YEATMAN

# SEED ORCHARDS AND STRATEGIES FOR TREE IMPROVEMENT

PROCEEDINGS OF THE EIGHTEENTH MEETING OF THE CANADIAN TREE IMPROVEMENT ASSOCIATION

## PART 2

DUNCAN BRITISH COLUMBIA AUGUST 17-20, 1981

EDITORS D.F.W. POLLARD D.G. EDWARDS C.W. YEATMAN

## COLLOQUE SUR LES VERGERS À GRAINES ET LES STRATÉGIES D'AMÉLIORATION DES ARBRES

COMPTE RENDUS DE LA DIX-HUITIÈME RÉUNION DE L'ASSOCIATION CANADIENNE POUR L'AMÉLIORATION DES ARBRES PARTIE 2

DUNCAN COLOMBIE-BRITANNIQUE DU 17 AU 20 AOÛT 1981

RÉDACTEURS D.F.W. POLLARD D.G. EDWARDS C.W. YEATMAN

## **PROCEEDINGS**

## OF THE EIGHTEENTH MEETING

## OF THE

## CANADIAN TREE IMPROVEMENT

## **ASSOCIATION**

## PART 2:

## SYMPOSIUM ON

# SEED ORCHARDS AND STRATEGIES FOR TREE IMPROVEMENT

## DUNCAN, BRITISH COLUMBIA

### AUGUST 17-20, 1981

EDITORS: D.F.W. POLLARD, D.G.W. EDWARDS AND C.W. YEATMAN

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### **COMPTES RENDUS**

## DE LA DIX-HUITIÈME CONFÉRENCE

DE

## L'ASSOCIATION CANADIENNE POUR L'AMÉLIORATION DES ARBRES

PARTIE 2:

## COLLOQUE SUR

# LES VERGERS À GRAINES ET LES STRATÉGIES D'AMÉLIORATION DES ARBRES

## DUNCAN COLOMBIE-BRITANNIQUE

DU 17 AU 20 AOÛT 1981

RÉDACTEURS: D.F.W. POLLARD, D.G.W. EDWARDS ET C.W. YEATMAN

## l<sup>re</sup> partie. Procès-verbaux et rapports des membres.

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#### PROCEEDINGS OF THE EIGHTEENTH MEETING OF

#### THE CANADIAN TREE IMPROVEMENT ASSOCIATION

#### With the compliments of the Association

Enquiries may be addressed to the authors or to Mr. M.J. Coles, Executive Secretary, C.T.I.A./A.C.A.A., N.B. Executive Forest Research Committee Inc. 500 Beaverbrook Court, Fredericton, N.B. E3B 5X4.

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The Ninteenth Meeting of the Association will be held in Toronto, Ontario, August 22-26, 1983. Speakers will be invited to address the topic of Vegetative Propagation and its Impact on Genetic Improvement and our Future Forests. Canadian and foreign visitors are welcome. Further information will be distributed in the fall 1982 to all members and to others on request. Enquiries concerning the 19th Meeting should be addressed to: Miss R.M. Rauter, Chairman, C.T.I.A./A.C.A.A., Forest Resources Branch, Ontario Ministry of Natural Resources, Parliament Buildings, Toronto, Ontario M7A 1W3.

To:

Dr. C.W. Yeatman, Editor, C.T.I.A./A.C.A.A. Canadian Forestry Service Petawawa National Forestry Institute Chalk River, Ontario K0J 1J0 CANADA

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Les demandes de renseignements peuvent être adressées aux auteurs ou à M.J. Coles, Secrétaire exécutif, A.C.A.A./C.T.I.A., N.B. Executive Forest Research Committee Inc. 500 Beaverbrook Court, Fredéricton, N.B. E3B 5X4.

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La dix-neuvième conference de l'Association aura lieu à Toronto, Ontario, du 22 au 26 Août 1983. Des orateurs seront invités à s'adresser au sujet de la propagation végétative et son impact sur l'amélioration génétique et sur nos forêts futures. Tous sont bienvenues. Des informations supplémentaires seront distribuées durant l'automne de 1982 à tous les membres et à tous ceux qui en feront la demande. Ces demandes de renseignements concernant la dix-neuvième réunion devrons être adressées à: Miss R.M. Rauter, Chairman, C.T.I.A./A.C.A.A., Forest Resources Branch, Ontario Ministry of Natural Resources, Parliament Buildings, Toronto, Ontario M7A 1W3.

À:	Dr. C.W. Yeatman, rédacteur, A.C.A.A./C.T.I.A. Environnement Canada Service canadien des forets Institut forestier national de Petawawa Chalk River, Ontario K0J 1J0																										
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The association is also indebted to the British Columbia Ministry of Forests for providing the expert and technical assistance of Mike Crown, vice chairman (local arrangements) and Judy Boyd, and for generous hospitality during the meeting. The Canadian Forestry Service provided expert assistance in preparing the program. Special thanks are extended to Frank Portlock who supervised preparation of these proceedings and to Doug Taylor, both of the Pacific Forest Research Centre. The Canadian Forestry Service supported in full the publication of proceedings.

> D.F.W. Pollard Vice Chairman (Symposium) D.G.W. Edwards (Seed Technology Workshop)

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L'Association désire également remercier Mike Crown, viceprésident (Dispositions locales) et Judy Boyd, du ministère des Forêts de la Colombie-Britannique, pour leur aide scientifique et technique, ainsi que pour l'accueil généreux offert aux participants. Le Service canadien des forêts a fourni une aide spécialisée pour la préparation du programme. Nous remercions plus particulièrement Frank Portlock, qui a supervisé la préparation du compte rendu, et Doug Taylor, tous deux du Centre de recherches forestières du Pacifique. Le Service canadien des forêts a payé la totalité des frais de publication du compte rendu.

> D.F.W. Pollard, vice-président (Colloque) D.G.W. Edwards (Atelier sur la technologie des graines)

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#### WELCOMING ADDRESS

#### T.M. Apsey

#### Deputy Minister of Forests

#### British Columbia Ministry of Forests

Ladies and Gentlemen, Good Morning

It is my pleasure and privilege to welcome you to this meeting on behalf of the Province of British Columbia and the Ministry of Forests.

Yours is a discipline that demands commitment. It demands commitment from yourselves and it also demands commitment from every other facet of forest management. From government. From industry.

A tree improvement program cannot be considered on its own. It must fit, like the vital piece of a jigsaw puzzle, into the overall pattern of increasingly intensive forest management practices. The achievements of such a program are measured in the number of seeds coming out of your seed orchards, the hectares of land reforested with superior stock and, years later, the increase in wood harvested - wood from trees that grew bigger and reached maturity faster than they would have in a natural forest. Before we reach these goals, there must be a broad-based commitment to, and long-term support for, tree improvement.

I am told that it has been ten years since this association last met in British Columbia. There have been some important changes since that 1971 meeting in Prince George:

- A major commitment to intensive forest management has been made by both the Ministry and the forest industry.
- Our new Ministry of Forests Act, proclaimed at the beginning of 1979, paved the way for a revolving system of resource analyses and five-year plans.
- And in the field of tree improvement we have built on the foundations established by Dr. Alan Orr-Ewing in his pioneering work in coastal Douglas fir. Commitments now have been made to work in other important coastal species and the program has expanded to embrace the enormous potential of the Interior forests.

During this week you will see evidence of these changes for yourselves. But before you begin, I believe it will be a valuable exercise to examine the role of tree improvement within the context of the overall management process.

Ask a tree breeder how his program is going and you will get

back an enthusiastic response about the great potential for enhancing the forestry practices of the future. He works with the program day by day. He has no problem living with the inherent long-term nature of such a project. However, the silviculturists, the forest managers and the wood processors must also be looking to the years ahead. They, too, must be planning how best to take advantage of these long-term possibilities.

The fall-down effect — the realization that even if second-growth forests are managed intensively they will not produce the same volumes of wood that were available from the old-growth forests hangs over all of us. Our job is to deal with this shortfall. That will require all the tools and techniques the silviculturist has at his disposal — choice of tree species, quick establishment, spacing control, possibly fertilization of forest lands. And underlying all this, as the true foundation, the genetic quality of the seeds we use.

The effects of using genetically-improved seed may take a long time to unfold but they are cumulative and their influence will be felt over the whole growth cycle and the eventual treatment of the crop. The actual cost of the seed is such a tiny fraction of the total crop value that additional investments to increase seed quality can be justified as money well spent, most particularly with those species that have a potentially high impact on wood supply.

Once there is a commitment to artificial regeneration and to planting programs, breeders can take steps to direct the crop towards the greatest return. Tree improvement practices will lead to assured seed supply and will influence the quality and quantity of wood produced in a given period of time. In this province, the move to more intensive forestry has been accompanied by the development of a co-operative approach. The work load for the total program is very large, even if you consider only the seed production function. By sharing that work with the forest industry, we are able to advance faster and more efficiently.

The province owns 94 per cent of the forest resource and the Ministy of Forests therefore holds the primary responsibility for managing the resource and ensuring the greatest benefit to the people of British Columbia. Some have referred to this arrangement as the "Big Brother Effect". I prefer to think of it as a true "Partnership". In any case, we have begun to share our responsibility with industry and the potential advantages of this partnership have already become evident.

You have heard about British Columbia's formation of a Coastal Tree Improvement Council. This body, made up of senior personnel from the Ministry and from major forest licencees, advises the Chief Forester on policy matters and actively works to strengthen the co-operative features of the program. Since then we have opened a program in the Interior and one of the first steps was to establish another organization: The Interior Tree Improvement Council.

The needs of this new program are already very large. For a start, the Ministry established an Interior target of 80 million improved

seedlings for 1995. For the province as a whole, the annual production target is 150 million improved seedlings by the year 2000.

These goals can be met only through a strong joint commitment by the minsitry and industry of both the tree breeding and seed production phases of the program. As recent evidence of this commitment, a new facility has been built at Vernon, to be officially opened in the near future. The Vernon Research Station and Seed Orchards will support the work of breeders and orchardists as well as physiologists and silviculture specialists who will provide much of the necessary knowledge and support. I hope by the time the CTIA comes back to British Columbia for another meeting, it will be able to meet at the Vernon centre. By then, too, the scale and scope of the Interior tree improvement programs will be closer to being on par with those on the coast. Indeed we expect the scale of the Interior programs will likely overtake the coastal commitments, despite the product value and high Mean Annual Increment of the coastal forests.

