantations in each of the two parts of the state.

There are also non-statistical aspects to consider. One is the fact that many progeny tests will ultimately be converted to seed orchards. In such cases, total size of the progeny test may be governed more by the need for large numbers of seed producing trees than by the need for data on inheritance. That may be reflected in increased size of individual plantations. Also, information on pest resistance is important in the improvement of several species. In both Austrian and Scotch pines (*Pinus nigra* Arn. and *P. sylvestris* L.) good data have been obtained from a few large plantations which experienced very heavy natural infestations of a damaging disease or insect. Such data would not have been forthcoming from plantations replicated only 2 or 3 times.

MEASUREMENT AND ANALYSIS

This is not the place to go into details of how or what to measure but a few general points are worth mentioning. First, data on mortality during the first two years are a good general measure of the success of a plantation, but are rarely indicative of genetic differences in ability to survive in a particular region. This, early mortality should be recorded to indicate mistakes that need correction and to help in keeping oriented in the future, but should not be considered in the same light as data on growth rate, etc.

Second, measurements should be made in such a way as to reflect genetic differences, not in a way which might be proper for inventory purposes. Consider the matter of tree form. Most northern trees grow straight unless subjected to some type of damage. Susceptibility to particular types of damage may be inherited and much more worthwhile measuring than mere presence or absence of crook.

Third, several traits such as growth rate, pest resistance and cold resistance are of obvious economic importance and therefore worth measuring. A great many other traits are of little economic value in themselves but are possibly related to those which are important. Considerable effort has gone into measuring the non-economic as well as the economic traits, in the hopes of establishing strong genetic correlations which might provide clues for the improvement of growth rate, etc. Little success has attended such efforts, so for practical work concentration on the economic traits is indicated.

Two refinements in data analysis could often be used to advantage. It is common practice to compute means, perform an analysis of variance on the data from each plantation, and include rather detailed tables showing the means of each seedlot in each plantation. A single combined analysis of the data from several plantations and a simple table showing the average over all plantations would often give a greater amount of information which might be interpreted more easily. The second refinement is to carry the analysis of variance a step farther and to show the portions of the total genetic variance due to parent-within-stand, stand of origin, region of origin, etc. Excellent examples of this type of analysis are contained in the recent paper by Ying (1974).

LITERATURE CITED

Falconer, D.S. 1960. Introduction to quantitative genetics. The Ronald Press, New York. 365 pp.

Ying, C.C. 1974. Genetic variation of eastern cottonwood. Univ. of Nebraska, Dept. of Forestry, Progress Rpt. 1. 148 pp.

THE ECONOMICS OF TREE IMPROVEMENT

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ABSTRACT

The report discusses the sources of costs and benefits of tree improvement in the context of plantation economics, and considers the ways a forester can control the profitability of establishing and managing forests. The response of Canadian tree species to selection and breeding, the ways tree improvement can help the forester, the costs and benefits of different tree improvement strategies, and quantification of costs and benefits are described. The sources of cost in tree improvement research, development and the plantation operation are compared. Future research needs are suggested.

RÉSUMÉ

Le rapport discute des sources des coûts et des bénéfices de l'amélioration des arbres dans le contexte de l'économique des plantations et considère les moyens par lesquels un forestier peut vérifier les avantages de l'établissement et de l'aménagement des forêts. La réponse des espèces d'arbres indigènes du Canada à la sélection et au croisement, les différents moyens par lesquels l'amélioration des arbres peut aider le forestier, les coûts et les bénéfices des différentes stratégies utlisées en amélioration des arbres ainsi que la quantification de ces coûts et bénéfices sont décrits. Les sources des coûts dans la recherche sur l'amélioration des arbres, le développement, les étapes de la production de plants et de la plantation elle-même sont comparés. Des besoins futurs en recherche sont suggérés.

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INTRODUCTION

The purpose of this paper is to consider the sources of costs and benefits in tree improvement, and what influence the forester has in controlling the profitability in establishing and managing forests.

Tree improvement programs aim at providing the forester with good seed for his planting and seeding programs. By "good" is meant seed that will germinate well and has the inherent ability to provide trees that grow rapidly, provide a good timber product, survive rigors of climate, soil and competition, withstand attacks by insects and diseases, and respond well to silvicultural treatments.

Tree improvement is only of value to the forester in the context of planting and seeding programs. If you look at the history of forestry in America and Europe it is obvious that, at least in the developed countries of the temperate zone, the greatest interest in tree improvement has been in countries that rely mainly on plantations of introduced species. Countries relying mainly on natural forests have been less enthusiastic about tree improvement research.

In Canada, we are still mainly in the natural woodland phase of forestry, although man-made forests are on the increase. Many forest managers, and even silviculturists, were sceptical of the value of tree improvement research until about six years ago when results of long term genetics trials began to be published. Some silviculturists are still sceptical in spite of the evidence of Canadian, American and European research, and seem reluctant to look to the future. They say "Why invest in tree improvement when yield can be increased even more by good cultural practices?" This report answers this question by presenting some of the facts. It is no longer necessary to support tree improvement programs just as a matter of faith. This support is a matter of monetary common sense and investment security, which even the most hard-nosed forest manager can appreciate.

HOW WELL DO TREES RESPOND TO SELECTION AND BREEDING IN CANADA?

The more variable a tree species and the more extensive its range, the more it is likely to respond to selection and breeding. In Canada we have some wide ranging species that are very variable, as well as species with more restricted distributions. For example, white spruce (*Picea glauca* (Moench) Voss) is a variable indigenous conifer of wide range, and provenances can be selected which will give good crop security and a 20% (or more) improvement in height growth compared with the local populations (Teich 1973). In contrast red pine (*Pinus resinosa* Ait.) is much less variable with a more restricted range, and the possible improvement by provenance selection is less than 10% (Holst 1971). As yet we have very few volume figures, but percent volume growth improvement will be more than the percent height growth improvements above. Preliminary calculations for white spruce improvement indicate volume increases of up to 80%, just by selecting better trees within provenances (Teich and Khalil 1973). We can expect at least 10% improvement in height growth by selecting in such Canadian species as jack pine (*Pinus banksiana* Lamb.) and black spruce (*Picea mariana* (Mill.) B.S.P.) without serious loss in hardiness. Unfortunately we know little about the response of Canadian hardwoods to selection and breeding. Research in this field will begin in the near future.

HOW CAN TREE IMPROVEMENT PROGRAMS HELP THE FOREST INDUSTRY

Trees can be selected for many attributes of economic importance such as growth rate, hardiness to harsh environments, resistance to pests and diseases, stem and crown form and timber quality. All of these characteristics are genetically controlled to some extent, although some, such as growth rate and tree form, are also much affected by the environment. The highest selection priority is, or should be, hardiness, as it is not much use planting a fast growing genotype if it succumbs to the first cold winter or late spring frost. Resistance to pests and diseases is also important though difficult to select and breed for if the pathogen adapts to the selected tree genotype. Growth rate and tree form are of great importance to the forester who is concerned with getting a marketable product as soon as possible after he has made the initial investment in establishing the trees. Timber quality is genetically controlled to some extent, and can have far reaching effects on mill profits. Davis (1969) pointed out that quality of the raw wood influences both the yield of product per unit volume of wood processed, and the time taken to process a given quantity of wood. He calculated that if yield of product per unit of wood processed were to be increased by 5% and processing time reduced by 5%, daily mill profits would be increased from 15% to 41%.

Tree improvement programs can, therefore, give the forest industry better growth, better crop security and a better product.

THE DIFFERENT TREE IMPROVEMENT STRATEGIES

All tree improvement programs take a long time, need a great deal of manpower, and cost a lot of money. The quickest results are obtained with fast growing species, such as poplars, which can be vegetatively propagated easily, and tree species which flower early.

The strategy adopted at Petawawa has been to concentrate initially on provenance trials to provide information on variation within and among provenances, locate the best provenances for immediate use by the foresters in particular regions, and follow this up with selection and breeding within the best provenances. Physiological research has aimed at finding ways of reducing the time scale of research by raising seedlings rapidly and screening young trees for high growth performance and hardiness. Some organizations have opted to begin straight away with large plus-tree selection programs, and this may well suit their particular situation.

Gains from provenance research have the great advantage that after only 15 to 20 years research you can get approximate guidelines as to which are the best provenances to use in particular areas. In many cases the natural stands from which the test material was taken still exist and can be used instantly as seed collection areas. In the case of within-provenance selection the time scale of selection, breeding, progeny testing and seed production in orchards is much longer (a single breeding cycle can take 30 years). We have no good examples of such gains in Canada as most of our progeny tests are still young, but Nikles (1969) gives examples of gains in yield realized for southern pines through progressively more intense breeding methods. He quotes modest gains of 10.7 to 13.0% in volume growth for simple phenotypic (plus-tree) selection and wind pollination, with selection intensity unspecified. In contrast, intense selection by saving 19% of the families in a progeny-test selection of the best full-sib families gave 32.5% gains in volume. It is of interest to note that in the many examples given by Nikles for southern pines, height growth gains were relatively modest (3.6 to 20.0%). In Canada we can probably do better with variable species such as white spruce, at least in terms of percent gain although our trees cannot compete with the fast growing southern pines for volume production per annum.

QUANTIFICATION OF COSTS AND BENEFITS

The only benefits from tree improvement programs that are relatively easy to quantify in dollar terms are better growth and better timber quality. Other benefits, such as increased crop security, better tree form, better product uniformity, better response to silvicultural practices, and continuance of the benefit into future tree generations, are all very important but difficult to express as dollar values.

The most intensive studies on costs and benefits of tree improvement have been carried out in connection with the southern pine programs in the U.S.A. (e.g. Davis 1967, 1969; Swofford 1968; van Buijtenen and Saitta 1972). These reports mostly deal with a breeding situation, and consider seed orchard costs in relation to gains in yield and timber quality. The general picture that emerges is that a yield increase of as little as 2% to 4% would more than cover the cost of improved seed. Notable recent work of van Buijtenen (1972, 1975) deals with costs and benefits of timber volume and quality increases, and brings techniques of linear programming to bear on this problem.

In eastern Canada, the situation is different. Firstly, most of the emphasis has been on provenance research rather than plus-tree selection; secondly, the indigenous tree species of economic importance are relatively slow growing; thirdly, few seed orchards are based on plus-tree selections; and fourthly, little is known about the costs of orchard operation and research.

Cost/benefit research in eastern Canada has concentrated on estimating what increase in growth can be expected from the results of provenance research, what this gain is worth in dollars, and how this dollar benefit compares with approximate costs. The main research has been done on white spruce. This applies to a specific situation quite different from that of the southern pine program. The evaluation of growth gains led to a study of the economics of white spruce plantations in general (Carlisle and Teich 1971).

In brief, a computer model was developed to evaluate the dollar value of different percent increases of white spruce plantation yield at rotation age, taking into account establishment and management costs, stumpage, interest and inflation at different tree spacings and site class indices. It is known that spruce height growth can be increased by 15% or more by provenance selection, and that volume gains will be much more. A minimal 15% increase in yield will generate about \$4.74 to \$11.91 per acre depending on site class, while the additional cost of producing improved seed in seed production areas to plant one acre (0.4 ha) at 8 x 8 feet (2.4 x 2.4 m) is only 43 cents. The income from increased yield, therefore, is more than 10 times the operational cost involved. It was also calculated that if the cost of a white spruce tree improvement research program is \$1.5 million including interest and this program leads to a 15% increase in yield this benefit is worth \$832,000 per annum in a 100,000 acre (40,500 ha) per annum planting program. The research is paid by two years improved yield in such a large scale program (Carlisle and Teich 1971). The important thing is that the researcher sees that his results reach the forester and are used. Otherwise the research is a total loss as far as practical forestry is concerned.

Kleinschmit (1974) used a similar model and concluded that it was less economic to breed Norway spruce (*Picea abies* Karst.) in seed orchards with the sole aim of improving yield, than collecting seed in stands of designated provenances, and propagation of selected genotypes by cuttings. However, he felt that comparing these improvement methods was unrealistic, as several techniques would be used as parts of a balanced tree improvement program.

It is apparent that in most instances the dollar value of the increases in yield that one can expect from most tree improvement programs are far greater than the extra cost of producing the improved seed. Although we know little about the relationship of total cost of research and seed production in relation to accrued benefits, there are indications that in the long term such research pays handsomely.

THE SOURCES OF COST

A great deal of information on costs of tree improvement research, seed orchard operation, and plantation establishment and management has been recorded in Canada but very little has been published. Much information has been published in the U.S.A., but these data do not apply to Canada. The rest of this paper describes the cost sources and their relative importance.

The Time Factor

Some enterprising fellow -- we forgot his name -- once calculated that if Julius Caesar had invested 10 cents at 8% compound interest, his heirs today would be multimillionaires. This illustrates the importance of time; over a tree rotation a small initial cost can become an alarming sum. For example, if the cost of establishing trees on one acre (0.4 ha) were $66, and the interest rate were 10% compounded over the rotation, at the age of 50 years this initial cost would balloon to $7,000, and at 60 years to $18,200. Also a management cost of $2.20 per acre (0.4 ha) per annum at the same interest rate and inflated at 6% per annum ballooned to $5,443 at 50 years and $14,932 by 60 years. These figures point out the need to reducing rotations where possible since time is the main enemy of the forester wanting to justify his activities in conventional economic terms. The data also show that even small reductions in initial costs can greatly affect the final balance sheet.