At present the emphasis of the Interior program is still on the interior spruces and lodgepole pine but some attention is being directed to the tree improvement potential in interior Douglas fir and western larch.

At the same time that we've been developing new initiatives in the Interior, we have moved to meet the increased propagation requirements for coastal programs through the expansion of research facilities at Cowichan Lake. The research station you will visit tomorrow is no longer just the home of the established program for coastal Douglas fir. The staff there is already involved in work on western hemlock and yellow cedar and in propagating Sitka spruce, amabilis fir, red cedar and other species. As part of the first stage of this expansion, 33,000 grafts were made there this spring. The staff and facilities are being built up. Clone banks are being established for all commerical coastal species to maintain the gene pool against losses through field exploitation. Similar developments are planned for the Interior at Vernon and Skimikin.

The work as you can see, goes on. We are making progress. But the main point I make today is this: tree improvement cannot supply fast answers: it needs a serious, long-term commitment. In British Columbia there is that commitment. Within our co-operative relationship with industry, the Ministry of Forests' Silviculture Branch spent \$3 million in the last fiscal year on seed orchard establishment, maintenance, service projects and the selection of "plus" trees. In the current fiscal year the amount is increased to \$3.5 million. These funds are in addition to the support given to the tree improvement section of the Ministry's research branch, where expenditures on breeding, provenance and research run at about the same dollar figure. Money, of course, it not the only commitment to be made, but you all know that having a firm, consistent fianancial base is an important part of laying the foundations for a stable, well-planned program on a useful scale. The British Columbia Ministry of Forests is relying on tree improvement to play a vital role in helping to meet future wood supply goals. You people meeting here today provide welcome reassurance that we are not alone, that commitments are being made to tree improvement in other provinces, other nations. I hope the experiences shared at this convention will help all participants expand their knowledge and speed up the essential work they are doing in this field.

The prime objective of the Canadian Tree Improvement Association, as stated in your constitution, is "to promote the use of scientifically and technically sound genetic practices in Canadian forestry." To which I say: "Go to it".

Roy Faulkner Principal Geneticist British Forestry Commission Northern Research Station Roslin, Lothian, Scotland

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**KEYNOTE ADDRESS** 

#### KEYNOTE ADDRESS

#### TREE IMPROVEMENT RESEARCH AND DEVELOPMENT - SOME THOUGHTS FOR THE 1980'S

#### Roy Faulkner

Principal Geneticist

British Forestry Commission

Northern Research Station

Roslin, Lothian, Scotland

#### INTRODUCTION

I am indeed honoured to have been invited to speak to the Canadian Tree Improvement Association and I look forward during the meeting to seeing and discussing mutual problems with you all - and, at the same time, to learn some of your recipes for success. You should not assume, however, that my crystal ball is any bigger or better than your own - in many respects it is undoubtedly inferior.

Before warming to my main theme, which mainly relates to north-temperate conifers, it will be helpful, perhaps, if I outline briefly the responsibilities and current work of my team engaged on tree breeding which started in Britain in 1949 and where we have an expanding forest estate - the current area of which is some 1 3/4 million hectares. The annual programme of new planting is in the order of 24,000 ha with a further 8,500 ha of re-stocking.

My association with this tree improvement programme goes back 23 years during which period I have seen many changes in forest policy, attitudes, thinking, methodology technologies, and, like most others, have passed through the hoops of economic appraisals and financial constraints. All these have affected our breeding strategies which have the ultimate goal of maximising improved saw-timber production per unit-of-time. It is of some interest, perhaps, to note that our manpower resource (which currently consists of five graduates, eight technicians and support labour of eleven men), has remained almost static since 1963. Total funding, which is currently 450,000 C\$ per year, has been kept broadly in line with inflation during the past decade. Nevertheless output per staff member has increased greatly due to ever-increasing experience; flexibility of management and job specification; a strong team spirit; integration and relationships with both forest manager and with our research colleagues in Silviculture and Physiology; by having only three well-located field stations; by having almost complete delegation of authority and control under one head; and by having responsibility for breeding research and development for both the private-and state-owned forestry sectors.

The research essentially applied but we have some involvement

in basic- applied projects. In round terms our annual capacity is: the survey of up to 1000 ha of plantations for registration as new seed collection areas and the resurvey of up to 500 ha of existing registered stands; making 10-12,000 grafts; designing and supervising the planting of 12 ha of new clonal or seedling orchards; making 7,500 isolations and artificially pollinating 20,000 flowers; raising 500 families (80,000 plants) and planting these in progeny tests on up to eight sites and up to 700 miles apart; and assessing an equivalent number of plants for height and stem form and a proportion for girth. Currently we have 38 ha of orchards of which 25 ha are 1.5 generation, 375 ha of progeny tests and 8,500 selected trees most of which are now under test.

In descending order of importance our species interests are: Sitka spruce, lodgepole pine, Scots pine, and Corsican pine (Pinus nigra var maritima). The hybrid between European and Japanese larches is also of importance and there is a growing interest in the hybrid between Sitka spruce and white spruce as a frost-hardy hybrid capable of growing well on very difficult sites in northern Scotland. Breeding effort and priorities are related broadly on a pro rata basis according to the importance of each species or hybrid. In addition to the main breeding programme we have established a number of research projects which aim to provide basic information to assist us in improving our strategies and techniques. Of these the more important ones have been: a plot-size and shape experiment; a population heritability study of 150 interbreeding trees representing all size classes; a complete diallel crossing-pattern of seven Sitka spruce trees; population studies of lodgepole pine and our own remnant native Scots pine stands using biochemical techniques; the development of standardised techniques for the assessment of experiments, mechanical data-handling and computation and interpretation of genotype x environment interactions, and a data bank.

On the international scene, and under the aegis of IUFRO, we have arranged and made a series of provenance seed collections of Sitka spruce, lodgepole pine, grand fir, noble fir and <u>A. lowiana</u> and have produced a handbook on seed orchards. In the early 1960's we were involved in launching the OECD scheme for the certification of forest reproductive material moving in international trade.

This sums up my experiences; it is against these that I present some thoughts on how I expect research and development in tree breeding to move during the next decade and which have relevance to some Canadian situations highlighted during the Petawawa Workshop of 1978.

The "crie de coeur" for more funds, staff and facilities is all too familiar; there are no glib answers for these matters which can only be realistically, if not always satisfactorily, settled by senior administrators and managers impartially discussing and firmly deciding how big the total research and development cake is to be over the next one or two decades, and how it should be divided. Johnston (1976) sets out some sound advice on the organization and management of forest research programmes and in particular he highlights the importance of retaining flexibility in staffing and producing long-, mid- and short-term plans which are regularly updated.

Now let us consider some of the activities connected with a tree improvement programme, including some which currently are not so important but which we should bear in mind for the future.

#### SEED SOURCES

Seed Stands

Seed stand registration and seed certification schemes were organized and operated on a voluntary basis in Britain during the period 1956-73; there were three phenotypically-based categories. Despite several propaganda campaigns the schemes were not a success and although the 300 members paid lip-service to the objects of the schemes they never gathered any impetus. The reasons for failure varied but primarily were because: there was no established tradition of collecting conifer seed (other than from Scots pine): we were highly dependent on imports which were easy to arrange through merchants in north-west America, Europe and Japan; seed crops on seed stands of all but the pioneer species were unpredictable and infrequent, financial statistics and methods of assessing cone crops were unreliable; the physical difficulties of collecting seed by climbing; the stringent safety rules and practical difficulties of training and retaining seed collection teams as a unit from one year to the next - and - perhaps our misfortune to have imported the American grey squirrel into Britain instead of Tamiasciurus douglassii!!

In the mid-1960's it was becoming increasingly difficult to obtain lodgepole pine seed from certain Canadian and American sources which had been proven to have merit in origin experiments established in the 1930's. Furthermore, collections from some places were impossible to arrange, or, excessively expensive - for example - seed from certain Alaskan sources was quoted at 370 C\$ per pound (820 C\$/kg). For this reason over 100 ha of seedling seed plantations were established on sites well isolated from contaminant pollen and based either on a single proven superior origin, or, six unproven origins from a given seed region or zone. Where six origins were used they were planted concurrently with (or a year or two later than) origin experiments based on the same seed lots but established on forest sites. On the seedling seed plantation site each origin is represented by pure lines in each of many randomised blocks across the site. Inferior origins - determined on the basis of data obtained from the forest experiments - are removed and the plantation of resultant 'hedges' is then managed for seed production. The final plantation may consist of a single origin or 2 or 3 origins if there are no significant differences between them in the forest experiments.

This method is well suited to precocious flowering species, such as lodgepole pine and jack pine, and it quickly provides a reliable "home" seed source of proven desirable origin. It is inexpensive and easy to organize and each plantation provides an excellent base population for intensive tree selection and further breeding work. Undoubtedly this method will be used in Britain well into the 1980's.

#### Seed Orchards

The initial concept of clonal seed orchards propounded by Syrach Larsen in 1934 was simple and in a wave of enthusiasm, which rapidly spread in the 1950's to the present date, tens of thousands of hectares of orchards have been established throughout the world. The most successful of these have been associated with pioneer species and amongst the conifers the pines in particular. Less satisfactory have been the sub-climax and climax species.

Amongst the many problems associated with orchards the most important are: ease of vegetatively propagating the ortets; root stock/scion incompatability; unpredictable flowering behaviour of selected clones in terms of amount and periodicity of flowering, sex ratio, period of female receptivity and pollen shedding, sexual compatibility, tolerance to selfing, and difficulties related to ground management, crop protection and cone harvesting. Many of these problems will remain with us for decades and many will, if ever, only be solved by local observation and experience. Because the number of variables involved is large and because most of them are the product of genotype x environment interactions, and because we are involved with a changing population of several hundreds of clones, it is obviously impossible to develop a satisfactory blanket prescription to cover all situations. Furthermore the scale of experimentation needed to solve or even shed light on some of the problems will require areas of ground far in excess of orchard requirements. Progress will mainly come about through painstaking detailed observations and recording over a long period such as the work on Scots pine flowering by Sarvas (1962) who pointed the way to the more recently reported observations by Eriksson (1978), on the analysis, interpretation and importance of temperature-sums on orchard productivity for Norway spruce, Scots pine and lodgepole pine.