The time factor also plays a key role in research and development costs. Most tree improvement research programs take at least 20 years, even if provenance research results are immediately applied to set up seed production areas in the designated natural stands. If one is involved in plus-tree selection, progeny testing, seed orchard establishment and management, then the breeding cycles may exceed 40 years.

It is necessary, therefore, to take advantage of any short cuts that give even modest gains and an acceptable risk of error. A long term breeding program may give much larger gains in growth compared with a shorter term provenance selection program, but the time scale of the former may offset the greater gain and render it uneconomic if conventional economic computations are used. We need to know much more about costs and benefits of tree improvement programs, including research, development and operational costs (not just seed orchard costs) using techniques, such as the linear programming, to find the optimum tree improvement strategy and optimize allocation of limited resources. In Canada, the achievement of this goal is greatly hampered by a lack of plantation yield data. The expected yields are unknown and ready-made points of comparison are therefore not possible.

Research Costs

Many reports on tree improvement economics skim over, or even ignore research costs, concentrating on costs and benefits from the seed orchard phase onwards to harvesting. Frequently a great deal of expense has been incurred in research before the orchard phase is reached, and these research costs should be included in the balance sheet. One difficulty, however, is that in tree improvement the research, development and operational phases are often closely linked, or even coincide, and are difficult to cost separately. Very little information on research costs has been made available. At Petawawa we are fortunate that our research costs are distinct from those of forest operations.

Mr. Paul Viidik (1973) has kept detailed records of labor costs for tree improvement trials over a period of 50 years (1924-73). These records are in terms of man-hours, and this is preferable in many ways to dollar costs, as man-hours *per se* are not affected by inflation and wage rate changes. In tree improvement research the main cost is in manpower.

Viidik's records describe the man-hours used in clearing, site preparation, planting, care and thinning for each plantation area and experiment. Even a swift glance at his tables shows that the most time consuming part of the trials is land clearance, which averages about 325 man-hours per acre (805 man-hours per ha). At present day labour rates (about $6 per hour) this costs about $1,950 per acre ($4,816 per ha). The next highest cost is planting, at about 25 to 33 man-hours per acre (62 to 82 man-hours per ha). Site preparation costs about 9 to 12 man-hours per acre (22 to 30 man-hours per ha) and subsequent care in the few years following planting about the same. The total labor incurred by these trials is about 375 to 425 man-hours per acre (928 to 1052 man-hours per ha), or, in terms of present day wages (at $6 per hour), $2,250 to $2,550 per acre ($5,569 to $6,311 per ha). If there are no clearance costs this figure is reduced by about 325 man-hours per acre (804 man-hours per ha) or $1,950 per acre ($4,826 per ha).

Not all trials involve land clearance and the overall labor use in all the tree improvement trials and arboreta for the 50 year period was 73,120 man-hours for 356.6 acres (883 man-hours per ha) of trials including 307 experiments, i.e. on average about 205 man-hours per acre (507 man-hours per ha), or 238 man-hours per experiment (Table 1). No attempt has been made to convert these to dollars as wages varied such a great deal over the half century.

The establishment costs in tree improvement trials are far higher than those incurred by provincial forest services in operational planting (about $100 to $120 per acre including site preparation; $247 to $296 per ha) with their access to newly harvested forest land and heavy machinery for land clearance and site preparation. Experimental tree planting costs are necessarily higher than operational planting costs due to the need to sort plants and take great care in plot lay-out. Planting complex, replicated trials is a slow, difficult business.

These figures indicate the desirability of large operational forestry organizations, such as provincial governments and industry, with access to low cost, cleared land and heavy machinery, being closely involved in field trials and the development phases of tree improvement. Research organizations without these assets can only carry out field trials on a small scale due to their higher costs. The ideal situation is one of close cooperation, and this has been achieved at Petawawa with many cooperators, with mutual benefit. It is, however, desirable that the researchers have some local trials, for reasons of security and continuity.

Table 1. Total man-hours used in tree improvement plantations and arboreta at Petawawa 1924-73.

	No. of experiments	Area (Acres)[1]	Cost in Man-hours	Period
Plantations at P.F.E.S.[2]	177	244.24	61,506	1924-73
Plantations on A.E.C.L.[3] land	24	31.78	1,286	1960-64
Plantations established by P.F.E.S. staff off Station	18	18.92	950	1963-71
Arboreta plots	88	61.67	9,378	1946-64
Total	307	356.61	73,120	

[1] (1 acre = .405 ha)

[2] Petawawa Forest Experiment Station, Chalk River, Ontario

[3] Atomic Energy of Canada Ltd., Chalk River, Ontario

In addition to the labor cost of tree improvement research there is the cost of researchers' and their technicians' wages. A researcher may be responsible for many trials and many peripheral activities, so that it is difficult to assign a cost to any individual trial. As an example the cost of a researcher and technician plus 100% overhead in the Petawawa white spruce improvement program (consisting of many trials) is about $60,000 per annum, excluding labor costs in field trials. The picture gets confused when it is remembered that the scientist in charge of this program spends part of his time on supervision of the computer installation on the Station and has other responsibilities, while the technician helps the field crews from time to time. The real cost of the research is probably about $50,000 per annum. When this is spread over the many trials, it is not very great, but compounding it over a 15-year program makes it add up to a considerable sum. However, in this program, it has been calculated that even this big investment can pay (Carlisle and Teich 1971) if the results are used.

At this point, we should perhaps pause and reflect on the true value of research. However carefully we plan, not all research will have a direct effect on forest production with a tangible dollar benefit. Some of the information published just adds to the sum of human knowledge and this, provided it is kept in the right proportion, is perfectly proper. It is a real benefit - some purists would even say the main benefit - but is difficult to quantify. In these research cost/benefit accountings, the research cost can be accounted with some accuracy while the benefits tend to be underestimated. If, using underestimated benefits, a tree improvement program can be shown to pay, then we are really in business.

PLANTATION MANAGEMENT COSTS AND BENEFITS

The forest manager concerned with the establishment and maintenance of plantations is continually faced with the spectre of the rising costs of collecting seed, raising trees, preparing sites, and planting; he also has to justify his operations in economic terms. All these costs occur at the beginning of the plantation cycle, and interest builds up annually. Yearly management costs may be individually small ($1 to $2 per acre per annum; $2.47 to $4.74 per hectare) but they inflate, carry interest and add up to a sizeable sum. At the same time the value of the timber is increasing with inflation. The dilemma of the forester is to find where he can cut his costs more effectively, and decide when is the best time to cut his timber.

The cost and benefit computer model of Carlisle and Teich (1971) was used to examine this problem and the results are given in Fig. 1. The baseline values of the 1971 model were used. The mean long-term (100 years) interest rate of 6% and inflation of 2% may seem far too low in the present economic situation. They will, however, suffice as an example. Recently several more combinations of interest and inflation levels have been tried and they all show the same relative result, i.e. that the establishment costs with compound interest increase at a far greater rate than the management cost, so that any reductions in the establishment cost and the rotation are far more effective than reducing management costs, provided the latter are kept at reasonable levels.

Fig. 1 illustrates the progression of plantation costs and timber value over time, for a specific example. Some of the principles illustrated have general application.

Initially the total cost is the establishment cost. With the passage of time the total cost increases due to (1) an interest charge on the establishment cost, and (2) the accumulation of management costs with their interest and inflation. Timber value remains zero until the first merchantable timber is available, in this case about 20 years from establishment.

Let us examine the input and output in this model to see which elements increase profit, which elements decrease profit and the possible impact of a forester's control.

In this example, which demonstrates a profit, the site class was good, i.e. 70. It is self evident that by planting the best sites growth and profit will be increased. Since only a small proportion of the forests harvested are replanted site selection is possible. Selecting the best sites for replanting is a powerful means to increase plantation profitability.

Most of the cost sources can be controlled by the forester to some extent. For example, the spacing at which trees are planted affects both planting costs and growth rate. It can also affect subsequent management costs if trees are too close and require early thinning. Except in the case of white spruce and red pine (Stiell and Berry 1973, 1973) we do not know a great deal about the effects of different tree spacing on yield in plantations. If the forester had these data he could compare costs and yield and prescribe an optimal system.

Establishment costs can be greatly reduced by controlling costs of site clearance, preparation and planting, and these are areas deserving the forester's attention. The new heavy machinery for site preparation, and developments in machine planting are both promising. The use of direct seeding, for example with jack pine, greatly reduces establishment costs, from about $100 per acre (247 per ha) to $30 per acre ($74 per ha).

Establishment costs are high enough without having the added cost of replacing failures, and it is here that tree improvement plays an important role. If the forest manager can use trees with inherent hardiness and high growth rates, he can reduce his losses from competition and low temperatures and avoid unnecessary replacement costs. Tree improvement and silviculture should be partners in an overall attempt to reduce establishment costs and increase yield.

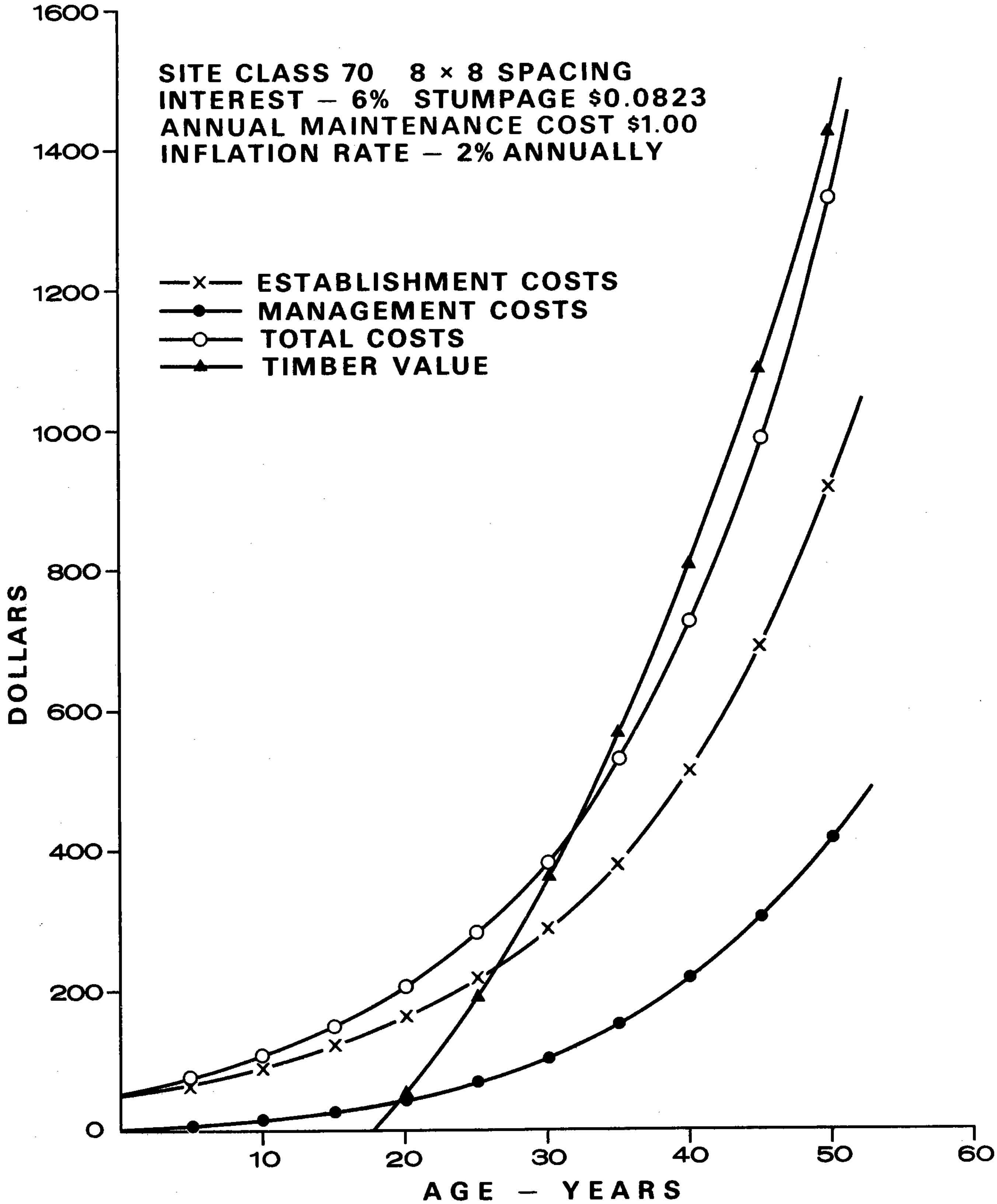

Fig. 1. The relative accumulated timber value, establishment cost, management cost and total cost, allowing for interest and inflation, of a white spruce plantation on a high quality (site class 70) site, with spacing of 8 ft. x 8 ft. (2.4 x 2.4 m).

Stumpage greatly affects the economic yield from plantations and is controllable by man in the context of supply and demand and other factors that affect commodity prices. The forester does not always have the degree of control over stumpage that he would like. The current stumpage of about 10¢ per cu. ft. (\$3.52 per m^3) appears to be just adequate for the forester to make a profit on the best sites in the plantation context.

The forester has no control over interest rate and inflation as these are affected by the overall national and international economic picture. Interest is a major component of cost; a small change in interest rate can dramatically affect cost over a 50-year rotation. A high inflation rate, however, tends to increase plantation profitability. It does not affect establishment cost over the rotation, affects management costs a certain amount (but these are generally low compared with establishment costs), and greatly increases timber value.

This general picture of sources of plantation costs pinpoints what the practical forester already knows instinctively, that reducing establishment costs should be the prime target.

FUTURE NEEDS

Tree improvement needs and priorities depend upon point of view, but for the time being we shall regard them from the aspect of impact on the nation's forest economy.

1. <u>Examination of the relative importance of tree species in the nation's planting and seeding programs; and the likelihood of these species to respond to selection and breeding</u>.

Something is known about which species are used in the areas planted and seeded annually in Canada, and this should influence research priorities. Planting and seeding programs should reflect the nation's future needs for timber. It is vital to breed those species likely to respond, by virtue of their variability. There is sometimes a tendency for researchers to concentrate on species which respond well to selection and breeding, but will only fill very small niches in the forest economy. This is acceptable for urban and amenity forestry, but tree improvement in the context of commercial forestry will only pay if the species has both good response and wide use.

2. <u>Investigation of the optimum allocation of the research dollar</u>.

There are many ways of improving trees; each produces a different gain and takes a different amount of time. Examples are provenance selection; within-provenance selection with progeny tests, plus-tree selection, and stand selection. We need to know what is the optimum research strategy for Canadian species in the Canadian economic context.

3. Refinement of tree improvement logistics.

Tree improvement techniques need to be examined so that the most efficient methods are used and the time scale of research and development reduced as far as possible. For example:

a. How much sampling is needed to represent the natural genetic variability of a species?

b. How many test sites are needed to represent site variability within the planting and seeding range?

c. How long need we test tree material to expose it to natural climatic variability? What are the probabilities of a stand succumbing to exceptional, severe climatic events throughout the rotation?

d. How much weight should be given to the prime goals of yield, hardiness, resistance and timber quality in tree improvement?

e. How can we predict adult tree performance from early test results, and thereby reduce the time scale of research?

f. How can we reduce the breeding cycle by inducing flowering in species such as white spruce, and reduce the time of the breeding cycle?

g. How can we widen the use of vegetative propagation and reduce risks of failure? The problem of stock/scion compatibility is an important one. We cannot afford to lose selected material at the seed orchard stage.

These are only a few of the problems that need to be solved if tree improvement is to be efficient. Many of them are concerned with overcoming the effects of time.

CONCLUSION

There is a great scarcity of published information on tree improvement research and development costs in Canada, and it is difficult to assess more than minimal benefits from tree improvement; many trials are still young and there are very few reliable plantation yield tables. Even so, the evidence is clear that, provided a tree species is sufficiently variable to respond to selection and the species is widely used in seeding and planting programs, tree improvement research and development costs are greatly exceeded by even minimal benefits.

There is also clear evidence that the main cost of tree improvement field trials is the site clearance, and this emphasizes the need for large organizations concerned with forest operations to participate in the field trials. These organizations have access to cleared land and heavy machinery that can prepare the site at relatively low cost. Research costs are high and programs should concentrate on the improvement of trees widely used in operational planting. This may seem self evident, but research has not always followed the guideline of operational need. The shortage of research dollars means taking a closer look at priorities.

Finally, the forester has considerable control over plantation profitability. He may not be able to control interest rates, inflation rate and stumpage but he can control tree growth rate and security. A forester concerned with making his plantations pay in the tree establishment to harvest context needs to use the best seed available to give him fast growing hardy trees that will reduce risk of costly failures, plant his trees on the best site, reduce his establishment costs to the minimum and keep his rotations short. Establishment cost, crop security and time are the key controllable components in the plantation economy. Management costs, provided they are kept within reasonable bounds, play a much smaller role than establishment costs in the economic picture, even though these management costs are affected by inflation. In Canada we need to take a much closer look at this interplay of economic factors and see how we can make best use of both operational and research dollars. In the future we need to take a much closer look at tree improvement research strategies and priorities, and try to reduce the time scale of research and development activities. Quite apart from economics, the forester wants good seed now, not 60 years hence.

LITERATURE CITED

Carlisle, A. and A.H. Teich. 1971. The costs and benefits of tree improvement programs. Can. Forest. Serv. Pub. 1302. 34 pp.

Davis, L.S. 1967. Investments in loblolly pine clonal seed orchards; production costs and economic potential. J. For. 65: 882 - 887.

Davis, L.S. 1969. Economic models for program evaluation. Doc. Second World Consult. Forest Tree Breed. 2: 1523 - 1543.

Holst, M.J. 1971. The genetic basis of improvement of red pine, Petawawa 1968 - 70. Pages 107 - 108 in Twelfth Meet. Comm. For. Tree Breed. Can. Part 2.

Kleinschmit, J. 1974. Considerations regarding breeding programs with Norway spruce (*Picea abies* Karst.). Pages 41 - 58 in Proc. IUFRO Joint Meetg. Working parties Population and Ecological Genetics, Breeding Theory and Progeny Testing. Publ. by Roy. Coll. Forestry, Stockholm.

Nikles, D.G. 1969. Breeding for high yielding characters - growth and yield. Second World Cons. For. Tree Breed. Washington, D.C. Section II, No. 2/1. 24 pp.

Stiell, W.M. and A.B. Berry. 1973. Yield of unthinned red pine plantations at the Petawawa Forest Experiment Station. Can. For. Serv. Pub. 1320. 16 pp.

Stiell, W.M. and A.B. Berry. 1973. Development of unthinned white spruce plantations to age 50 at Petawawa Forest Experiment Station. Can. For. Serv. Pub. 1317. 18 pp.

Swofford, T.F. 1968. Profit and quality gain through tree improvement. S. Lumberm. 217(2704): 170 - 172.

Teich, A.H. 1973. White spruce provenances in Canada. Can. For. Serv. Inf. Rep. PS-X-40. 27 pp.

Teich, A.H. and M.A.K. Khalil. 1973. Predicting potential volume growth by progeny testing white spruce plus trees. Bi-Monthly Res. Notes 29: 27 - 28.

Teich, A.H., D.A. Skeates and E.K. Morgenstern. 1975. Performance of white spruce provenances in Ontario. Special Joint Report No. 1. Environment Canada and Ontario Ministry of Natural Resources. 31 pp.

van Buijtenen, J.P. and W.W. Saitta. 1972. Linear programming applied to economic analysis of forest tree improvement. Forest Genetics Laboratory, Texas Forest Service. 4 pp. + 6 tables.

van Buijtenen, J.P., et al. 1975. How will tree improvement and intensive forestry affect pulp manufacture. Pers. comm. 16 pp.

Viidik, P. 1973. Complete inventory of Petawawa Forest Experiment Station experimental plantations with cost analysis. 1924 - 1973. (unpublished report).

TREE SEED PROGRAM IN ONTARIO

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ABSTRACT

The regeneration program in the province of Ontario requires large quantities of tree seed annually. It is estimated that 1 billion viable seeds will be required to meet the 1975 needs of the program. Forest tree improvement has been developed to effectively improve the availability of tree seed and to improve seed quality on a scale sufficiently massive to meet the requirements of the reforestation program.

RÉSUMÉ

Le programme de régénération de l'Ontario requiert annuellement d'importantes quantités de semences forestières. On estime qu'un milliard de graines viables seront nécessaires pour satisfaire les besoins du programme de 1975. L'amélioration des arbres forestiers y a donc été développée de façon à accroître efficacement la disponibilité de la semence forestière, tout en augmentant sa qualité sur une échelle suffisamment grande pour rencontrer les exigences du programme de reboisement.

The present regeneration program in the province of Ontario requires large quantities of tree seed annually.

In 1974 we used 272 million viable seeds for the production of planting stock and 554 million viable seeds for direct seeding, or a total of 826 million viable seeds.

This volume consists of seed of 85 species of trees and shrubs. However, five species comprise the bulk of the seed used, as follows:

Jack Pine	547,000,000
Black Spruce	117,000,000
White Spruce	70,000,000
Red Pine	35,000,000
White Pine	20,000,000
Other Species (80)	37,000,000
Total	826,000,000

It is estimated that 1 billion viable seeds will be required to meet the needs of the regeneration program this year, 1975. This amount of seed requires the annual collection of 15,000 hectolitres (hl) (41,250 bushels) of cones and rough seed.

Our forest tree improvement then, has been developed to effectively improve the availability of tree seed and to improve seed quality on a scale sufficiently massive to meet the requirements of the reforestation program. Because we are concerned with production, it was necessary to consider the relative importance of the species in the program and taking into account both the short-term and long-term aspects of tree improvement.

As a result, we are using three basic techniques in our tree improvement which will be described below.

SEED COLLECTION AREAS

These are large pure uniform stands of average or above average quality of good seed producing age. The areas are not managed or treated specifically for seed production. At present this technique is being applied to jack pine stands of 100 acres (40 ha) or larger, and can also be applied to black spruce stands. Each year a sufficient area of the stand is cut to supply the required amount of seed. A portion of the seed or planting stock produced is used to regenerate the cut area to keep the gene pool pure.

At present we have 3,000 acres (1,200 ha) of seed collection area reserved for the supply of seed. Cone collection is from slash after cutting. The average cost is $32.50/hl for jack pine.

SEED PRODUCTION AREAS

These areas are reserved in above average stands (natural or plantations) and are managed for the express purpose of seed production. The seed production area is rogued, based on the desired phenotypic characteristics for the species, to an optimum density for seed production.

The condition and age of the stand at the time of selection is most important in developing a seed production area. Stands that have reached the polewood stage and are dense enough that individual trees have lost 50% of their crowns are most difficult to develop into a suitable area. Especially for white spruce, suitable seed production areas should be selected before the stand closes to retain full crowns. This usually occurs between 10 and 15 years of age for this species. As natural stands of white spruce in a suitable age class are difficult to find in Ontario, we have had greatest success in using better than average plantations. Logically, plantations are the optimum place to select for the traits that will be important in plantation grown trees - form, apical dominance, insect and disease resistance, planting survival, seed production, climatic and site adaptation.

The seed production area technique is used for white pine, red pine, white spruce and black spruce as well as several hardwood and shrub species. To date we have 600 acres (240 ha) established.

Collection methods vary, but the most efficient method to date is by using ladders to climb the trees. Each picker is given a ladder and usually paid on a contract or piece-work basis at a per hl rate. Rates per hl of cones are: white spruce - $35.00; black spruce - $40.00; white pine - $20.00; red pine - $30.00.

Other techniques such as truck platforms at picking height have been used effectively when trucks are available. Other equipment such as hydraulic ladders, "Up-Ups", cherry pickers, and cone towers have been used on a limited scale. Much of this equipment is limited in the number of pickers each piece can efficiently place into the tree; and as the quantity of cones picked is directly proportional to the number of pickers working, efficiency is low, cost high.

In 1974 we collected 365 hl of cones from seed production areas. This year we have plans and targets for more than 1,500 hl from established seed production areas. Seed production areas will supply the bulk of the improved seed for several years to come until our seed orchards are producing sufficiently large volumes to have an effect.

SEED ORCHARDS

The clonal seed orchard is the third technique in use particularly for white pine, white spruce and black spruce. At present we have 200 acres (80 ha) established. This long-term aspect of tree improvement will, we expect, give us the greatest genetic gains in our program.

For several years now, 10% of the tree seed used in the production of planting stock in Ontario is improved seed from seed production areas and seed orchards. This percentage will increase each year as our seed production areas and orchards come into production.

The collection of sufficient tree seed is a basic requirement in the maintenance of a program of artificial regeneration on productive forest land. The present and expected program can only be carried out within the limits of availability of seed.

The establishment and development of seed production areas and seed orchards must play an increasing role in maintaining and improving the quality and quantity of tree seed available for collection and processing to meet the needs of the regeneration program.

SEED ORCHARDS

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ABSTRACT

The objective of a seed orchard is to mass produce improved seed of the desired quality as economically as possible, and usually also as quickly as possible. The major steps involved are: (1) mass selection of desirable trees; (2) establishing the seed orchard; (3) progeny testing the orchard; (4) roguing the orchard on the basis of the results of the progeny tests.

Seed orchard establishment includes the following major steps: site selection, site preparation, seed orchard design and graft establishment. Site fertility, drainage and location are all important considerations. Site preparation should be done thoroughly but usually presents no serious problems. Spacing should be such that the orchard will not require roguing before information from progeny tests is available, but close enough to give reasonable cone production at an early age. The design should consider such factors as providing a sufficient number of clones to form an adequate genetic base, optimizing cross pollination among clones, providing an adequate supply of improved pollen for the orchard, minimizing the proportion of contaminating pollen, and limiting the amount of inbreeding in the orchard.

Three systems of handling grafts are in common use: pot grafting, bed grafting, and field grafting. Each of them is an acceptable method but has its own advantage and disadvantages.