From experiences in Scandinavia with the sub-climax species Norway spruce it is recognized that the location of an orchard can be of paramount importance for regular and heavy cone production. In general orchards located to the south of and at lower elevations than the site of the original natural population encourages heavier flowering - probably as a consequence of higher accumulated temperatures and perhaps coupled with higher moisture stress associated with lower rainfall and higher transpiration losses by the ground cover. For these reasons the Danes have already arranged for a Douglas fir orchard to be established in southern France, to give them a shift of 12 degrees to the south in order to achieve heavier and regular flowering. Undoubtedly other countries with similar problems will increasingly seek to cooperate in this way in the 80's. However, further investigations of the effects of plant development from seeds derived from parent material growing in a totally different environment to the original parents are needed to support or modify Bjørnstad's (1981) findings that local environmental effects, for example photoperiod may modify growth rhythms and give rise to

biochemical changes in grafts which may be transmitted by cytoplasmic inheritance.

Mini-intensive orchards grown within plastic-skinned greenhouses have been successfully used for several years in Finland. They are ideal for the mass-production of small-seeded precociously flowering broadleaved trees such as birch and alder, but their general suitability for conifers is very much less because of the lower attainable seed yields per unit of floor space. Furthermore several successive crops of grafts are needed since the life of a graft, grown intensively under these conditions, is unlikely to exceed 4-5 years. Nevertheless such orchards provide opportunities for mass artificialpollinations when the aim is the regular production of very valuable hybrids for vegetative mass-propagation schemes. Double the quantities of seeds might be obtained if containerised stock can be raised on pallets for easy mechanical shifting into and out of the orchard "house". Because of the earlier growth and consequent earlier date of flower initiation it should be possible to induce two flower crops per season one on each of the two successive graft crops.

Normal seed orchards are wasteful of space - particularly in the formative years and the intensity of thinning and periodicity of thinning has to be carefully planned to optimize seed production throughout a rotation. Similar problems have arisen in top-fruit orchards where intensive management of the crowns by regular pruning occurs. More recently development has swung towards growing cordon "maidens" for 3-4 years before clearing the crop and restarting. In shy-to-flower conifers it seems inevitable that more intensive research should be undertaken to control the shape and height of orchard trees and to manipulate the angle of branching in ways which will promote flowering and produce the maximum number of easily accessible flowering-sites/per tree. Perhaps orchardists will begin to renew and reconsider the work reported in the 1950's and early 60's which aimed to develop more potential flowering sites by judicious partial crown removal and pruning for spruce (Nienstaedt 1981), and cordoning, by intensive crown-training to produce "flat" tree forms in, for example, larch.

New ideas should be tried such as those produced by Sweet <u>et</u> <u>al.</u> (1978) who discuss bi-clonal orchards based on parents with exceptionally high specific-combiningability and the use of supplemental mass-pollination; the use of growth retardants; and use of both chemical and mechanical methods of inducing flowering; and flexible designs (Bell <u>et al.</u> 1978). Good progress has already been made in these fields and must be pursued further.

To those involved in research I make the following pleas: to those working on flowering - report the number of potential flowering points per unit of crown when presenting your flowering data; to those applying fertilizers - report the levels of nutrient elements in the rooting zone of the soils before your fertilizer applications are made in order to indicate the starting fertility levels; to those providing irrigation data and flowering responses provide data on the soil water potential at more than one depth - using tensiometers and, when feasible, the plant water potential from pressure-bomb measurements - together with a record of the ground vegetation and its management.

#### RESEARCH AND DEVELOPMENT OBJECTIVES

Published objectives of most breeding programmes are: to increase yields, or, to raise the harvest index and produce higher quality timber (Namkoong et al. 1980); the increases arising from speedier establishment of the young crop and faster rate of height and diameter-growth, and the higher qualities of timber deriving from having straighter and more circular stems and finer branching. Only occasionally are the factors of total dry-matter production per unit-of-volume of the saleable stem-wood, cell wall-thickness, fibre lengths, or proportions of spring-wood to autumn-wood referred to - yet all of these are of great importance when defining conifer wood quality. It is my firm opinion that tree breeders will shortly be forced more and more into looking critically at the end-product - wood - rather than continuing to place emphasis on the easily assessed phenotypic characters of height, girth and stem- straightness.

Many years ago cattle breeders in Britain selected and bred animals "for the show-ring" - concentrating their efforts on width of forehead, symmetry of horns, coat color, etc; they paid scant attention to milk yield and its butter-fat content with consequences which took a long period to rectify. We must profit from their negligence and ensure that similar errors are not repeated in our programmes, so that due to indirect selection we produce crops with unacceptably low wood-density, or, timber with undesirably short fibres.

FOREST MANAGEMENT AND TREE BREEDING INTERRELATIONSHIPS

#### Timber Quality

The use of mechanical stress-grading techniques on sawn-timber is rapidly increasing. From data so far obtained it can be generalised that spruce timber of even-growth, and grown at a rate equivalent to an annual production of more than 14 m<sup>3</sup>/ha/ann, may produce timber below the top grade (MS 75) standard. The weighted British national average yield-class for Sitka spruce, for example, is 12 m<sup>3</sup>/ha/ann and lies within a range of 6-24 m<sup>3</sup>/ha/ann, thus it is probable that a substantial proportion of timber inferior to grade MS 75 will be produced unless through selection and breeding, the breeder can substantially improve timber strength- properties.

As a consequence British foresters are now reconsidering some of their silviculture and management practices and particularly those concerned with plant espacement, improving survival, inputs of fertilizers, and later thinning regimes - all of which interact and have significant effects on sawn-timber quality and its value. However,

Cannell (1978) points out that many breeders tend to select progenitors of crops which are adapted to grow well on a variety of sites, under a range of climates, using current site preparation and forest management techniques; and without really considering more intensive cultural treatments including high fertilizer inputs which assist crops to speedily capture the site and establish a full canopy quickly. Obviously there are conflicts of opinion on the basic silvicultural techniques to be applied to those species and in those situations where faster growth, without some compensatory higher autumn-wood/spring-wood ratios, or, an overall increase in wood density, could have commercially-important harmful effects in the longer-term. Clearly it is essential to critically examine wood samples taken from progeny tests on a variety of sites in order to establish the genetic and environmental components of variation to the total phenotypic variance and to establish the importance of any gene x site interactions. Nicholls et al. (1980) recently provided a model report on wood factors to be considered and how the data should be treated.

Speculation on the pro's and con's of fast-grown timber, the possible loss in dry matter resulting from indirect selection due to negative correlations between ring width and density and the narrow-sense heritability estimates for the more important wood characters, will not be settled until breeders, silviculturists and economists begin to interact more effectively themselves.

#### Ideotype

On certain sites and particularly on marginal sites at higher latitudes, future management may be directed towards the establishment of forests which are grown to rotation age with minimal thinning or even no thinnings at all. This problem is already being discussed in Finland (Karki 1980) where the debate centres on whether or not to select and breed ideotypes (ideal plant types) with long, narrow crowns which can be grown to maturity with only one or even no thinning. Landscape gardeners have used selected ideotypes to good effect over many centuries and the challenge of selecting and breeding forest tree ideotypes for special forestry purposes must not be overlooked and, perhaps, more so for those species which can be easily and cheaply propagated vegetatively. Several important advantages are claimed for columnar narrow-crowned trees, such as: improved stem quality, stem-wood percent, saw log percent, and value per unit of timber: fewer plants and lower planting costs: reduced needs for early economic thinning, cost of limbing, transport and processing (and associated energy needs); and higher resistance to storms and snow. The chief disadvantages are higher establishment costs and smaller mean stem diameters from the final fellings. Certainly the time is ripe for the establishment of well-designed experiments to provide indications of the most effective ideotypes and/or ideotype mixtures for different situations, their the financial benefits, if any, and of certain ideotypes in silviculture and management techniques and on wood volume production and quality.

Nutrient Requirements

To enhance tree growth, fertilizers are now commonly and in some case repeatedly applied as a routine forest management practice, but the recent very sharp increases in fertilizers and their application costs are now causing managers to reconsider their policies. Between-family responses and interactions to different fertilizer inputs have been clearly demonstrated for many tree species but mainly in pot and nursery experiments. The rewards for developing tree varieties which perform well under minimal nutritional regimes should be high and it is now timely for breeders and nutritionists to jointly design experiments for screening trees of low soil N, P and K fertilizer regimes throughout a rotation. Such projects will be costly in terms of land, the provision of plants, maintenance and assessment costs and particularly if both seedling families and clones are tested over a range of environments. It is essential for tree breeders to think boldly and provide adequate research material for their successors even though this creates "hiccups" in their annual breeding programmes - which in many cases have become rather stereotyped now that strategies and reliable breeding techniques have been developed and introduced.

#### RISK FACTORS

Foresters are usually very cautious, largely because their training and the long life-cycle of their crops make them aware of their responsibilities to succeeding generations. Recently this awareness has been sharpened by the overtures from the gene-ecologists, conservationists and the economists who predict world-wide timber shortages in the next century. During their training many foresters, and particularly the more senior ones, have been influenced by European silvicultural practices which until fairly recently were often based on natural regeneration and crops of mixed species and ages. Even today the extremists shun the thought of changing to more productive species or origins, and the idea of monocultures and large areas of even-aged forests are abhorrent to them. It seems inevitable, however, that from a purely economic point of view that much of the world's future wood will be derived from plantations of pure species, and probably more productive exotic species planted to produce a mosaic of pure stands.

Choice and Use of Seed Origins

Once the decision to change species has been made the question of choice of seed origin arises immediately and the testing of different origins for adaptive traits becomes a major research task. Unless the area of the origin selected for testing is prescribed and then adequately and carefully sampled, any results obtained from the comparative tests may be inconclusive. Ignoring this basic requirement in some research and development programmes has led to very many wasted years and today there can be no excuse for repeating these errors. Due to physical and financial limits it is always impossible to adequately sample a species range, or zone within a range, and the variation in performance between origins is often high and often higher still within origins. Similarly it is impossible to adequately sample the sites on which the material may be planted commercially. Experimental data therefore should be very thoroughly examined and should always include a critical examination of within-plot variation before reaching major decisions. Where experimental data from origin experiments show no clear-cut answer, it makes sense to encourage the use of mixed origins in commercial practice - mixing two or more seedlots of those origins where the rate-of-growth and stem quality is likely to meet the potential needs of the user within the region or zone in question. Samples of each origin can usefully be kept separate and planted in pure plots of upwards of 5 ha for further research and/or general confirmation of many experimental tests results. In future years the best of these sources may give an additional bonus by providing a suitable and sizeable "home" seed source.