Seed orchard management practices are designed directly or indirectly to keep seed orchard trees healthy and to produce the maximum amount of seed. Increased flower production is secured by a combination of subsoiling, irrigation and fertilization. The seed orchard is protected and kept in a healthy condition by mulching, fire protection, protection from diseases and insects, and proper care of the orchard during harvesting.

RÉSUMÉ

Le but du verger à graines est de produire en grande quantité la semence génétiquement améliorée et de qualité désirée aussi économiquement que possible et habituellement aussi rapidement que possible. Les principales étapes impliquées sont (1) la sélection individuelle d'arbres désirables, (2) l'établissement du verger à graines, (3) l'évaluation de la qualité génétique des vergers à graines au moyen de tests de descendances, (4) l'éclaircie des vergers à graines à la lumière des résultats obtenus des tests de descendances.

L'établissement des vergers à graines inclut les étapes principales suivantes: le choix du site, la préparation du site, le dispositif du verger à graines et l'établissement des greffes. La fertilité du site, le drainage et l'emplacement du verger sont des considérations importantes. La préparation du site doit être soigneusement effectuée mais elle ne présente habituellement pas de difficultés. L'espacement doit être tel que le verger n'exigera pas d'éclaircie avant que l'information en provenance des tests de descendances ne soit disponible, mais suffisamment serrée pour permettre une production raisonnable de cônes à bas âge. Le dispositif devrait prendre en considération des facteurs tels qu'un nombre suffisant de clones, de façon à former une base génétique adéquate, l'optimisation de l'interfécondation entre les clones, la production en quantité suffisante de pollen amélioré pour tout le verger, la minimisation de la contamination par le pollen étranger et la limitation des croisements consanguins dans le verger.

Trois méthodes de greffages sont communément utilisées: le greffage en pot, le greffage dans la plate-bande et le greffage en champ. Chacune de ces méthodes est acceptable mais à ses propres avantages et désavantages.

Les pratiques d'aménagement du verger à graines sont directement ou indirectement destinées à garder les arbres du verger en bonne santé et aptes à produire le maximum de semences. Un accroissement de la production d'inflorescence est assuré par une combinaison du labourage en profondeur, de l'irrigation et de la fertilisation. Le verger à graines est protégé et gardé sain par le paillage, la protection contre le feu, la protection contre les insectes et les maladies et par des soins attentifs au moment de la cueillette des cônes.

THE SEED ORCHARD APPROACH TO TREE IMPROVEMENT

The seed orchard approach to tree improvement involves the following steps: (1) Mass selection of desirable trees in natural stands and plantations. (2) Setting up seed orchards - using these selected trees as parents or as a source of grafts -, for the mass production of improved seed. (3) Progeny testing the seed orchards. (4) Roguing the seed orchards on the basis of the results of the progeny tests. Roguing is the removal of genetically undesirable trees from the orchard.

The seed orchard approach is suitable when the following conditions are met: (1) the nature of the species makes selection the most promising approach; (2) a large amount of seed is needed to fill projected planting needs; and (3) the need for seed is urgent.

In many cases, selection is the most promising approach to tree improvement. Hybridization may be useful in some cases but would have to be preceded by selection anyway. Mass selection in existing forest tree stands is therefore obviously the first step in any tree improvement program.

When the need for seed is urgent, the next step is immediate establishment of seed orchards. Otherwise selections can be put into scion banks or holding areas.

The genetic value of the selections, however, is still unproven, since the selected trees owe their desirable qualities in part to what they inherited from their parents and in part to the environment in which they grew up. It is therefore necessary to follow up the establishment of the orchard by testing the progeny of the selected trees. Until roguing, a number of trees will be carried in the seed orchard which will turn out to be undesirable from a genetic point of view. This is the price to be paid for having seed available 15 to 20 years sooner than would be the case if the progeny testing were done before the orchard was established, as is the common procedure in agricultural and horticultural breeding.

Because of time limitations this discussion will be restricted to grafted orchards. Seedling seed orchards are sometimes appropriate but are much more difficult to handle.

SEED ORCHARD ESTABLISHMENT

Seed orchard establishment includes the following major steps: site selection, site preparation, design of the orchard, and establishment of the grafts.

Site Selection

The first and most critical step is the selection of the seed orchard site. It will have to support the orchard for as much as 40 years and can make or break the program. Following are some comments on what constitutes a good site for a seed orchard. This is mostly based on experience with the southern pines, but will probably be true for a good many other species as well.

(1) The site should be intermediate in fertility for the species concerned. Very poor and extremely good sites have caused difficulties. If anything, a low fertility level is preferable since it can be readily corrected by fertilization.

(2) It is extremely important to have good drainage in the orchard for several reasons:

(a) survival of grafts or understock for field grafting is better;

(b) the area should be accessible for heavy equipment at all times.

(3) The orchard should be located in an area where it is least subjected to natural hazards of various kinds, such as frost and snow and ice damage.

Site Preparation

The next important step is site preparation. Since the expected life of an orchard is about 40 years or more, it is worthwhile to do a thorough job of site preparation, including stump removal and levelling if the site has a stand of trees on it. If a permanent irrigation system is to be installed, this also would be the best time to accomplish this.

Spacing

There are several common spacings in use which will depend on the species involved. One of the most common for southern pines is an initial 30 x 30 feet (9.5 x 9.5 m) spacing. If the spacing is too close the orchard will require roguing before information from progeny tests is available. On the other hand a close initial spacing will result in somewhat greater cone production at an early age. A uniform and fairly wide spacing is highly desirable. Irregular spacing and poor design can cause problems in management for the entire life of the orchard.

Design

The main objectives in designing a seed orchard are:

(1) Provide a sufficient number of clones to:

(a) reduce the risk of failure due to graft - scion incompatability or lack of cone production in some clones.

(b) Provide for an opportunity to rogue.

(c) Provide an adequate amount of material for future breeding.

(2) Optimize cross pollination among clones. This can be accomplished by making sure that each tree in the orchard is surrounded by at least two rings of unrelated individuals.

(3) Provide an adequate supply of improved pollen throughout the orchard. In first generation orchards this cannot be influenced by the design. In more advanced orchards special pollinator clones can be distributed through the orchard.

(4) Minimize the proportion of contaminating pollen. For this reason the orchard is usually surrounded by an isolation strip 400 - 500 ft. (120 - 150 m) in width.

(5) Minimize the amount of inbreeding in the orchard. In first generation orchards one can help the problem by not planting relatives or members of the same clone in close proximity. In more advanced orchards one can favor clones which are highly self-sterile or whose selfed progeny is as good as the crosses.

Establishment of Grafts

For some species it is practical to use rooted cuttings. Most forest trees however are difficult to propagate this way and to date the greatest amount of experience has been accumulated with grafted seed orchards. For this reason the following discussion is limited to this method of establishment.

Three systems of handling grafts are in common use: pot grafting, bed grafting, and field grafting. Pot grafting is fast and convenient, but will often result in pot binding. This however can be overcome by proper treatment as the understock is transplanted. Grafting in nursery beds avoids the problem of pot binding but necessitates transplanting the grafts. Grafts can be transplanted either bare root or with a ball of soil. In general this latter method is preferred. Field grafting involves planting several seedlings at each desired location and grafting on some of the best ones the following season. It is the most successful of the three methods, but often results in several successful grafts in one location and none at another. A certain amount of transplanting is therefore necessary in conjunction with this method.

SEED ORCHARD MANAGEMENT

Most seed orchard practices are designed directly or indirectly to keep seed orchard trees healthy and to produce the maximum amount of seed. Management principles aimed at protection and the stimulation of seed production have been developed and applied with varying degrees of success.

Increased Flower Production

A combination of subsoiling, irrigation, and fertilization has been reported to substantially increase seed production in some orchards.

Disking. Although it has been shown that disking can promote flowering in orchards, especially the production of male flowers, a stable ground cover is usually desirable to prevent erosion and disking is a suitable treatment only under special conditions.

Subsoiling. Subsoiling is used to stimulate growth and seed production in orchard trees. It also prevents growth of roots close to surface which are subject to injury and would provide infection points for disease.

Irrigation. Irrigation may be very important during the establishment phase of a seed orchard. In the South, it has also been found to enhance flowering when used in combination with fertilization. The timing of irrigation can be critical since some studies indicate that a dry period during the summer enhances the formation of flower initials.

Fertilization. It is difficult to generalize about fertilization because soil and climatic conditions influence the response of trees to fertilizer. In addition clones differ in their ability to respond to fertilizer with increased seed production. A desired fertility level should be predetermined for the species concerned and a balanced commercial fertilizer applied, on the basis of soil tests, in amounts sufficient to attain the desired fertility level. Timing of fertilization is also important. A late summer or fall application is most effective in southern pines.

Girdling. Attempts to initiate distress flowering through girdling a part of the tree trunk have been made on trees of various size in both seed orchards and seed production areas. It has not been satisfactory as a practical method to stimulate cone production.

Pruning. Stimulation of flower production by various levels of pruning compared to unpruned controls has been tried experimentally in pines. Again, no increase in flowering was noted.

Protection of the Seed Orchard

Mulching. Immediately after transplanting a graft or seedling rootstock to an orchard the application of a layer of mulch can help increase survival. Mulch provides a layer of insulation which affects soil temperature at ground level and helps retain soil moisture while reducing competing vegetation.

Fire. Because of the expense of establishing and maintaining a seed orchard, considerable effort should be made to remove any possibility of damage by fire. The wide spacing of trees in seed orchards and applications of fertilizer often provides a tall dense cover of grasses and weeds. When this fuel dries in the fall it provides a fire danger which cannot be ignored.

Mowing to keep the ground cover short and facilitate decay of mowed grass is one of the best precautions against fire an orchard manager can take to preserve his orchard.

Firelanes maintained outside the orchard boundaries can prevent fires from creeping into the orchard. They also serve as a reminder that fire is a hazard in the orchard.

Exterior fences or some means of controlling access to the orchard site reduce the number of people who enter the orchard and consequently reduce the problems they can create. Many organizations have employees living adjacent to seed orchards to discourage vandalism.

Disease. Diseased grafts should be discarded prior to planting or removed as soon as possible after disease is detected in the planted grafts.

On larger orchard trees pruning to remove low limbs is a desirable orchard practice to facilitate equipment movement. Pruning-wounds need to be promptly covered with wound dressing such as asphalt base paint or they may provide an entrance point for insects and fungi.

Exposed roots or stumps may provide infection courts for *Fomes annosus* or other root diseases. Field grafting usually involves planting two to four seedlings per location, then removing the less healthy of these or those on which grafting is unsuccessful, thus providing a possible infection court for *Fomes* sp. Roguing older orchards may also provide stumps susceptible to *Fomes* sp. infection. To prevent *Fomes* sp. infection, stump treatment with borax immediately after cutting is a good practice. Some orchard managers rogue by pushing out the entire tree, stump included, with a bulldozer and then filling the stump hole.

Erosion. Orchards located on slopes may require terracing to prevent erosion. Even on relatively gently slopes erosion can be a problem until a suitable ground cover is established.

Insects. In many orchards insect control is the number one problem. The problem is made even more serious by the growing concern about using pesticides which may contribute to environmental pollution, leaving fewer insecticides available for the control of cone and seed insects.

Cases have been documented in the South where 75% or more of the cones have been lost. Because of the high value of the seed - estimates run from $100 to $1,000 per pound - an adequate control program is extremely important even for moderate losses.

Maximum control does not necessarily follow adoption of a control system reported effective in another geographic region on a different tree species or even on the same tree species. Even control methods reported effective in the same general area may not work in a given orchard. The possibility for developing biological insect control in the future holds some promise. Such controls are highly desirable but at present are not sufficiently developed for orchard use. Another possibility is the increasing of orchard size to compensate for seed losses. This may be admission of defeat but could be the only viable solution in some cases.

<u>Harvesting</u>

Because of the overlapping of cone crops and the difficulties in hand picking cones this is a critical period in the life of successive cone crops. If the end of a limb containing a group of cones is broken off at the point of mature cone attachment, the following year's crop is also destroyed as are the primordia for the next year's crop. This happens all too frequently by accident or carelessness. Occasionally untrained or thoughtless workers will break the twig to more easily remove cones.

If you look closely at a recently picked orchard you may find some or many of the branch tips broken off. A short training session immediately prior to cone collecting can pay big dividends in reducing damage to trees due to picking and thus increase cone crops in subsequent years.

FOREST TREE SEED QUALITY

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ABSTRACT

With the increase in reforestation in Canada, seed is becoming a valuable commodity because of increasing demand. Seed production is governed by many factors but this paper only discusses seed quality as affected by the post-harvest handling of cones and processing, testing, storing and shipping of seeds. To improve seed quality and the economic use of collected seeds, a close control is required from time of cone collection through cone handling, and processing, testing and storage to shipping of the seeds for field sowing. Until all these factors are adequately controlled, the success of reforestation programs is unpredictable.

RÉSUMÉ

L'augmentation du reboisement au Canada accroît la demande en graines et en fait une denrée de valeur. La production des graines est fonction de plusieurs facteurs. Il ne sera question ici que de la qualité des graines telle qu'affecteé par la manipulation des cônes après la cueillette, l'extraction, la vérification, l'entreposage et l'expédition des graines. Afin d'améliorer la qualité des graines et leur usage économique, un contrôle rigoureux est requis depuis la cueillette des cônes jusqu'à l'extraction, la vérification, l'entreposage et l'expédition des graines pour l'ensemencement. Tant que tous ces facteurs ne seront pas contrôlés adéquatement, le succès des programmes de reboisement est imprévisible.