#### Use of Planting Stock Derived from Orchards

Breeders in the north temperate regions are now at the stage where they have established and are collecting seed from multi-clonal orchards based on untested clones. As yet few have established orchards based on tested clones and these are mostly confined to precocious flowering pioneer species. The untested orchards are normally based on clones derived from a single phenotypically superior stand, a forest, or a region, and few contain more than 40 clones; many are based on only 20-30 clones. By the time those clones with very early, very late or even lack of flowering have been rogued or discounted such orchards will have a much reduced or very narrow effective genetic base and the risk of inbreeding through selfing may be high. The risk factor to the manager using material from such a source is unknown and will vary in an unpredictable way from orchard to orchard. The gain from using seed from such orchards may be high, but it could be negative depending on circumstances. The question arises how should the seed be used during the period until 1.5- and second-generation orchards based on tested clones begin to bear fruit? Again I would suggest that mixing seed or plants derived from different orchards, based on clones from the same zone or even in some cases adjacent zones where phenotypic variation across an artificial boundary between zones or regions is continuous, should be seriously considered. National seed certification schemes and regulations intended to protect the purchaser by guaranteeing trueness of species, variety and origin or provenance should, at this stage in our development, include a clause to permit mixing of lots providing the accompanying certificate accurately describes the material. If it is mixed then the certificate should clearly indicate the components and proportions of the components in the mixture.

#### Clonal Planting Material

There are great economic attractions for clonal plantations, mainly because these allow the breeder to take advantage of the highest genetic gain from heterosis, rare combinations, useful aberrant forms, aneuploids and polyploids and to get these into commerce far more quickly than through the tested-orchard approach - thereby enhancing the all important genetic gain per unit-of-time. In a spruce breeding programme it normally takes 12-14 years from the year of pollination to the completion of a progeny test - two more years to provide a graft - 10 more years before the first commerical quantities of seed are available from the orchard - and a further five-ten years before achieving full orchard seed production, i.e., approximately 30-35 years. Assuming a genetic gain of 15 percent the mean annual gain is only half a percent! In contrast one seedling from a desirable controlled cross can be cloned-up to yield say 500 plants within five years, which equates to 10-15000 plants per hand-pollinated flower or up to 1 1/2 million plants per thousand cones five to seven years after a pollination. This is equivalent to a mean annual gain of 2 1/2 - 3%! These are compelling statistics and certainly must have considerable impact on our long-term policies and expansion plans for orchards.

The risks of failure of plantations based on a single clone are unpredictable and cannot be quantified. Some forestry organizations have taken such risks and, for example, Destremaux (1980) refers to 250,000 ha of poplar plantations in France of which 75 percent consist of clone I214 robusta, and of four centuries of clonal forest practice in Japan with Cryptomeria japonica. Pomologists have taken similar risks, and by 1980 it was estimated that some 10,000 million Golden Delicious apple trees derived from a single seedling selected in Virginia in 1914 have been cultivated. However evidence from agricultural crops clearly suggests that the risk of loss or debility from attacks by pathogens or insects must be much higher from a single than from a mixture of clones, which Tigerstedt (1974) suggests should be used in tens rather than just a few; Kleinschmit et al. (1977) recommends over one hundred. Heybroek (1978, 1980) points out the need for genetic variation (which will not preclude disease damage) to limit the impact of a disease by spreading the risk and by compensation when mixtures are used.

Clone mixtures are expected to show less phenotypic variation than single clone cultivations and should be more reliable ecologically and particularly with regard to host-parasite systems; if combined optimally they should out-perform pure cultures. It was suggested (Stern, 1969) that a major task for tree breeders should be the selection of optimal clone mixtures. I think it is doubtful that such a project will ever have a substantial pay-off since breeders are expected to produce a continuous stream of new and better clones. Thus by the time satisfactory mixtures of the first batches of the ten-prevailing best clones have been determined and "commercialised" they will, in all probability, have been superseded by others of greater potential merit.

In some rather elementary comparisons of growth data made on seedling and single clone forest plantations the coefficient of variation of the former was calculated to be 65 percent whereas in the latter it was 15 percent - again a powerful argument indeed for clonal plantations. But - who could really say what fraction of the 15 percent was attributable to clonal drift rather than environmental variation?

In horticulture searching for useful mutation has been a passive occupation in the past and today some fruit tree breeders are now

encouraging slight changes in their clonal stocks by the controlled use of mutagenic agents - aiming to secure, by chance, unaffected fruit qualities but perhaps higher resistance to pests and diseases. This is an approach to improvement which could be pursued by tree breeders when, having obtained a vastly superior clone by regular selection and breeding methods, they could then introduce minor genetic variations, having no effect on say vigour or stem form but which could provide improvements in disease resistance or rooting qualities. There is at least a case for exploratory investigations in this field in order to develop methods and techniques for achieving minor mutations in tree bud and cutting material.

Whilst on this subject one should also mention the risk, again unquantifiable, associated with cytological instability arising during cell and callus culture, particularly, perhaps, where chemical stimulants are used for rooting or encouraging re-juvenation. There is also a probability of producing some chimaeras arising from meristem cultures, or, root chimaeras from rooted cuttings. As research and development in these fields is pursued, it is essential for breeders to make detailed observations on the plantlets produced and their subsequent performance.

#### PROBABLE IMPLICATIONS OF SOME RECENT TECHNOLOGIES

#### Vegetative Propagation

Rooting pine, spruce and larch cuttings has been intensively researched during the past three decades. Most workers have reported large between-clone differences in rooting ability, a rapid decrease in rooting ability with age of the ortet, and difficulties in satisfactorily weaning the resultant rooted cuttings. Stock plants under three to six years of age are preferred for the commerical production of cutting material in order to achieve high rooting success and to minimize topophysis and the frequently associated plagiotropism. This poses a serious dilemma since breeders usually wait 8-10 years before deciding which progenies under tests have sufficient merit to warrant propagation, an age at which any selected tree can no longer be satisfactorily used as a stock plant for cuttings. As a result the only real options are to resow some of the original seed to produce stock plants for propagation whilst it is still very juvenile, or, to create a new batch of seed by repeating the appropriate specific crosses and then to resow. However a very useful option may soon become available if a promising technique, under development in the research department of the French Organization 'Association Foret-Cellulose', proves successful. The method involves four cycles of re-propagating very old plants (in their case 400-years-old P. pinaster trees) by means of grafting. After the fourth cycle complete re-juvenation of the material appears to have occurred and rooted cuttings with primary needles have been obtained. The problems of maturation and how to reverse it, and methods for the detection and measurement of juvenility, are of enormous importance to all plant propagators and conifer breeders and it is in this field of investigation that our colleagues in physiology and biochemistry have such an important continuing role to play.

Variation between  $R_1$  and  $R_2$  generations of <u>P</u>. radiata have already been noted by Shelbourne <u>et al</u>. (1974) and as they rightly point out these could have wide implications in clonal selection programmes. It must also be accepted that both genetic and non-genetic causes may affect early performance and therefore the speed of establishment of clonal crops. Clearly the field for further investigation is large and of major importance (Lindgren, 1977; Morgenstern, 1980).

#### Tissue Culture

Probable practical applications and problems of tissue culture in forestry have been listed and briefly discussed by Winton <u>et al.</u> (1976), Bonga (1977) and Reinhart <u>et al.</u> (1977) from which it is clear that tree physiologists have much work ahead of them before the very large problems associated with embryogenesis and organogenesis are solved. Furthermore, the reported incidence of chromosomal abnormalities in gymnosperm cultures is strongly indicative that this is unlikely to be a practical technique for conifers. Organic chemical compounds, and terpenoids and phenolics in particular, may be responsible for adverse growth and survival of tissue cultures in pines and spruces. Current research in Sweden is aimed at the reduction or inhibition of excess phenolics (Erikson <u>et al.</u> 1980). A technique for lobiolly pine has been recently published by Mott <u>et al.</u> (1981).

#### Haploid Culture

The load of deleterious genes carried by many conifers is perhaps the largest deterrent to pursuing research in the development of haploid cultures from the readily available and bulky megagametophytic tissues. Coupled with this are the reported difficulties of getting haploid tissues to differentiate during culture and again there is a risk of mutations occurring; these three factors suggest that this particularly difficult field of research should not be actively pursued at the moment.

#### Protoplast Hybridisation

Hybridisation of somatic or haploid protoplasts is being researched in several plant genera of commercially important plant species. Success has already been achieved in both potatoes and wheat two crop species for which much is already known about their genetic composition. It seems unlikely that tree breeders will enter this field until they have a much better understanding of the genetics of the individuals they wish to combine. In the meantime geneticists and tree physiologists should not be discouraged from investigating and developing suitable techniques for future application in both conifer and broadleaved species since protoplast hybridisation could have much to offer tree improvers in the future.

#### Gene Manipulation

This is concerned with the formation of new combinations of

heritable material by the introduction of nucleic acid molecules from an outside source into a virus, bacterial plasmid or other vector system, and to allow their incorporation into a host organism in which they do not naturally occur but in which they are capable of continued reproduction. It requires very sophisticated techniques in which fragments of DNA are first attached to a suitable vector. At present suitable vectors for higher plants have to be discovered but the DNA plant viruses and the Ti plasmid of Agrobacterium tumefaciens appear to be the two most probable candidates (Old <u>et al.</u> 1980). Since conifers are generally devoid of viruses there seem to be little hope for the first method but the Ti plasmid of <u>A. tumefaciens</u> may have a future role for some hardwoods. A 1978/79 Delphi study made no mention of a recombinant DNA break-through in forest trees but did suggest a high probability of the development of new nitrogen-fixed plants by the year 2000 (Stewman and Lincoln, 1981).

Genetic engineering research and development programmes are extremely expensive and are associated with many technical, organizational, staff and financial problems. In Europe it is now acknowledged that the budget needed to initiate and bring to term research and development in a molecular biology project tends to exceed the capabilities of a single institute. For this reason alone it seems highly improbable, both now and for several decades ahead, that tree improvement work in this field can be adequately and justifiably financed for what is very speculative research.

#### **Biochemical Studies**

To date these have had little impact on the management of forest resources but they have contributed to our understanding of the spatial and temporal dynamics of populations (Forrest, 1980a). In tree breeding programmes chemical features offer a possible sound method for monitoring progeny selection and testing programmes. There are two possibilities for research into factors responsible for chemotypic variation. First, investigations into the secondary products, for example, monoterpenes and polyphenols, which are important in themselves, since certain chemotypes have been naturally selected in different areas of the natural distribution (Forrest, 1980b). In this case chemotypic variation may be used for selecting trees if the characters are commercially important, for example, disease or insect resistance. Second, they may be directly selected by linkage association with other directly selected characters (Weissenberg, 1976).

Monopterpenes could be used for refining the description of natural geographic variation and therefore are likely to be used for seed certification purposes - using, in certain species perhaps, seed coat terpenes (or polyphenols) in addition.

Inheritance patterns will require investigation for the main commercial species and, when completed, could perhaps be used for monitoring hybrid-origin programmes.

#### Polyphenols

Polyphenols have a possible role to play as indicators of heartwood quality in relation to resistance to rot and in hardwood variation studies where resins are absent. The part that polyphenols play in resistance to browsing or insect damage should not be overlooked and, if there is a link, it would provide a most valuable tool for indirect selection.

#### Isozymes

A greatly increased understanding of isozyme variants within populations is required in order to determine the ecological significance of allelic variation; for example, different alleles may have different optimal temperatures for activity, in which case metabolically important enzymes could be used for selecting trees best adapted to growing under different climates. For these reasons there needs to be an extension of the enzyme system which can be conveniently analysed to include those known to be involved in controlling photosynthesis, respiration, and the synthesis of secondary products which are accumulated and locked-up to form energy reserves.

Much research is required to establish relationships between the different biochemical approaches and to determine which are best for variation studies and which will give evidence. At present it appears that isozymes are of limited value in studies of natural geographical variation but they are likely to have greater relevance in monitoring individually selected lines where distinctions are relatively 'fine' and in progeny-testing programmes.

#### Gentotype x Mycorrhiza Interactions

In the mid-1970's the mycorrhizal fungus <u>Pisolithus tinctorius</u> when compared with other mycorrhiza-forming species was reported to enhance the growth of loblolly pine seedlings (Marx <u>et al.</u> 1979). This suggested that it might be possible to screen mycorrhizal fungi for effectiveness as symbionts and so, perhaps, grow large seedlings and perhaps even trees to rotation age more quickly. Recent observations, however, have shown that different mycorrhizal species and mixtures of species occur at different developmental stages of a tree crop and also that the benefits may be highly dependent upon the levels of available soil nutrients.

Despite the difficulties of identifying mycorrhizal fungi and establishing and culturing pure strains, it does seem worthwhile to research this field for a longer period. During the process of vegetative propagation by cuttings it should be possible to exercise a much greater influence on mycorrhizal associations than is possible by raising seedlings and transplant stocks in normal nurseries, in the same way that associations can be influenced during containerised seedling production. If this proves to be so then investigating the interactions between tree clone x mycorrhizal species x mycorrhizal strain should quickly demonstrate the potential value and importance of further research in this field. It is interesting to speculate that in routine progeny tests some of the rapid changes in ranking for vigour between individuals both within and between plots, and especially in the early years, may be due, partly to mycorrhizal species or strain changes and their interactions with each tree genotype, and partly to seasonal macroand micro-climatic effects.

#### CONCLUSION

When I was invited to prepare this address my remit gave me plenty of latitude - and as a result I have had to treat most of the material quite sketchily and to leave many topics without comment at all. Perhaps during our time together over the next few days we can make the opportunities to discuss some of these matters more fully. Nobody ever got a quart out of a pint pot nor did anyone run satisfactorily before he In the formative years of a tree improvement programme there could walk. is a real danger of trying to emulate the work of breeders of agricultural crops and of trying to keep apace and use new technologies and methods for which we are ill-equipped to do. Tree breeding is, and always will be, a long-term activity and, despite all the words of wisdom which have been written and spoken in the last 20 years it must, in practical terms, remain a very imprecise art for several decades to come. Only after the broadsword has been used, albeit crudely, to reduce the breeding base-populations to a manageable size, can tree breeders and geneticists hope to get out and use their scalpels to refine existing and newer techniques to real effect. The tempo and order in which this is done depends on many things but foremost is the available resource both in terms of personnel and its quality, and money. Because the turbulent 80's are likely to be affected by financial instability and strigency any aimless meandering by R&D staff must not be condoned.

The common goals of increased volume production coupled with increased value, lower costs and minimal losses are very clear but the route to them is still hazy. For this reason we must retain a degree of flexibility and adaptability so that we can mould to changing patterns as they emerge and this can only be done by being opportunist and quick off the mark and by taking things forward technologically in a pragmatic and tactical manner.

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## SEED ORCHARDS

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Chairman:

Mike Crown British Columbia Ministry of Forests Duncan, B.C.

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#### THE SEED ORCHARD PROGRAM IN BRITISH COLUMBIA

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#### ABSTRACT

The majority of seed orchards in British Columbia are developed under the auspices of two (Coastal and Interior) Tree Improvement Councils. Priorities are identified by each Council, while design and management guidelines are set by Technical Planning Committees. Coastal orchards are invariably clonal, produced mainly by grafting; graft incompatibility has not been a problem. The major management considerations of site selection, root pruning, insect control and the phenological control, supplementation and collection of pollen are outlined. The 25 coastal orchards established or planned for 7 species and 9 orchard planning zones, and 9 proposed orchards are briefly described.

#### RÉSUMÉ

La plupart des vergers à graines de la Colombie-Britannique sont exploités sous l'égide de deux conseils d'amélioration des arbres: l'un pour la région côtière, l'autre pour l'interiéur. Chacun des conseils établit des priorités, tandis que les comités de planification technique émettent des recommandations pour ce qui est de la conception et de l'aménagement. Les vergers côtiers sont toujours de type clonal et ils sont établis surtout par greffage; il n'y a pas eu de problème d'incompatibilité des greffes. On donne un aperçu général des principaux aspects de l'aménagement: le choix de la station, l'élagage des racines, la lutte contre les insectes, ainsi que le contrôle phénologique, l'amélioration et la récolte de pollen. On fait une brève description des 25 vergers côtiers déjà etablis ou qu'on se propose d'établir pour 7 espèces, de 9 zones proposées pour des vergers, ainsi que de 9 vergers proposés.
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# INTRODUCTION

The majority of seed orchards in coastal British Columbia are managed or being developed under the auspices of the Coastal Tree Improvement Council (C.T.I.C.). This is a government-industry cooperative tree improvement program. Its history and development have been well documented elsewhere (Crown 1979, 1980). Recently an Interior Tree Improvement Council (C.T.I.C.) has been formed to serve the same function in the interior of the province.

Twenty-five seed orchards are established or planned for establishment by the coastal cooperators (Table I). These orchards will cover seven different species (F, Hw, Ba, Cr, Cy, Ss, Se) and nine seed orchard planning zones (Figure 1).

An additional nine orchards are proposed for the coastal portion of Prince Rupert Region. These orchards would cover five species (F, Hw, Pl, Ss,  $Sx)^{\underline{l}}$  and four seed orchard planning zones (Figure 1).

To arrive at priorities for the establishment of seed orchards, questionnaires were sent in 1979 to both government and industry forest managers. The managers were asked to outline their planting programs and species preferences in 1979 and to project these figures to 1994. The projected figures for 1994 were compiled and used by the C.T.I.C. to arrive at priorities for seed orchard establishment.

A Technical Planning Committee (T.P.C.) was formed to provide technical input to the establishment and management of seed orchards within the cooperative. The T.P.C. is made up of breeders and tree improvement personnel from the British Columbia Ministry of Forests (BCMF) and industry.

After the C.T.I.C. had established the priorities for seed orchard development, the T.P.C. set guidelines for the number of clones each orchard should contain, estimated seed yields to determine orchard sizes and general establishment and management principles.

The C.T.I.C. seed orchards will be established at nine seed orchard complexes. Four of the complexes will be managed by the BCMF and

1	F -	- Douglas-fir - Psuedotsuga menziesii
	Hw -	Western hemlock - Tsuga heterophylla
	Ba -	- Amabilis Fir - Abies amabilis
	Cr -	- Western red cedar - Thuja plicata
	Cy -	· Yellow cypress - Chamaecyparis nootkatensis
	Ss -	Sitka spruce - Picea sitchensis
	Se -	Englemann spruce - P. engelmanii
	P1 -	Lodgepole pine - Pinus contorta
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Sx - Interior spruce - Picea spp.