INTRODUCTION

Seed production is governed by many factors: availability and accessibility of suitable stands, frequency of good cone crop years, control of insect infestation, timing of cone collection, and handling of cones and processing of seeds. One important aspect of seed production is seed quality control. This paper discusses only the effects of post-harvest operations on seed quality including the handling of cones before seed extraction, and processing, testing, storing and shipping of seeds.

With the steady increase in reforestation in Canada, seed is in great demand and is becoming a valuable commodity. Its collection, processing, storage and distribution require careful planning together with technical skill and capacity. To insure a sustained production of planting stock and supply of seeds for direct seeding in the field, we have to increase not only the quantity of seed but also its quality by accurate timing of cone collection and by careful handling of cones, processing of seed, and safe storage. Until all these operations are adequately controlled, the success of reforestation programs is unpredictable.

HANDLING OF CONES

When freshly collected cones of conifers and most hardwoods are received care must be taken: (1) to place the cones in thin layers on screened cone trays in a cool, well-ventilated environment to avoid heating from respiration of green material or molding from fungi, and (2) to maintain the identity of seedlots from different sources by careful marking and labelling. Seeds enclosed in fleshy fruits also require careful storage to avoid harmful fermentation when they cannot be processed soon after harvesting (Stein et al 1974). Unless cones are collected fully ripe, they still have a high moisture content and should be air-dried for a period before extraction.

Although mature cones of most species can be processed immediately or shortly after collection, some species such as eastern white pine (*Pinus strobus* L.) require a period of air-drying sufficient to set their resinous coating (Ritz 1941) while others such as noble fir (*Abies procera* Rehd.) require a period of post-harvest ripening of seeds in cones for best seed quality (Rediske and Nicholson 1965). According to these authors, the ripening process of noble fir seed is correlated to a calendar date, and is affected by a period of movement and accumulation of organic materials from fresh cones to seeds and a period of post-harvest ripening.

When it is necessary to extend a seed collection season, immature cones from some areas will be picked before seeds reach their full maturity. This is especially true with white spruce (*Picea glauca* (Moench) Voss) for which the maximum allowable period of cone collection is only two to three weeks. In some years a high percentage of cones from some species in far northern latitudes or high elevations may not reach full maturity (e.g. Scots pine, *Pinus sylvestris* L. and Norway spruce, *Picea abies* (L.) Karst.) (Ehrenberg et al. 1955, Andersson 1965). Pfister (1966) found that the grand fir (*Abies grandis* (Dougl.) Lindl.) seed-collection season can be effectively lengthened by 2 to 4 weeks by artificial ripening treatments. Others have successfully ripened slightly immature seeds of slash pine (*Pinus elliottii* Engelm. var. *elliottii*) in the cones after removal from the tree, of sugar pine (*Pinus lambertiana* Dougl.) in cold moist storage, and of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in sacks at cool and well-ventilated conditions or layered in moist peat moss (Rediske 1961, Silen 1958, Krugman and Jenkinson 1974). However, prolonged storage of mature cones of some species (e.g. Douglas-fir) will result in poor seed quality (Rediske 1961).

It is evident from these examples that the treatment of cones after collection affects both the quantity and quality of seed produced. Thus it is necessary to understand not only the relationship between the degree of seed maturity and time of collection but also the requirements for post-harvest ripening of individual species or species groups.

SEED PROCESSING

Seed processing involves extracting seeds from cones, and dewinging, cleaning and conditioning of seeds. Although cones and seeds of different species require different procedures due to their physical and physiological characteristics, effects of processing will vary with the degree of seed maturity at collection, with the period of air-drying, or with other post-harvest treatments which the cones and seeds have received before processing (Allen 1957a).

Seed Extraction

Most hardwood seeds require only a short period of air-drying (Fig. 1). Some coniferous cones require only air-drying or low temperature kiln-drying for seed release while others must be opened by high temperature kiln-drying for maximum seed yield. On the other hand, hardwood seeds enclosed in fleshy fruits are usually processed immediately after harvesting by macerating or abrading the flesh, separating the seeds with water, drying and cleaning (Stein et al. 1974).

Excessive drying temperatures and high relative humidities are known to cause seed injury (Allen 1957a, Eliason and Heit 1940). According to Ritz (1941), an efficient cone-drying kiln should provide three essential conditions: (1) heat for moisture evaporation, (2) air circulation for heat conduction, and (3) control of temperature and relative humidity for the prevention of seed injury. However, extraction injury to seeds can be avoided by selecting drying temperature, relative humidity and duration within the predetermined safe limits for different species or by reducing the cone moisture gradually within the first two to three hours of the total cone-drying period at 5 to 10°C lower than the maximum drying temperature (Ritz 1941, Rudolf 1961). Information on safe limits of exposure to temperature and relative humidity, and on standard kiln schedules for various species has been given by Eliason and Heit (1940), Ritz (1940), Wakeley (1954), Carmichael (1958), Rudolf (1961), Wang (1973b), and U.S.D.A. (1974).

Since immature, diseased or insect infested cones are difficult to open and yield seeds of low quality, they should be rejected in the course of cone harvesting.

Dewinging

Seed damage from dewinging is commonly caused by crushing, cracking or abrasion by mechanical dewingers (Eliason and Heit 1940, Huss 1956, Allen 1957a, and Heit 1961). Seeds with thin coats (e.g. *Abies* spp.) are especially susceptible. Mechanical dewinging injury to seeds can be greatly reduced by careful adjustment of the rotating speed, clearance between brushes or knobs, by maintaining a continuous flow of seeds, and by removing sharp and hard debris (Morandini 1961). At Petawawa as well as at the Angus Seed Extraction Plant of the Ontario Ministry of Natural Resources, moist dewinging with a cement mixer has been practised for many years with excellent results. Mechanical damage to seeds is completely avoided by this technique in which winged seeds are moistened with water and left to soak for 20 - 30 minutes before they are stirred with a soft brush, and dried at moderate temperatures before cleaning.

Cleaning

Cleaning is an essential operation in seed processing to remove detached wings, broken twigs, scales, empty seeds and other foreign matter from clean, filled seeds. The quality of seeds in terms of pure, filled seeds if greatly affected by the efficiency of cleaning. High-quality seeds are especially required for container seedling production and for mechanical seed operations. Today many types of modern equipment for effective seed cleaning are available on the market, e.g. air aspirators, screen cleaners, gravity separators and combine cleaners (Morandini 1961, Lowman 1975).

Conditioning

Following cleaning, seed needs to be conditioned only when its moisture content is higher than is suitable for safe storage. Many studies have demonstrated that a moisture content of less than 8% (fresh-weight basis) is the best for both short- or long-term storage of all coniferous and small seeded hardwood seeds (Wang 1974).

Conditioning is especially necessary when seeds have been dewinged by moist technique. The moisture content of most genera is determined by oven methods in which seeds are dried at 105°C for 16 hours; in six other genera, i.e. true fir (*Abies*), cedar (*Cedrus*), beech (*Fagus*), spruce (*Picea*), pine (*Pinus*), and hemlock (*Tsuga*), it should be determined by toluene distillation (International Seed Testing Association 1966). However, an electric or electronic moisture meter which provides instant reading will facilitate moisture content determination of seed of many species, thus eliminating the need for time-consuming oven and distillation methods.

SEED TESTING

The primary objective of seed testing is to provide a reliable estimate of germinability for nursery sowing or direct seeding. The term germinability is not used as a synonym of viability because not all viable seeds are germinable. The test information is needed for the economic use of the valuable seed, especially that of superior sources, by calculating sowing rates either for optimum nursery bed density, or for direct seeding in the field. Seed testing can also assess the efficiency of seed processing with respect to seed injury which will not only affect germinability but also storability of seeds. As Bonner (1974) pointed out, seed testing is essential on two occasions: first immediately after processing and subsequently before seeding if the seed has been held in storage.

Testing of seeds usually includes purity analysis, and determination of moisture content, 1000-seed weight and germinability. Germinability can be tested either by standard methods or by a quick test such as tetrazolium staining or excised embryo germination depending upon the species. In Canada, most tree seeds required for reforestation are collected, processed, tested and stored by provincial forest services and forest industries, and each organization has its own standards and procedures for testing seeds according to its particular needs (Wang and Sziklai 1969). However, seed moving in international trade must be tested by accredited official seed laboratories according to international rules (International Seed Testing Association 1966). The Forest Tree Seed Centre at Petawawa was designated the accredited laboratory for testing tree seed in Canada as of March, 1974.

The function of accredited official seed testing laboratories is to test seeds according to prescribed rules and procedures and interpretations with respect to sampling, test methods and conditions, germination criteria, and reporting of results. There are two sets of official seed testing rules recognized by the international trade - international rules for seed testing (International Seed Testing Association 1966) and rules for testing seeds (Association of Official Seed Analysts 1970). The former are recognized by many countries in the world while the latter are only recognized in North America. Such official rules are not static; revisions are being made to improve prescriptions based on up-to-date research results. However, the official testing rules only emphasize the species moving in international trade. For information on testing of species that are not included in the official rules, one should consult the recently published and revised edition of "Seeds of woody plants in the United States" (U.S.D.A. 1974).

Standard methods for seed testing assure consistency and applicability of results, but weaknesses still exist. One of these, for example, is that germination criteria are based on viability rather than germinability (or germination vigor). Our research results with both red pine (*Pinus resinosa* Ait.) and white spruce showed consistently that only seeds that germinate with high vigor (i.e. with well developed hypocotyl and root, and with seedcoat completely or partly shed) are significantly correlated with greenhouse or nursery germination and survival (Wang 1973a). As pointed out by Rudolf (1961), nursery and field germination of tree seed usually amounts to 50 to 80 percent of laboratory germination. This is probably a reflection of the weakness in laboratory germination tests based on viability of seed.

SEED STORAGE

Storage of tree seed is necessary because of periodic cone crop production. For this reason, seed of some species with irregular intervals between crop years (e.g. Douglas-fir, red pine, white spruce) needs to be stored for 10 years or more. Regardless of how long the seed is stored, the aim is to provide the best conditions for maintaining high germinability.

The storability of seeds is affected by many factors from flowering through development, harvesting, and handling to processing of cones and seeds. Unless all these factors are properly controlled, storability will decrease as seeds go through each stage of the process (Wang and Zasada 1975). The most critical factors affecting seed in storage are initial seed quality, moisture content, storage temperature and storage method (Wang 1974). Due to the difference in degree of tolerance to drying, temperature, aeration and moisture requirements, the effect of each factor on seed storability will vary with species. The majority of coniferous and small seeded hardwood seed can be stored effectively for 8 to 30 years with low moisture content (below 8%) in sealed containers at above freezing temperatures (1 to 5°C), whereas seeds of poplars (*Populus*), true firs and some maple (*Acer*) species retain their germinability much longer at subfreezing temperatures (-10 to -18°C) (Wang 1974). Safe storage of large hardwood seeds, however, requires a high seed moisture content (25 to 79% of fresh weight), slightly aerated containers, a mixing medium (sand or peat moss), and a storage temperature of -1° to 1°C. For detailed information on seed characteristics, storage requirements and factors affecting seed storage of North American tree species, one should consult Baldwin (1942), Allen (1957b), Holmes and Buszewicz (1958), Barton (1961), Jones (1962), Heit (1967a 1967b), Bonner (1971), U.S.D.A. (1974), and Wang (1974).