# CTIC SEED ORCHARDS

# TARGET AREA

1       MoF       F       EVI $300 - 700$ $38.3$ 11       Tahsis       F       WVI $0 - 600$ $20.8$ 14       MoF       F       SCM/CIT $300 - 900$ $22.4$ 15       MoF       F       JS $0 - 450$ $19.8$ 16       CFP       F       EVI/JS $600 - 900$ $20.5$ 18       Tahsis       Ss       WVI/NU $0 - 900$ $3.8$ 20       MoF       F       CIT $760 - 1070$ $52.4$ 26       WFP       Hw       NVI/WCC(s) $0 - 450$ $2.9$ 27       WFP       Hw       NVI/WCC(s) $0 - 450$ $2.9$ 27       WFP       Hw       NVI/WCC(s) $0 - 450$ $2.9$ 28       WFP       Cr       NVI/WCC $0 - 600$ $0.9$ 29       BCFP       Ba       WVI/JS $0 - 450$ $2.9$ 33       CFP       Hw       WVI $0 - 450$ $2.3$ 34       CZ       F       JS $0 - 450$ $1.3$ 35       M	No.	AGENT	SPECIES	ZONE	ELEVATION (m)	SEED TARGET (kg)
11       Tahsis       F       WVI       0 - 600       20.8         14       MoF       F       SCM/CIT       300 - 900       22.4         15       MoF       F       JS       0 - 450       19.8         16       CFP       F       EVI/JS       600 - 900       20.5         18       Tahsis       Ss       WVI/WI       0 - 900       3.8         20       MoF       F       CIT       760 - 1070       52.4         26       WFP       Hw       NVI/WCC(s)       0 - 450       2.9         27       WFP       Hw       NVI/WCC(s)       0 - 450       2.9         27       WFP       Hw       NVI/WCC 0       - 600       0.9         28       WFP       Cr       NVI/WCC 0       - 600       0.9         29       BCFP       Ba       WVI JS       0 - 450       1.3         30       BCFP       Hw       WVI       0 - 450       1.3         31       MoF       Se       CIT/SC       1100 - 1500       11.4         32       MB       Hw       WVI       0 - 600       1.3         34       CZ       F       JS       <	1	MoF	F	EVI	300 - 700	38,3
14       MoF       F       SCM/CIT       300 - 900       22.4         15       MoF       F       JS       0 - 450       19.8         16       CFP       F       EVI/JS       600 - 900       20.5         18       Tahsis       Ss       WVI/NVI       0 - 900       3.8         20       MoF       F       CIT       760 - 1070       52.4         26       WFP       Hw       NVI/WCC(s)       0 - 450       2.9         27       WFP       Hw       NVI/WCC (s)       0 - 450       2.9         27       WFP       Hw       NVI/WCC (s)       0 - 450       2.9         27       WFP       Hw       NVI/WCC (s)       0 - 450       2.9         28       WFP       Cr       NVI/WCC (s)       0 - 450       2.9         29       BCFP       Ba       WVI/JS       0 - 450       2.9         30       BCFP       Hw       WVI       0 - 450       2.9         33       CZ       F       JS       0 - 450       2.1         34       CZ       F       JS       0 - 600       1.3         37       MB       Ba       EVI/SCM	11	Tahsis	F	WVI	0 - 600	20.8
15       MoF       F       JS       0 - 450       19.8         16       CFP       F       EVI/JS       600 - 900       20.5         18       Tahsis       Ss       WVI/NVI       0 - 900       3.8         20       MoF       F       CIT       760 - 1070       52.4         26       WFP       Hw       NVI/WCC(s)       0 - 450       2.9         27       WFP       Hw       NVI/WCC(s)       450 - 900       1.8         28       WFP       Cr       NVI/WCC(s)       0 - 450       2.9         27       WFP       Hw       NVI/WCC(s)       0 - 450       2.9         28       WFP       Cr       NVI/WCC 0       0 - 600       0.9         29       BCFP       Ba       WVI/JS       0 - 450       2.9         30       BCFP       Hw       WVI       0 - 450       2.9         33       CFP       Hw       JS/SCM       0 - 450       1.3         34       CZ       F       JS       0 - 600       1.3         37       MB       Ba       EVI/SCM       900 +       3.2         38       CZ       Cy       WVI/EVI/JS <td>14</td> <td>MoF</td> <td>F</td> <td>SCM/CIT</td> <td>300 - 900</td> <td>22.4</td>	14	MoF	F	SCM/CIT	300 - 900	22.4
16       CFP       F       EVI/JS       600       900       20.5         18       Tahsis       Ss       WVI/NVI       0       900       3.8         20       MoF       F       CIT       760       1070       52.4         26       WFP       Hw       NVI/WCC(s)       0       -450       2.9         27       WFP       Hw       NVI/WCC(s)       0       -600       0.9         29       BCFP       Ba       WVI/JS       0       -450       40.6         30       BCFP       Hw       WVI       600       +       4.4         31       MoF       Se       CIT/SC       1100       -1500       11.4         32       MB       Hw       WVI       0       -450       2.9         33       CFP       Hw       JS/SCM       0       -450       1.3         34       CZ       F       JS       0       -450       1.3         37       MB       Ba       EVI/SCM       900       +       31.7         36       Tahsis       Hw       WVI       0       - 600       1.6         40       CZ	15	MoF	F	JS	0 - 450	19.8
18       Tahsis       Ss       WVI/NVI       0 - 900       3.8         20       MoF       F       CIT       760 - 1070       52.4         26       WFP       Hw       NVI/WCC(s)       0 - 450       2.9         27       WFP       Hw       NVI/WCC(s)       450 - 900       1.8         28       WFP       Cr       NVI/WCC       0 - 450       40.6         30       BCFP       Ba       WVI/JS       0 - 450       40.6         30       BCFP       Hw       WVI       600 +       4.4         31       MoF       Se       CIT/SC       1100 - 1500       11.4         32       MB       Hw       WVI       0 - 450       2.9         33       CFP       Hw       JS/SCM       0 - 450       1.3         34       CZ       F       JS       0 - 450       1.3         35       MB       Ba       EVI/SCM       900 +       31.7         36       Tahs1s       Hw       WVI       0 - 600       1.3         37       MB       CY       SCM/CIT       700 - 1200       3.2         38       CZ       CY       WVI/EVI/JS	16	CFP	F	EVI/JS	600 - 900	20.5
20MOFFCIT $760 - 1070$ $52.4$ 26WFPHwNVI/WCC(s) $0 - 450$ $2.9$ 27WFPHwNVI/WCC(s) $450 - 900$ $1.8$ 28WFPCrNVI/WCC $0 - 600$ $0.9$ 29BCFPBaWVI/JS $0 - 450$ $40.6$ 30BCFPHwWVI $600 +$ $4.4$ 31MoFSeCIT/SC $1100 - 1500$ $11.4$ 32MBHwWVI $0 - 450$ $2.9$ 33CFPHwJS/SCM $0 - 450$ $2.9$ 34CZFJS $0 - 450$ $21.7$ 35MBBaEVI/SCM $900 +$ $31.7$ 36TahsisHwWVI $0 - 600$ $1.3$ 37MBCySCM/CIT $700 - 1200$ $3.2$ 38CZCyWVI/SVIJS $600 - 1200$ $3.2$ 39MBCrWVI $0 - 600$ $1.6$ 40CZCrEVI/SCM $0 - 600$ $1.6$ 40CZCrEVI/SCM $0 - 600$ $3.5$ 41MoFBaSCM/EVI/JS $450 - 900$ $2.7$ $42$ WFPSsQCI $0 - 450$ $2.2$ $R-1*$ SxT $450 - 900$ $2.7$ $R-2*$ SsNC $0 - 450$ $2.2$ $R-4*$ SsQCI $450 - 900$ $2.2$ $R-5*$ SsNC $0 - 450$ $2.0$ <td>18</td> <td>Tahsis</td> <td>Ss</td> <td>WVI/NVI</td> <td>0 - 900</td> <td>3.8</td>	18	Tahsis	Ss	WVI/NVI	0 - 900	3.8
26WFPHwNVI/WCC(s) $0 - 450$ $2.9$ 27WFPHwNVI/WCC(s) $450 - 900$ $1.8$ 28WFPCrNVI/WCC $0 - 600$ $0.9$ 29BCFPBaWVI/JS $0 - 450$ $40.6$ 30BCFPHwWVI $600 +$ $4.4$ 31MoFSeCIT/SC $1100 - 1500$ $11.4$ 32MBHwWVI $0 - 450$ $2.9$ 33CFPHwJS/SCM $0 - 450$ $2.9$ 33CFPHwJS/SCM $0 - 450$ $1.3$ 34CZFJS $0 - 450$ $21.7$ 35MBBaEVI/SCM $900 +$ $31.7$ 36TahsisHwWVI $0 - 600$ $1.6$ 40CZCrEVI/SCM $0 - 600$ $1.6$ 40CZCrEVI/SCM $0 - 600$ $1.6$ 41MoFBaSCM/CUT $0 - 600$ $1.6$ 42WFPSsQCI $0 - 450$ $3.5$ 43MoFHwJS/SCM $450 - 900$ $2.7$ $R - 2*$ SsNC $450 - 900$ $2.2$ $R - 4*$ SsQCI $450 - 900$ $2.2$ $R - 5*$ SsNC $0 - 450$ $2.0$ $R - 4*$ SsQCI $450 - 900$ $3.1$ $R - 7*$ FMC $0 - 450$ $2.0$ $R - 5*$ SsNC $0 - 450$ $4.8$ $R - 7*$	20	MoF	F	CIT	760 - 1070	52.4
27WFPHwNVI/WCC(s) $450 - 900$ 1.828WFPCrNVI/WCC0 - 6000.929BCFPBaWVI/JS0 - 45040.630BCFPHwWVI600 +4.431MoFSeCIT/SC1100 - 150011.432MBHwWVI0 - 4502.933CFPHwJS/SCM0 - 4501.334CZFJS0 - 45021.735MBBaEVI/SCM900 +31.736TahsisHwWVI0 - 6001.337MBCySCM/CIT700 - 12003.238CZCyWVI/EVI/JS600 - 12003.239MBCrWVI0 - 6001.640CZCrEVI/SCM0 - 6000.541MoFBaSCM/EVI/JS450 - 90027.542WFPSsQCI0 - 4503.543MoFHwJS/SCM450 - 9002.7R-3*SsMC0 - 4502.2R-4*SsQCI450 - 9003.1R-7*FMC0 - 4502.0R-6*P1T450 - 9003.1R-7*FMC0 - 4504.8R-8*HwNC450 - 9003.0	26	WFP	Hw	NVI/WCC(s)	0 - 450 .	2.9
28WFPCrNVI/WCC0 - 6000.929BCFPBaWVI/JS0 - 45040.630BCFPHwWVI600 +4.431MoFSeCIT/SC1100 - 150011.432MBHwWVI0 - 4502.933CFPHwJS/SCM0 - 4501.334CZFJS0 - 45021.735MBBaEVI/SCM900 +31.736TahsisHwWVI0 - 6001.337MBCySCM/CIT700 - 12003.238CZCyWVI/EVI/JS600 - 12003.239MBCrWVI0 - 6001.640CZCrEVI/SCM0 - 6001.640CZCrEVI/SCM0 - 6003.541MoFBaSCM/EVI/JS450 - 90027.542WFPSsQCI0 - 4503.543MoFHwJS/SCM450 - 9002.7R-3*SsMC0 - 4502.2R-4*SsQCI450 - 9002.2R-5*SsNC0 - 4502.0R-6*P1T450 - 9003.1R-7*FMC0 - 4504.8R-8*HwNC450 - 9002.0	27	WFP	Hw	NVI/WCC(s)	450 <b>- 9</b> 00	1.8
29BCFPBaWVI/JS0 - 45040.630BCFPHwWVI600 +4.431MoFSeCIT/SC1100 - 150011.432MBHwWVI0 - 4502.933CFPHwJS/SCM0 - 4501.334CZFJS0 - 45021.735MBBaEVI/SCM900 +31.736TahsisHwWVI0 - 6001.337MBCySCM/CIT700 - 12003.238CZCyWVI/EVI/JS600 - 12003.239MBCrWVI0 - 6001.640CZCrEVI/SCM0 - 6001.541MoFBaSCM/EVI/JS450 - 90027.542WFPSsQCI0 - 4503.543MoFHwJS/SCM450 - 9002.7R-1*SxT450 - 9002.2R-4*SsMC0 - 4502.2R-5*SsNC0 - 4502.0R-6*P1T450 - 9003.1R-7*FMC0 - 4504.8R-8*HwNC450 - 9002.0	28	WFP	Cr	NVI/WCC	0 - 600	0.9
30BCFPHwWVI $600 +$ $4.4$ $31$ MoFSeCIT/SC $1100 - 1500$ $11.4$ $32$ MBHwWVI $0 - 450$ $2.9$ $33$ CFPHwJS/SCM $0 - 450$ $1.3$ $34$ CZFJS $0 - 450$ $21.7$ $35$ MBBaEVI/SCM $900 +$ $31.7$ $36$ TahsisHwWVI $0 - 600$ $1.3$ $37$ MBCySCM/CIT $700 - 1200$ $3.2$ $38$ CZCyWVI/EVI/JS $600 - 1200$ $3.2$ $39$ MBCrWVI $0 - 600$ $1.6$ $40$ CZCrEVI/SCM $0 - 600$ $0.5$ $41$ MoFBaSCM/EVI/JS $450 - 900$ $27.5$ $42$ WFPSsQCI $0 - 450$ $3.5$ $43$ MoFHwJS/SCM $450 - 900$ $2.7$ $R-3*$ SsNC $0 - 450$ $2.2$ $R-4*$ SsQCI $450 - 900$ $2.2$ $R-5*$ SsNC $0 - 450$ $2.0$ $R-6*$ P1T $450 - 900$ $3.1$ $R-7*$ FMC $0 - 450$ $4.8$ $R-8*$ HwNC $450 - 900$ $2.0$	29	BCFP	Ba	WVI/JS	0 - 450	40.6
31MoFSeCIT/SC1100 - 150011.432MBHwWVI0 - 4502.933CFPHwJS/SCM0 - 4501.334CZFJS0 - 45021.735MBBaEVI/SCM900 +31.736TahsisHwWVI0 - 6001.337MBCySCM/CIT700 - 12003.238CZCyWVI/EVI/JS600 - 12003.239MBCrWVI0 - 6001.640CZCrEVI/SCM0 - 6000.541MoFBaSCM/EVI/JS450 - 90027.542WFPSsQCI0 - 4503.543MoFHwJS/SCM450 - 9002.7 $R-2*$ SsNC0 - 4502.2 $R-4*$ SsQCI450 - 9002.2 $R-5*$ SsNC0 - 4502.0 $R-5*$ SsNC0 - 4502.0 $R-7*$ FMC0 - 4504.8 $R-8*$ HwNC450 - 9002.0	30	BCFP	Hw	WVI	600 +	4.4
32MBHwWVI $0 - 450$ $2.9$ $33$ CFPHwJS/SCM $0 - 450$ $1.3$ $34$ CZFJS $0 - 450$ $21.7$ $35$ MBBaEVI/SCM $900 +$ $31.7$ $36$ Tahs1sHwWVI $0 - 600$ $1.3$ $37$ MBCySCM/CIT $700 - 1200$ $3.2$ $38$ CZCyWVI/EVI/JS $600 - 1200$ $3.2$ $39$ MBCrWVI $0 - 600$ $1.6$ $40$ CZCrEVI/SCM $0 - 600$ $0.5$ $41$ MoFBaSCM/EVI/JS $450 - 900$ $27.5$ $42$ WFPSsQCI $0 - 450$ $3.5$ $43$ MoFHwJS/SCM $450 - 900$ $2.7$ $R-2*$ SsNC $0 - 450$ $2.2$ $R-4*$ SsQCI $450 - 900$ $2.2$ $R-4*$ SsQCI $450 - 900$ $2.2$ $R-5*$ SsNC $0 - 450$ $2.0$ $R-5*$ SsNC $0 - 450$ $2.0$ $R-7*$ FMC $0 - 450$ $4.8$ $R-8*$ HwNC $450 - 900$ $2.0$	31	MoF	Se	CIT/SC	1100 - 1500	11.4
33CFPHwJS/SCM0 - 4501.334CZFJS0 - 45021.735MBBaEVI/SCM900 +31.736TahsisHwWVI0 - 6001.337MBCySCM/CIT700 - 12003.238CZCyWVI/EVI/JS600 - 12003.239MBCrWVI0 - 6001.640CZCrEVI/SCM0 - 6000.541MoFBaSCM/EVI/JS450 - 90027.542WFPSsQCI0 - 4503.543MoFHwJS/SCM450 - 9002.7R-1*SxT450 - 9002.7R-3*SsMC0 - 4502.2R-4*SsQCI450 - 9002.2R-5*SsNC0 - 4502.2R-5*SsNC0 - 4502.0R-6*P1T450 - 9003.1R-7*FMC0 - 4504.8R-8*HwNC450 - 9002.0	32	MB	Hw	WVI	0 - 450	2.9
$34$ $CZ$ FJS $0 - 450$ $21.7$ $35$ MBBaEVI/SCM $900 +$ $31.7$ $36$ TahsisHwWVI $0 - 600$ $1.3$ $37$ MBCySCM/CIT $700 - 1200$ $3.2$ $38$ CZCyWVI/EVI/JS $600 - 1200$ $3.2$ $39$ MBCrWVI $0 - 600$ $1.6$ $40$ CZCrEVI/SCM $0 - 600$ $0.5$ $41$ MoFBaSCM/EVI/JS $450 - 900$ $27.5$ $42$ WFPSsQCI $0 - 450$ $3.5$ $43$ MoFHwJS/SCM $450 - 900$ $2.7$ $R^{-1*}$ SxT $450 - 900$ $2.7$ $R^{-3*}$ SsMC $0 - 450$ $2.2$ $R^{-4*}$ SsQCI $450 - 900$ $2.2$ $R^{-5*}$ SsNC $0 - 450$ $2.0$ $R^{-7*}$ FMC $0 - 450$ $4.8$ $R^{-8*}$ HwNC $450 - 900$ $2.0$	33	CFP	Hw	JS/SCM	0 - 450	1.3
35MBBaEVI/SCM $900 +$ $31.7$ 36TahsisHwWVI $0 - 600$ $1.3$ 37MBCySCM/CIT $700 - 1200$ $3.2$ 38CZCyWVI/EVI/JS $600 - 1200$ $3.2$ 39MBCrWVI $0 - 600$ $1.6$ 40CZCrEVI/SCM $0 - 600$ $0.5$ 41MoFBaSCM/EVI/JS $450 - 900$ $27.5$ 42WFPSsQCI $0 - 450$ $3.5$ 43MoFHwJS/SCM $450 - 900$ $2.7$ $R-1*$ SxT $450 - 900$ $2.7$ $R-2*$ SsNC $0 - 450$ $2.2$ $R-4*$ SsQCI $450 - 900$ $2.2$ $R-5*$ SsNC $0 - 450$ $2.2$ $R-5*$ SsNC $0 - 450$ $2.0$ $R-7*$ FMC $0 - 450$ $4.8$ $R-8*$ HwNC $450 - 900$ $2.0$	34	CZ	F	JS	0 - 450	21.7
36TahsisHwWVI $0 - 600$ 1.3 $37$ MBCySCM/CIT $700 - 1200$ $3.2$ $38$ CZCyWVI/EVI/JS $600 - 1200$ $3.2$ $39$ MBCrWVI $0 - 600$ $1.6$ $40$ CZCrEVI/SCM $0 - 600$ $0.5$ $41$ MoFBaSCM/EVI/JS $450 - 900$ $27.5$ $42$ WFPSsQCI $0 - 450$ $3.5$ $43$ MoFHwJS/SCM $450 - 900$ $2.7$ $R-2*$ SsNC $450 - 900$ $2.7$ $R-3*$ SsMC $0 - 450$ $2.2$ $R-4*$ SsQCI $450 - 900$ $2.2$ $R-5*$ SsNC $0 - 450$ $2.0$ $R-6*$ P1T $450 - 900$ $3.1$ $R-7*$ FMC $0 - 450$ $4.8$ $R-8*$ HwNC $450 - 900$ $2.0$	35	MB	Ba	EVI/SCM	900 +	31.7
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R-3*SsMC $0-450$ $2.2$ $R-4*$ SsQCI $450-900$ $2.2$ $R-5*$ SsNC $0-450$ $2.0$ $R-6*$ P1T $450-900$ $3.1$ $R-7*$ FMC $0-450$ $4.8$ $R-8*$ HwNC $450-900$ $2.0$	R-2*		Ss	NC	450 - 900	2.7
R-4*SsQCI450 - 9002.2 $R-5*$ SsNC0 - 4502.0 $R-6*$ P1T450 - 9003.1 $R-7*$ FMC0 - 4504.8 $R-8*$ HwNC450 - 9002.0 $P-9*$ HwNC450 - 9002.0	R-3*		Ss	MC	0 - 450	2.2
R-5*SsNC $0-450$ $2.0$ $R-6*$ P1T $450-900$ $3.1$ $R-7*$ FMC $0-450$ $4.8$ $R-8*$ HwNC $450-900$ $2.0$ $P-9*$ HwNC $450-900$ $2.0$	R-4*		Ss	QCI	450 - 900	2.2
R-6*P1T $450 - 900$ $3.1$ $R-7*$ FMC $0 - 450$ $4.8$ $R-8*$ HwNC $450 - 900$ $2.0$ $P-9*$ HuMC $450 - 900$ $2.0$	R-5*		Ss	NC	0 - 450	2.0
R-7*         F         MC         0 - 450         4.8           R-8*         Hw         NC         450 - 900         2.0           P-9*         Hu         MC         450 - 900         2.0	R-6*		P1	Т	450 - 900	3.1
R-8* Hw NC 450 - 900 2.0	R-7*		F	MC	0 - 450	4.8
	R-8*		Hw	NC	450 <b>- 90</b> 0	2.0
$10^{-10}$ $10^{-10}$ $10^{-10}$ $10^{-10}$ $2.0$	R-9*		Hw	MC	450 - 900	2.0