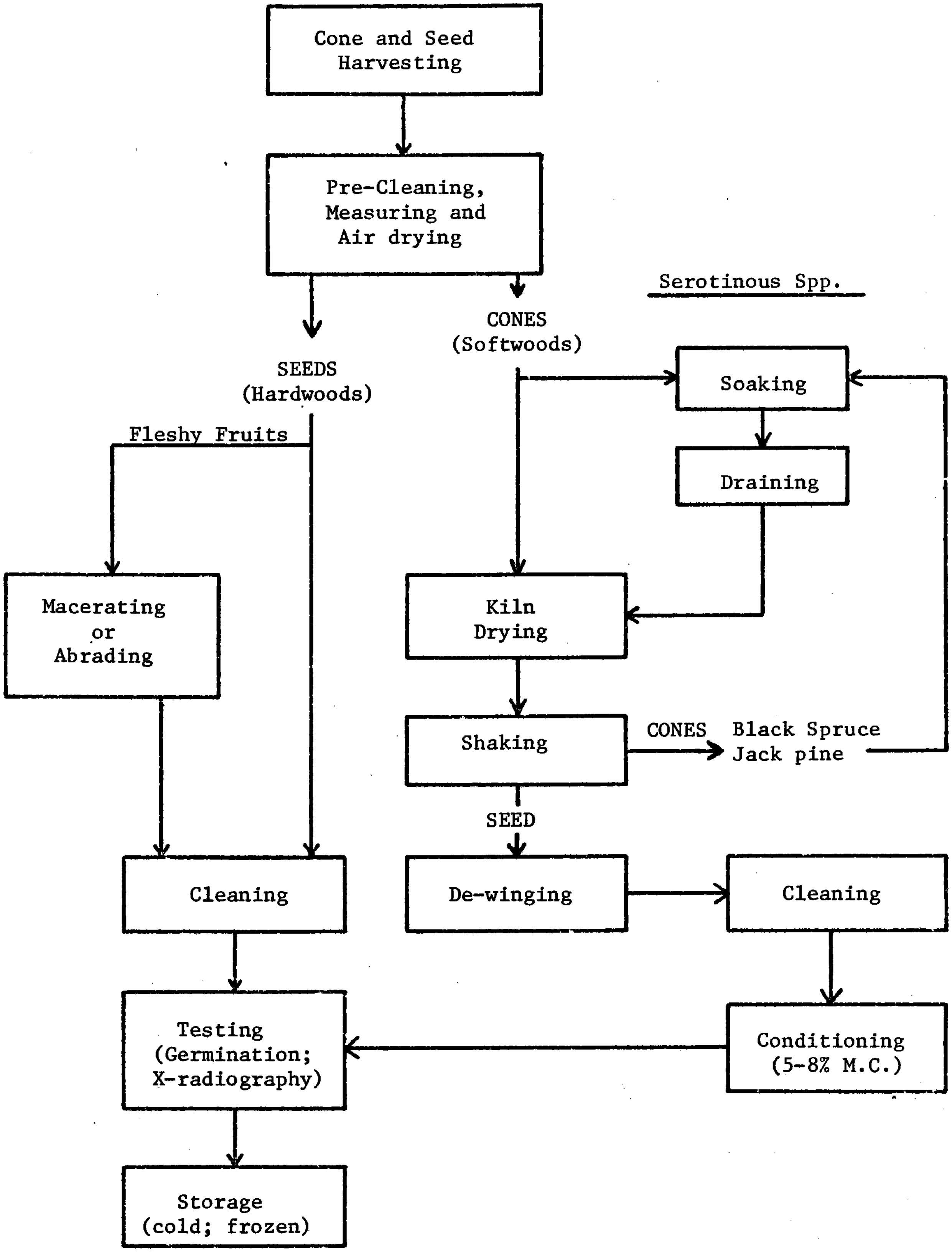

Fig. 1. Diagram of seed processing.

PACKING AND SHIPPING OF SEED

In reforestation operations seed processing and storage are often centered in one location. It is then necessary to ship large quantities of seeds to other places for seedling production or for direct seeding. Several factors that can affect seed quality during shipping are: condition of previous storage, methods of packing, and time and conditions of shipping.

According to Barton (1961), the better the conditions under which the seeds were stored before removal, the greater the chances to maintain original germinability when moving them to less favorable environments.

Since high and fluctuating temperatures and high relative humidities are considered the main causes of germinability losses in shipping, proper packaging of seeds with durable and waterproof containers such as heavy plastic or foil liner bags will minimize such hazards (Stein et al. 1974). Seeds requiring high moisture (e.g. most large seeded hardwoods) should be shipped in moist peatmoss, sawdust or Kimpak paper wadding in water-resistant containers with some aeration. Packaging in Kraft paper bags has been known to cause seed deterioration in agricultural seeds and should be avoided (Barton 1961).

Time and conditions in transit are uncontrollable and therefore, transit time should be kept as short as possible. Calvert's recent survey (1973) indicated that most seed shipments by commercial carriers within provincial forest services take only 1 to 2 days, 4 to 7 days being rare exceptions.

It should be stressed here that storage of seeds after shipment is as important as that prior to shipment. If seeds shipped cannot be used immediately, they ought to be stored at low temperature and low relative humidity.

LITERATURE CITED

Allen, G.S. 1957a. Better handling of a scarce commodity. B.C. Lumberman 41 (7): 32 - 36.

Allen, G.S. 1957b. Storage behavior of conifer seeds in sealed containers held at 0°F., 32°F., and room temperature. J. For. 55: 278 - 218.

Andersson, E. 1965. Cone and seed studies in Norway spruce (*Picea abies* (L.) Karst.). Stud. Forest. Suec. No. 23. 214 pp.

Association of Official Seed Analysts. 1970. Rules for testing seeds. Proc. Ass. Off. Seed Anal. 60: 1 - 116.

Baldwin, H.I. 1942. Forest tree seed of the north temperate regions with special reference to North America. Chronica Botanica Co., Waltham, Mass. 240 pp.

Barton, L.V. 1961. Seed preservation and longevity. Leonard Hill Books Ltd., London. 216 pp.

Bonner, F.T. 1971. Storage of acorns and other large hardwood seeds - problems and possibilities. Pages 77 - 82 in Proc. Southeast. Nurserymen's Conf.

Bonner, F.T. 1974. Seed testing. Paged 13 - 152 in Seeds of woody plants in the United States. Forest Serv., U.S. Dept. Agric. Handbook No. 450.

Calvert, R.F. 1973. Seed procurement and handling: spruce and pine. Pages 91 - 102 in Direct seeding symposium. Can. Forest Serv. Pub. 1339.

Carmichael, A.J. 1958. Determination of the maximum air temperature tolerated by red pine, jack pine, white spruce and black spruce seeds at low relative humidities. For. Chron. 34: 387 - 392.

Ehrenberg, C., A. Gustafsson, C.P. Forshell and M. Simak. 1955. Seed quality and the principles of forest genetics. Hereditas 41: 291 - 366.

Eliason, E.J. and C.E. Heit. 1940. The results of laboratory tests as applied to large scale extraction of red pine seed. J. For. 38: 426 - 429.

Heit, E.C. 1961. Abnormal germination during laboratory testing in coniferous tree seed. Proc. Int. Seed Test. Ass. 26: 419 - 427.

Heit, E.C. 1967a. Propagation from seed. Part 10. Storage methods for conifer seeds. Amer. Nurseryman 126(8): 14 - 15, 38 - 54.

Heit, E.C. 1967b. Propagation from seed. Part 11. Storage of deciduous tree and shrub seeds. Amer. Nurseryman 126(10): 12 - 13, 86 - 94.

Holmes, G.D. and G. Buszewicz. 1958. The storage of seed of temperate forest tree species. Forest. Abstr. 19: 313 - 322, 455 - 476.

Huss, E. 1956. On the quality of conifer seed and other factors affecting the plant. Medd. Skogsforskningsinst. 46(9). 59 pp.

International Seed Testing Association. 1966. International rules for seed testing. Proc. Int. Seed Test. Ass. 31(1): 1 - 152.

Jones, LeRoy. 1962. Recommendations for successful storage of tree seed. Tree Planters' Notes 55: 9 - 20.

Krugman, S.L. and J.L. Jenkinson. 1974. *Pinus* L. (pine). Pages 598 - 638 in Seeds of woody plants in the United States. Forest Serv., U.S. Dept. Agric. Handbook No. 450.

Lowman, B.J. 1975. Catalog - Equipment for processing small seed lots. U.S. Forest Serv., Equipment Develop. Centre Pub. 7524 2505. Missoula, Mont.

Morandini, R. 1961. Forest seed handling, equipment and procedures. I. Seed production, collection and extraction. Unasylva 15(4): 185 - 199.

Pfister, R.D. 1966. Artificial ripening of grand fir cones. Northwest Sci. 40: 103 - 112.

Rediske, J.H. 1961. Maturation of Douglas-fir seed - a biochemical study. For. Sci. 7: 204 - 213.

Rediske, J.H., and D.C. Nicholson. 1965. Maturation of noble fir seed - a biochemcial study. Weyerhaeuser Forest. Pap. 2. 15 pp.

Ritz, R.C. 1941. Kiln design and development of schedules for extracting seed from cones. U.S. Dept. Agric. Tech. Bull. No. 773. 70 pp.

Rudolf, P.O. 1961. Collecting and handling seeds of forest trees. Pages 221 - 226 in Seeds. The Yearbook of Agriculture. U.S. Dept. Agric., Washington, D.C.

Silen, R.R. 1958. Artificial ripening of Douglas-fir cones. J. For. 56: 410 - 413.

Stein, W.I., P.E. Slabaugh, and A.P. Plummer. 1974. Harvesting processing, and storage of fruits and seeds. Pages 98 - 125 in Seeds of woody plants in the United States. Forest Serv., U.S. Dept. Agric. Handbook No. 450.

U.S.D.A. 1974. Seeds of woody plants in the United States. Forest Serv., U.S. Dept. Agric. Handbook No. 450. 883 pp.

Wakeley, W.C. 1954. Planting the southern pines. U.S. Forest Serv. Agric. Monogr. 18. 233 pp.

Wang, B.S.P. 1973a. Laboratory germination criteria for red pine (*Pinus resinosa* Ait.) seed. Proc. Ass. Off. Seed Anal. 63: 94 - 101.

Wang, B.S.P. 1973b. Collecting, processing and storing tree seed for research use. Proc. IUFRO Int. Symp. on Seed Process., Bergen, Norway, 1973, Pap. No. 17. 12 pp.

Wang, B.S.P. 1974. Tree-seed storage. Can. For. Serv. Pub. 1335. 32 pp.

Wang, B.S.P. and O. Sziklai. 1969. A review of forest tree seed certification. For. Chron. 45: 378 - 385.

Wang, B.S.P. and J.C. Zasada. 1975. A review of papers published in the Proceedings of the IUFRO International Symposium on Seed Processing. Seed Sci. and Technol. (in press).

DISCUSSION

MORNING SESSION: BREEDING ACTIVITIES

O. Sziklai: I would like to comment on Dr. Nienstaedt's statement regarding gene pool conservation. He said, quoting C.W. Yeatman, that only local sources should be used. In my view this is only a preservation of the status quo, since we know that quite frequently non-local sources do better than the local ones. For example, the Swedes are introducing lodgepole pine for the simple reason that lodgepole pine produces 50 - 100% more wood than their native Scots pine, when they are using certain sources from northern B.C. and Yukon. Therefore, why not go a step ahead instead of maintaining the status quo? If there is reliable information available, why not speed up evolution of the species? Do you agree?

H. Nienstaedt: I fully agree with what you say, Oskar. The point is, in many cases today we don't have the information and until we do, we should make sure that we don't back ourselves into a situation where we take an inferior genotype and plant it into an area where, in fact, we do have a good genotype.

C.W. Yeatman: If I may comment briefly, my remarks were not made in the context of reforestation in general, but with reference to the reservation of designated gene pool reserves as samples of bigger populations. In general reforestation programs we should of course use to advantage whatever information we have available for the different species. For instance, in jack pine populations north of Lake Superior we appear to have sources that are inferior to sources east and west of that area. So in that area we should leave only one, two or three areas designated as gene pool reserves to be regenerated from the local trees. These would remain as regional population standards. We could integrate this objective with wood production by operating on these few thousand acres, cutting periodically and collecting cones as needed to regenerate the reserves only. The bulk of artificial regeneration in this region could well be of non-local stock of preferred origin.

S. Swan: I think we should clarify the question of gene pool reserves. We were talking about making recommendations about these to the forest services and industries. It will make a world of difference whether we are talking about 10,000, 1,000, 100 or even 10 acres. It is very important that we are clear about making very specific suggestions. We should say who is to designate these areas. This is all very important and we should be very specific about what we are after.

R. Grinnell: I think the modified harvest cutting system is an answer to the problem of gene pool reservation. This will preserve the genetic base and silviculturally it is also a way of getting the job done by promoting natural regeneration, and it is a big job. Your suggestions regarding this point will be helpful to us.

G. Kokocinski: I have a question for Dr. Nienstaedt. You have suggested that future seed collection may be made from trees far apart. Does this refer to seed production areas?

H. Nienstaedt: Distance is a consideration not used in individual seed production areas. In general, seed production areas are very good - but we should not fool ourselves and think that they are a good representation of the populations. They only give us seed from that particular small area, a part of the population that may be much larger. But obviously, when you are talking about a large area with a couple of thousand pounds of seed, as C.W. Yeatman is, this is different.

M. Rauter: I can see George's point. Unfortunately some people are happy with one good seed production area and they take all the seed they can get from that area. I think we have to be careful about this. Particularly in Ontario we need many seed production areas within a particular site region and then mix the seed. But if we have only one we are in trouble genetically.

H. Nienstaedt: Precisely.

R. Grinnell: That is why we are so interested in the modified harvest cutting system to ensure that we are maintaining a wide enough genetic base to get back to, to avoid the problem Miss Rauter is talking about.

C.W. Yeatman: I agree with Marie except that I don't quite agree with the mixing of the seed. It is better to keep track of the seed of individual seed production areas. This is partly a problem of documentation.

M. Rauter: O.K., when you can work with individual seed production areas, this is possible. But when you can't, knowing that the seed came from a variety of known sources is much better than having only one.

<u>C.W. Yeatman:</u> With respect to Stewart Swan's remarks concerning gene pool conservation, I think the matter should be left to the local people who carry the responsibility, to put gene pool conservation into effect. And I think the central idea is that gene pool conservation is integrated into land management. The choice of species, size of area, location of it, this must not be considered as something separate, it must be integrated with land management.

<u>Question:</u> Mr. Kiss, when you selected your plus trees, did you obtain ages?

<u>G. Kiss:</u> No I didn't. Most of the trees were very old, and I would have spent too much time counting rings. The surrounding trees were usually more or less the same age. We compared the selected trees with their own neighbors.

<u>Question:</u> Were the stands even-aged?

<u>G. Kiss:</u> Yes, most of the stands were even-aged. We realize that selection at this stage is problematic and that's why we put more emphasis on progeny trials.

<u>G. Kokocinski:</u> You have mentioned that most of your trees were about 120 years old. Did you have difficulties obtaining the scion material for grafting?

<u>G. Kiss:</u> Sometimes we did. This is why we only made a few grafts at the beginning. But once we had started the clone bank, we could get enough scions there within three or four years from the grafts.

<u>G. Kokocinski:</u> You mentioned that you got both cones and scions together. How did you do it? Did you do the selections in the fall?

<u>G. Kiss:</u> That's right. It is not always possible, though. In Engelmann spruce you can collect the scions just about the same time as the cones. Unfortunately, as we changed our location and went to the Smithers area, we found that it can't be done because they were not yet hardened in the fall.

<u>D. Dorn:</u> You mentioned something about the 200 - 300% differences between families in the progeny?

<u>G. Kiss:</u> That's right. The best family could be three times as tall as the poorest family at 2 years of age in the nursery.

<u>H. Kriebel:</u> What is the maximum area from which you would incorporate clones into the same seed orchard to avoid any possible difference in flowering time? I imagine some control is needed here. Otherwise some clones would never participate in cross-pollination and seed production.

G. Kiss: Well, I would say about 1 1/2 degrees in latitude and 2 degrees in longitude. As far as flowering is concerned, unfortunately we have to wait until the clones start flowering and then perhaps we have to make some phenological observations and perhaps group them in such a way that there will be better pollination.

H. Nienstaedt: How long are you planning to continue with the selection?

G. Kiss: Well, we have nearly completed the selection and will soon begin with controlled pollination using some sort of partial diallel crossing scheme. We have plans for moving some of the material south, into the Okanagan Valley, where the climate is better for flowering, and where we expect more frequent flowering than at Prince George.

Question: And how soon will you be able to supply seed?

G. Kiss: As soon as our Reforestation Division is ready for establishment of seed orchards, we can supply material to them, and after we have the information, we will eliminate poor clones.

AFTERNOON SESSION: SEED PRODUCTION

D.P. Fowler: I have a question for Mr. Lane. Do you have a program for the testing of seed production and seed collection areas?

C.H. Lane: Yes, Miss Rauter is including some of these in her tests. These tests are based upon individual-tree collections from these areas with comparison from general collections.

D.P. Fowler: Are there any results yet?

C.H. Lane: It is a little early yet. We need another two or three years.

M. Rauter: More. We are presently having trouble getting seed from enough seed production areas for satisfactory testing.

C.H. Lane: I can say that we watch this material very closely when we sow it in the nursery and compare it with general collections. Quite a difference shows up. I would say there is at least a 10% improvement for seed from production areas over general collections. This is assessed on the basis of size of trees at the age of 3-0 and shippable number of trees per square foot of nursery bed. So it really shows up in the nursery. We hope this will carry on in plantations.

Question: Are you using any special techniques to stimulate the production from clones, or growing material under special conditions as is done in Finland?

C.H. Lane: Like fertilizing, or growing seedlings under plastic? Well we have tried fertilization, using methods developed at Petawawa. Mark Holst has done a lot of work along these lines. So far, not too much has come out of it. We do fertilize - there was some information that potassium and phosphorus or both induce flowering in red pine. I am not so sure about the results; they don't seem to be consistent.

A. Denys: We have some 12-year-old mixed plantations of red and white pine where the red pine is suppressed and the white pine weevilled. What is your idea regarding development of a seed production area in this situation?

C.H. Lane: Using the white pine?

A. Denys: Yes.

C.H. Lane: Well I suspect it may be a bit late.

A. Denys: They are still growing and have fairly big crowns.

C.H. Lane: If the seed source is good, and there are enough straight (i.e. non-weevilled) stems for selection, there might be a possibility. You should also look at the location, the soil. Is the white pine producing cones yet?

A. Denys: It is starting.

C.H. Lane: If it is a good source and a good plantation for white pine it may be suitable. What site region is it in?

A. Denys: 6E.

C.H. Lane: Yes we need white pine seed for Region 6E.

Question: Do you have any problems with cone insects?

C.H. Lane: Yes. I wish some of our researchers would work on cone insects. Our biggest problem is in red pine seed production areas. All of our red pine seed now comes from seed production areas. We follow advice of workers in the U.S., and burn grass underneath the trees early in the spring. This is where the insects pupate and the fire destroys them, in theory.

Question: At what rate were the girls paid that collected seed in the seed production area shown in your slide?

C.H. Lane: The SWEEP (students working in environmental enhancement program) worked at an hourly rate. In some other areas we pay on a straight contract or piece work basis - $35 per hectolitre of white spruce cones. Red pine is collected the same way at $30 per hectolitre.

Question: Do you keep track of variation in viability of seed between individual trees?

C.H. Lane: No. There is always variation in viability and these differences have always been with us and we don't keep track of them. We work with bulked seedlots from individual seed production areas. Once we have blown out all the hollow seed, the viability is quite good. If I'm not mistaken, it is normally about 90%, that is, above average. 85% is about average for white spruce.

H. Nienstaedt: What sort of seed zone arrangement do you use and how do you distribute the seed from the plantations of unknown origin?

C.H. Lane: The origin of the seed production area in this slide is probably Beachburg. We use the seed from it in Region 6E; if it is from the Orono plantation we use it in the Lindsay, perhaps in the Maple and Tweed districts. It will be sown in Orono Nursery and each nursery supplies 3 - 4 surrounding districts.

Y. Lamontagne: Ladies and gentlemen, we will have to stop here. Thank you all for your participation.

ABSTRACTS OF PAPERS

12TH LAKE STATES FOREST TREE IMPROVEMENT CONFERENCE

The complete papers of this Conference are given in the Conference Proceedings, published by the North Central Forest Experiment Station, U.S. Forest Service, St. Paul, Minnesota, U.S.A. (U.S. Forest Serv. Gen. Tech. Rep. NC-26. 206 pp. 1976).

THE POTENTIAL FOR CLONING WHITE SPRUCE VIA TISSUE CULTURE

Robert A. Campbell and Donald J. Durzan[1]

ABSTRACT

When hypocotyl segments of white spruce were placed with their apical ends in an agar medium containing 10^{-5} M 1-naphthaleneacetic acid (NAA) but no 6-benzylaminopurine (BAP), 50 percent formed roots. Almost all segments placed with their basal end in a medium containing 10^{-5} M BAP with 10^{-7} M NAA formed scalelike organs. When explants with the scalelike organs were transferred to media containing neither BAP nor NAA, the organs grew into needles, buds developed, and elongated, branched shoots were obtained from these buds. A number of shoots have been obtained from a single hypocotyl segment. One such shoot has rooted. These results strengthen the hypothesis that a small explant could be used to mass propagate a superior tree.

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THE CLONAL TEST, AN AID TO PROGENY TESTING AND A WAY TO SPEED UP GENETIC GAINS

Armand G. Corriveau[1]

ABSTRACT

Phenotypic measurements of loblolly pine (*Pinus taeda* L.) and Virginia pine (*Pinus virginiana* Mill.) were obtained from parent trees in wild stands, from ramets in clonal orchards and from seedlings in control pollinated progeny tests. Total tree height, stem diameter, crown form, bole straightness and wood density were the characteristics assessed. The degree of resemblance between ortets and ramets, ramets and progeny and between parent trees and progeny was determined through estimation of variances and heritabilities. Broad and narrow sense heritabilities were estimated from clonal and progeny populations. Ortet-clone, ortet-seedling and clone-seedling regression and correlation analyses were used to measure the likeness between parent and progeny. These analyses revealed greater similarities between progeny and ramets than between progeny and mature parent trees in the forest indicating the possibility of improving the efficiency of selection through clonal testing. Calculations of expected genetic gains confirmed the importance of roguing inferior clones from the seed orchards as a step toward maximizing gain in a single generation. Clonal tests that can be converted into seed production orchards are recommended as aids to the more standard and expensive progeny tests and to speed up genetic gains both for Virginia and loblolly pines.

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IMPROVED STRAINS OF DOUGLAS-FIR FOR THE NORTHEASTERN UNITED STATES

Donald H. DeHayes and Jonathan W. Wright[1]

ABSTRACT

Provenances from the interior range of Douglas-fir were tested in Kalamazoo, Cass, and Osceola Counties, Michigan. Mortality, height growth, foliage color, spring frost damage, time of leafing out, and foliar moisture contents and drying rates were evaluated. Trees from Arizona and New Mexico (ARINEM race) grew faster followed by trees from northern Idaho and northwestern Montana (INEMP). On good sites these provenances produced merchantable Christmas trees in 7-8 years. Trees from central Montana (CMON) and northern Colorado (NOROC) grew half as fast. NOCOL and SOCOL races suffered severe frost injury while ARINEM was moderately to heavily damaged. In contrast northern races (NOROC and INEMP) suffered relatively little damage. From the leafing-out data it was clear the correlation between leafing out and injury was significant. NOROC and INEMP races leaf out 2-3 weeks after the southern races and avoid frost damage. Also tall trees suffered relatively little damage. The Arizona provenance had the greatest foliar moisture content as well as the slowest rate of drying; and the ARINEM race was characterized by having the bluest needles of the material tested. Recommends ARINEM for Christmas trees where frost is no problem; where frost may occur provenances from northern Idaho may give better results. Using mixtures of the two races would reduce risk.

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EASTERN WHITE PINE SEED SOURCE VARIATION IN THE NORTHEASTERN UNITED STATES: 16-YEAR RESULTS

Maurice E. Demeritt, Jr., and Harry C. Kettlewood[1]

ABSTRACT

Twelve eastern white pine (*Pinus strobus* L.) provenance plantations in the northeastern United States were measured for 16-year height and diameter. Differences in height between northern and southern sources have diminished since the 10-year measurements. In general, the 16-year diameter measurements follow the same trends as do the 16-year-height measurements. Recommendations for selection and movement of seed from one region to another are discussed.

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STAND, FAMILY, AND SITE EFFECTS IN UPPER OTTAWA VALLEY WHITE SPRUCE[1]

N.K. Dhir[2]

ABSTRACT

Forty-nine open-pollinated white spruce progenies from eight Upper Ottawa Valley white spruce stands were tested at three sites located within 10 miles of each other. Statistical analyses were limited to 42 families - 6 from each of 7 of the stands. Performance was site dependent with nearly a two-fold difference between the best and the poorest. Differences due to stands were not important. The best family was 28 percent taller than the family mean height, but performance was not consistent from site to site in spite of a nonsignificant family-site interaction term. This probably was due to limitations imposed by the statistical design. Heritability estimates for heights were: h_1^2 (individual-tree heritability) = 0.10; h_2^2 (family heritability) = 0.39. Genetic gain in 10-year height through one cycle of simple mass selection was estimated to be 8.6 percent; establishing a clonal orchard with the best trees (4 percent selection intensity) from the best families (10 percent selection intensity) in the test boosts the estimated gain to 11 percent. The genetic parameters determined in this study are compared with previously published data.

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1 This study was done while the author was a postdoctoral fellow at Petawawa Forest Experiment Station, Canadian Forestry Service, Chalk River, Ontario, Canada.

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CONTROLLED POLLINATION IN EASTERN REDCEDAR AND ROCKY MOUNTAIN JUNIPER[1]

Gilbert H. Fechner[2]

ABSTRACT

Pollination with forced and fresh eastern redcedar pollen was compared to wind pollination (and unpollinated controls). This is the first attempt at controlled pollination in juniper. Seeds were extracted, and cutting tests and germination tests were conducted to evaluate the success of pollinations. Artificial crosses were also made with eastern redcedar pollen on a single Rocky Mountain juniper female tree. First-year fruits were collected and evaluated. Preliminary results indicate that wind pollination is less reliable than control-pollination in obtaining sound seed set of eastern redcedar. This may explain the high proportion of empty seeds found and the low reproduction obtained in many natural stands.

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1 This research was supported in part by the McIntire-Stennis Cooperative Forestry Research Program.

2 Professor of Forest Genetics, Colorado State University, Fort Collins.
The author wishes to thank Karim Djavanshir, University of Teheran, Iran, Jon Johnson and Karen Southward, Colorado State University, for field and laboratory assistance on this study.

MANAGEMENT OF TREE GROWTH AND RESEARCH PLANTATIONS

Donald A. Fraser[1]

ABSTRACT

Reports vegetative growth and reproductive responses in white and black spruce resulting from: control of soil moisture by means of overhead sprinklers, photoperiod by means of incandescent lamps, and thermoperiod by means of heated plastic shelters. Increased lateral branch and diameter growth resulted in white spruce from irrigation (a). Continuous light (b), increased apical growth but not diameter. Raised temperature (c) forced early bud growth as well as early apical growth cessation. (b) plus (c) caused early bud growth and late apical growth cessation. (a) as well as (b) plus (c) resulted in early, more abundant male and female conelet production in white spruce. Root-pruning had an immediate, additional stimulatory effect, but subsequently reduced vigor had deleterious effects on conelet production. The responses in black spruce were similar. Photoperiod and gibberellic acid responses in growth chambers are briefly mentioned.

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REPORT ON THE CROSS *PINUS RESINOSA* X *P. TROPICALIS*[1]

Richard B. Hall, David F. Karnosky, and Donald P. Fowler[2]

ABSTRACT

Interspecific hybridization was attempted between *Pinus resinosa* and *P. tropicalis*, the only two New World members of the *Pinus* group *Sylvestres*. Thirteen *P. resinosa* trees at Madison, Wisconsin, and nine trees near Fredericton, New Brunswick, were used as female parents in crosses with *P. tropicalis* pollen. A total of 504 pollinated strobili yielded 115 mature cones, but only 2 putative hybrid seeds contained filled embryos as determined by X-ray photography. The two seeds failed to germinate.

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1 Contribution No. 93 from the University of Wisconsin Arboretum.

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JACK PINE SEEDLING SEED ORCHARD ESTABLISHMENT AND PROJECTED SEED YIELDS

Richard M. Jeffers[1]

ABSTRACT

Jack pine test plantings of open pollinated progenies from proven seed sources can be converted to seedling seed orchards. A combined selection index based on individual as well as family performance can be used to select the best individuals to retain in the orchards. Use of the index will result in retention of more families than under alternate schemes and permit more rigorous selection within families. A broad genetic base is maintained, the dangers of inbreeding are reduced, and the greatest genetic gain is assured. This scheme was applied to a set of data from a 90-seed-source test, a complement of seed sources was selected, and flowering and cone data from these seed sources were used to predict early seed yields in jack pine seedling seed orchards. After initial thinning, 1 hectare of orchard established according to the suggested scheme may yield 266.8 M full seed annually. This is probably a conservative estimate.

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SELECTION AND BREEDING EASTERN COTTONWOOD FOR RESISTANCE TO FOLIAGE DISEASES[1]

J.J. Jokela and W.R. Lovett[2]

ABSTRACT

The incidence and effects of *Melampsora* leaf rust and *Marssonina* leaf spot on eastern cottonwood in the central United States are discussed. Yield at age 15 in an Illinois plantation was related to means of leaf-rust scores observed in September of the second and third growing season. An increase of 1 rust score class on a 5-point scale (1 = light infection...5 = severe infection) reduced yield by about 20 percent. The need for selection and breeding for resistance is stressed and methods for attaining resistance are presented.

1 Study was supported in part by the North Central Regional Project NC-99, "Improvement of Forest Trees through Selection and Breeding", and the Illinois Agricultural Experiment Station.

2 Associate Professor and former Graduate Research Assistant, University of Illinois.

WHITE PINE POLLEN SPECIES AND YEAR DO NOT AFFECT CONELET DROP OR CONE SIZE IN *PINUS STROBUS*

H.B. Kriebel[1]

ABSTRACT

Statistical analysis of 6 years' breeding experiments on *Pinus strobus* L. showed that conelet drop was controlled by female parent but not by white pine pollen species or year of pollination. Crossing with a species never yielding viable seed did not increase conelet drop. The degree of loss was the same after self- and open-pollination as it was after controlled crossing. The length and weight of mature cones also depended only on female parent. A possible relation is suggested in pines between the presence or absence of a pollen effect on cone retention and the type of crossability barrier.

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[1] Professor, Department of Forestry, Ohio Agricultural Research and Development Center, Wooster, Ohio 44691. Approved for publication as Journal Article No. 86-75 of the OARDC.

GEOGRAPHIC VARIATION OF GROWTH AND WOOD PROPERTIES IN JAPANESE LARCH IN SOUTHWESTERN LOWER MICHIGAN[1]

Chen Hui Lee[2]

ABSTRACT

Growth and wood characteristics at age 10 from planting were assessed on the 22 seedlots of Japanese larch outplanted in the Kellogg Forest, Augusta, Michigan using a randomized complete block design. Results did not indicate any geographic trends for most traits studied but did suggest the operation of genetic drift and inbreeding. Fast growing seedlots continued to perform well in southwestern Lower Michigan. Recommends that seed for plantings in the Lake States area should be from the Mt. Nantai area in the northeast species range.

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1 This study was financed by the Deans' Council Research Grant, University of Wisconsin-Stevens Point.

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PROVENANCE AND FAMILY VARIATION IN BALSAM FIR FROM MICHIGAN AND WISCONSIN

D.T. Lester, R.M. Jeffers, and J.W Wright[1]

ABSTRACT

Variation in height, branching, and flushing was measured for wind-pollinated families from six provenances at age 11 in from one to four plantations. Seed collected at one location in the Lower Peninsula of Michigan produced trees that were 20 percent taller, had 40 percent more lateral branches in the top whorl, and had a flushing score 25 percent later than average. Variation among families within provenances was between 30 and 40 percent of respective provenance means. Both provenance and family effects were significant, but provenance effects were generally much larger. Provenance selection clearly would be worthwhile in the Lake States.

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[1] The authors are, respectively, Assoc. Prof. of Forest Genetics, Dept. of Forestry, University of Wisconsin, Madison, Wisconsin; Plant Geneticist, USDA Forest Service, Institute of Forest Genetics, Rhinelander, Wisconsin; and Prof. of Forestry, Dept. of Forestry, Michigan State University, East Lansing, Michigan. Funds for this research were provided in part by each employing institution, and in part by the U.S. Dept. of Agriculture through regional project NC-99 "Improvement of Forest Trees Through Selection and Breeding".

FOREST TREE IMPROVEMENT PROGRAM FOR THE NATIONAL FORESTS IN THE LAKE STATES

R.G. Miller and J.D. Murphy[1]

ABSTRACT

The Eastern Region of the USDA Forest Service has been conducting a Forest Tree Improvement Program on the national forests in the Lake States since the early 1960's. This paper presents a general review of the program, including objectives, organization, species priorities, and basic steps and procedures. Also discusses accomplishments and future plans.

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A WHITE SPRUCE PROGENY TEST--SEEDLING SEED ORCHARD: 12TH YEAR PROGRESS REPORT[1]

C.A. Mohn, D.E. Riemenschneider, W. Cromell, and L.C. Peterson[2]

ABSTRACT

Two hundred thirty-nine open-pollinated progenies of white spruce were established in a combination progeny test-seedling seed orchard near Grand Rapids, Minnesota. Characteristics evaluated included, total heights at 2-0 and 2-2 in the nursery and 9 and 12 years from seed (in the field); field survival 9 years from seed was included. Survival was just over 77 percent. Family mean heights were from 60 to 167 percent of the nursery test mean at 2-0 and decreased in variation to from 52 to 125 percent of the plantation mean at age 12. Narrow sense heritabilities (computed as four times the intraclass correlation) were 0.27 at age 9 and 0.35 at age 12 and are comparable to earlier results with white spruce in Wisconsin. They exceed Canadian results probably because Canadian material represented a more narrow geographic base. Data suggest a possible relation between growth rates and climatic seed collection zones. Pending further study, nurserymen should not collect seed in the extreme climatic zones in northeastern Minnesota. Plans for conversion of the test to a seed orchard are described. Possible genetic gains of from 15 to 20 percent are predicted on the basis of present genetic parameters.

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NUCLEAR PROTEINS OF DRY AND GERMINATING CONIFER SEEDS

J.A. Pitel and D.J. Durzan[1]

ABSTRACT

The proteins of the nuclear sap, the histones, and the non-histone chromosomal proteins (NHCP) were extracted from a number of dry and germinating seeds and their composition was examined by polyacrylamide gel electrophoresis. The nuclear fraction was isolated and washed extensively with several buffer mixtures. The chromosomal material was then solubilized in a high salt-high urea buffer. After removal of the DNA by ultracentrifugation, the chromosomal proteins were passed through a QAE-Sephadex column to separate the histones from the NHCP. Gel patterns of the NHCP varied quantitatively during the early germination of jack pine and minor qualitative differences in protein complement were also detected. Differences in the profiles of the NHCP were found among species of the *Pinaceae*. Histones from coniferous seeds compared favorably with pea histones in classification and electrophoretic mobilities. The changes in histones in profiles from different species and with different stages of germination were due mainly to the heterogeneous FI fraction. The methods are suitable for studies of nuclear protein metabolism and genetic regulation and expression in tree improvement programs. Biochemical techniques for extracting and characterizing nuclear proteins are summarized.

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PRESCRIPTION FOR THE AERIAL ENVIRONMENT OF A PLASTIC GREENHOUSE NURSERY

D.F.W. Pollard and K.T. Logan[1]

ABSTRACT

Investigations into the aerial environment favoring rapid growth of tree seedlings in plastic greenhouses are described. Controllable factors studied were day and night temperatures, and high and low intensity extension of photoperiod; a confounding influence of carbon dioxide enrichment and high humidity was also examined. Experiments were designed within the limits of applicability of results to the greenhouse control system, and were made on three commercially important species: jack pine, black spruce, and white spruce. Recommendations are given for each species, and also a single prescription is given for greenhouses containing all three species. The merits of high and low intensity photoperiod supplements are discussed.

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TEN-YEAR PERFORMANCE OF DOUGLAS-FIR PROVENANCES IN EASTERN NEBRASKA

Ralph A. Read and John A. Sprackling[1]

ABSTRACT

Seedlings from 55 seed sources were established in a field test as 1+1+1 potted transplants on a silt loam soil near Plattsmouth, Nebraska. Mortality was 76 percent in the nursery the first year, increased to 89 percent for potted seedlings the second year, and reached 98 percent 1 year after field planting. All coastal types died and survival was low for north-central provenances. Arizona and New Mexico seed sources gave the best survival (20 percent). Height-latitude correlation was r = 0.81, southern Colorado, New Mexico, and Arizona seed sources grew best. Some north-central provenances have grown well in recent years. Spring growth flush is earlier in southern than in northern material. The pattern agrees with the spring frost pattern in Michigan: southern sources are damaged while northern sources are not. In Nebraska the southern material suffered fall frost damage perhaps as a result of delayed growth cessation. A Durango, Colorado, provenance is recommended for landscape, greenbelt, and Christmas tree plantings in eastern Nebraska. A Mt. Lemmon, Arizona, provenance is recommended for Christmas trees in eastern Nebraska sites protected from spring frosts and winter winds.

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GENETIC CONTROL OF RESISTANCE TO HYPOXYLON INFECTION AND CANKER DEVELOPMENT IN *POPULUS TREMULOIDES*[1]

Fredrick A. Valentine, Paul D. Manion and Kathleen E. Moore[2]

ABSTRACT

The responses of 24 families of *P. tremuloides* (6 groups of 4 maternal half-sibling families each) to 4 sources of *Hypoxylon mammatum* were observed. Three mechanisms of resistance to the disease were studied: (1) callus formation, (2) branch death, and (3) resistance through retardation of canker growth. Resistance by callus formation is due to a hypersensitive response of the host to the pathogen. Little variation exists in the nature or time of the host response, but the pathogen's ability to elicit the host response, expressed as incidence per inoculum, varies from about 3 to 35 percent. Evidence suggests that a few major genes control this trait and are the basis for Mendelian ratios within families and discrete differences between groups of half-sibling families. Resistance by branch death occurs at a low incidence (8.3 percent) and death is due to the canker encircling the branch. Heritability estimates are low, 0.075 or less in response to the four inocula and 0.027 for all data. These are probably underestimates because all potentially resistant phenotypes most likely have not been expressed 4 months after inoculation. The third form of resistance, retardation of the spread of the pathogen, is measured as canker length. h^2 is low for the three inocula ($\leq$ 0.074), but reasonably high (0.254 for the fourth source.

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[1] Miss Moore completed the Veldman computer analysis of canker lengths as an undergraduate research problem.

[2] College of Environmental Science and Forestry, State University of New York, Syracuse.

GENETIC VARIATION IN THE HEIGHT-DIAMETER RATIO IN SCOTCH PINE

Jonathan W. Wright[1]

ABSTRACT

A range-wide provenance test including seed from 110 parts of the species' natural range was established in 1961 in three Michigan plantations. The trees were measured in 1973-1974, shortly after crown closure. At that time the plantation in the Upper Peninsula averaged 12.7 ft. tall and 3.3 in. diameter-at-1-foot; the two plantations in the Lower Peninsula averaged 23.9 and 23.2 ft. tall and 6.0 and 6.2 in. diameter, respectively. The average height/diameter ratio (feet/feet) was 54:1 in all three plantations. The six tallest seedlots (30 percent taller than average) were from Belgium, northern France, West Germany, and eastern Czechoslovakia. Their height/diameter ratio varied from 50:1 to 54:1 (differences not significant); all six were among the eight largest in diameter. Thus, selection for rapid volume growth can be done on the basis of either height or diameter. Trees from the north (northern Sweden, Siberia, and the Ural Mountains) grew at very slow to moderate rates (40 to 90 percent of average). Such trees were more slender than average, having height/diameter ratios of 56:1 to 58:1. The stockiest trees (i.e., lowest height/diameter ratios) were from Spain, Greece, Turkey, and northern Italy (average height/diameter ratios of 44:1, 49:1, 50:1, and 50:1, respectively). Those races grew at moderate rates (80 to 100 percent of average) and are among the best for Christmas tree production from the standpoints of foliage color and needle length.

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