i.

\* Proposed New Orchards.



Fig. 1. Seed orchard planning zones.

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five by Companies. Each seed orchard manager prepares a composite working plan according to a standard format for the seed orchard complex under his/her management. This plan serves as a working document. It is revised annually and reviewed by a five-six member Technical Review Committee. The Technical Review Committee is comprised of the seed orchard coordinator, BCMF breeders and two industry representatives.

# SEED ORCHARD MANAGEMENT

Seed orchard management in British Columbia is still in its infancy since most orchards are in the establishment phase.

All of the C.T.I.C. orchards will be clonal. Parent tree lists are prepared by the seed orchard manager and approved by the T.P.C. Permutated neighbourhood or randomized complete block (with restricted randomization) designs are being used for the C.T.I.C. orchards.

Most of the clonal material will be reproduced by grafting. Limited amounts of hemlock, cedar and cypress will be reproduced as rooted cuttings. Most of the propagation for coastal seed orchards will be carried out at the Cowichan Lake Experimental Station. New facilities have been constructed for this purpose.

Based on our current level of knowledge, graft incompatibility does not appear to be a problem in any species except Douglas-fir. The BCMF is carrying on an intensive screening and breeding program for the purpose of producing highly compatible Douglas-fir rootstocks.

Past experience in seed orchard management has shown the importance of orchard location in relation to cone production. Areas experiencing summer drought are now considered prime areas for seed orchard establishment. From 1963 to 1979 some 25 seed orchards were established on the coast; 65% of the total seed produced has been by the four seed orchards located in areas of summer drought (Crown 1980).

Root pruning, using a large (44") tree spade, has proven to be an effective method of inducing cones in Douglas-fir orchards on the fringe of the summer drought areas. In one test Karlsson (1977) reported a five-fold increase in cone production from root pruning. Filled seeds per cone was the same for treated and control.

Phenology data and pollen flight data are routinely collected in most seed orchards. Since most of the present Douglas-fir orchards are established in close proximity to natural stands, pollen contamination is a very real problem. One method of overcoming this problem is the use of solid set irrigation systems. The concept of using the cooling effects of water spray to delay reproductive bud development was the first reported by Silen and Keane (1968). In a more recent paper, Fashler and Devitt (1980), reported that cooling successfully delayed 76% of the clones in Pacific Forest Products' seed orchard past the peak pollen flight period. An added benefit of reproductive bud delay is the possibility of some insect control. Miller (personal communication1) reports that if buds can be delayed by ten days, reasonably good control of the Douglas-fir cone gall midge (Contarinia oregonensis Foote) can be achieved. The process is quite weather dependent and insecticides remain the most effective method of control.

Supplemental pollination is frequently practiced due to the pollen contamination problems, young orchards producing inadequate quantities of pollen, and a desire to influence the genetic structure of a particular seedlot. The BCMF has done considerable work on supplemental pollination techniques. However, these techniques are still generally at the prototype or testing stage.

The use of supplemental pollination requires the ability to collect and store large quantities of pollen. Most orchard complexes are developing facilities for the extraction and short-term storage of pollen. The BCMF is developing a pollen bank for long-term storage of pollen at Duncan. Evacuated, vacuum-sealed containers consistently produce better seed yields although Webber (1980) is working on more efficient methods of storing large quantities of pollen.

The work of Owens <u>et al.</u> (1981) will prove invaluable in determining the timing of supplemental pollination in Douglas-fir.

As the orchards are still relatively young, few technical or logistical problems have been encountered in cone harvest. Orchard lifts or orchard ladders are presently used for access to the trees. Cones are placed in 1/3 hl cone sacks and stored on racks in cone sheds before shipment to the extractory.

### CONCLUSION

In conclusion, seed orchard management in British Columbia is in a very exciting time. We are starting to learn to manage Douglas-fir seed orchards with some degree of expertise but the establishment of orchards of six to eight additional species will provide considerable challenge and tax our ingenuity to the fullest.

<u>1</u> Gordon Miller, Entomologist, Canadian Forest Service, PFRC, Victoria

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## ABSTRACT

Recent developments in techniques to enhance flowering and seed production in conifers are reviewed. Current operation status and future requirements are discussed, and optimum strategies for their use in seed orchards considered. The conventional method of producing "genetically improved" seed in wind-pollinated, soil-based orchards is found wanting. Two new seed orchard concepts - the hedged outside, and indoor potted orchards - both full-sibling, and both offering the potential for earlier seed production and higher genetic gains, are also examined.

# RÉSUMÉ

Les auteurs examinent les progrès récents des techniques d'amélioration de la floraison et de la production de graines chez les conifères. Ils discutent de leurs applications actuelles et futures et considèrent les façons optimales de les utiliser dans les vergers à graines. Selon eux, la méthode classique de production de graines génétiquement améliorées, dans les vergers en pleine terre où la pollinisation est anémophile, est déficiente. Ils examinent deux nouvilles méthodes: les vergers à graines à l'extérieur et entourés de haies ou à l'intérieur et constitués de plants en pots, dans les deux cas de descendance biparentale et offrant la possibilité d'une production plus précoce de graines et d'améliorations génétiques plus considérables.

# INTRODUCTION

Poor flowering in seed orchards remains a major obstacle to the rapid and full realization of tree improvement benefits. Significant progress, however, has and is continuing to be made both in the area of more effective techniques to enhance flowering and cone production, and in new concepts of orchard management. These recent developments, with particular emphasis on current operation status and further research needs, are reviewed herein.

# FLOWERING ENHANCEMENT AND CONE PRODUCTION TECHNIQUES IN CONVENTIONAL ORCHARDS

Within the conventional seed orchards we are confined to basically four techniques: the cultural treatments of nitrogen fertilization, girdling and root-pruning, and the application of hormones, of which gibberellins (GAs) show the most promise. Other treatment/techniques may be feasible in the "new concept seed orchard", but discussion of these will be deferred to later sections.

Properly used in conjunction with other management practices (discussed under Growth Control) these four treatments offer considerable potential for enhancing yields of present-day seed orchards. And, increased effectiveness from all four treatments has resulted from our better understanding of the critical time(s) for influencing flowering (see Owens and Molder 1978). Additionally, we are now aware of the importance of proper siting (e.g. on well-drained soils and in regions of high solar insolation during the conebud differentiation period) for new orchards to ensure earlier and more abundant seed production.

# Cultural Treatments

As Masters (1981) has examined Weyerhaeuser Company's experience with the cultural treatments of girdling and nitrogen fertilization in Douglas-fir orchards, our discussion of them will be brief (see also reviews by Puritch 1972, Jackson and Sweet 1972, Lee 1979). Girdling has generally been the more effective cultural treatment, but for both treatments commercially significant increases in seed production are confined to sexually mature trees on favourable sites, and during years that are very favourable for flowering in the region as a whole. Even so, these treatments have the advantage of being operationally feasible, relatively inexpensive, and can be cost-effective when properly used (Masters 1981).

Puritch (1972) concluded that rootpruning, the third cultural treatment, requires further experimentation before it can be considered an acceptable cone-induction technique in conventional seed orchards. At that time rootpruning had given quite variable results with different species. There was also concern that repeated rootpruning would invite infection and otherwise adversely affect tree health. Since 1972 rootpruning has been successfully used for many years in some southern pine orchards without adverse effects (Gregory and Davey 1977). It has subsequently been shown in numerous operational and research trials to be one of the most consistently effective flower stimulation treatments for Douglas-fir (Silen 1973, Anon. 1977, Masters 1981, Ebell per. comm.).

In trials on Douglas-fir, 10-fold and greater increases in both female and male flowering were not uncommon, although, as with all treatments, best results were obtained in years that were favourable for cone induction in the region as a whole. Since inadequate pollen production rather than poor female flowering is the major problem in young orchards, it is particularly significant that rootpruning is especially effective for inducing pollen cone-buds on ramets and seedlings that are too young to respond well to other treatments, including GAs.

Based on a review of the mainly unpublished results on rootpruning in Douglas-fir, Ebell (pers. comm.) concluded that rootpruning should be sufficiently severe to cause a 40-60% reduction in height increment for maximum flowering response. Cone abortion and even death of the tree can result if the stress during induction is much higher. Ebell also observed that repeated annual rootpruning depressed accumulated cone yields, whereas biennial treatment consistently resulted in good biennial cone-bud induction. Trees should be well fertilized and irrigated the year following stress treatment, otherwise a two-year wait will be required for the next rootpruning treatment to be effective (Karlsson<sup>2</sup> pers. comm.).

Better methods for rootpruning large trees must still be developed before routine treatment of seed orchards can be considered cost-effective. Commercial tree spades commonly used in the West are, however, suitable for rootpruning small numbers of small trees. Unfortunately, the models required for larger seed-orchard trees are too expensive and too slow for operational use on a large scale. Sub-soiling by means of a tractor-mounted ripping blade, or vibrating plow, has proved to be a quick and effective treatment in loblolly pine orchards (Gregory and Davey 1977), and its use in one Douglas-fir orchard is currently being evaluated by Masters (1981). Additional research is also required to optimize treatment timing (spring vs fall), severity (depth and distance from tree) of initial and re-treatment in relation to tree size and site, and the optimum tree size to begin a regime of biennial rootpruning.

Gibberellins

For many years it appeared that GAs would only promote flowering in members of the Cupressaceae and Taxodiaceae families (see review by Pharis and Kuo 1977). For these species precocious and

 $<sup>\</sup>frac{1}{2}$  L.F. Ebell, B.C. Ministry of Forests, Victoria, B.C.

 $<sup>\</sup>frac{2}{2}$  S.A.I. Karlsson, B.C. Ministry of Forests, Victoria, B.C.

enhanced flowering could readily be induced, even in very young seedlings by exogenous applications of a number of gibberellins, including the most readily available one, gibberellic acid (GA<sub>3</sub>). Unfortunately, Pinaceae species were virtually unaffected by GA<sub>3</sub>. However, in 1973, following leads from bioassay investigation, we (Ross and Pharis 1976) found that certain other GAs, notably the mono-hydroxylated GA<sub>4</sub>/7 mixture (e.g. GA<sub>4</sub> and GA<sub>7</sub> exist in a less oxidized form than GA<sub>3</sub> which has two hydroxyl groups), would promote flowering in Douglas-fir. The efficacy of GA<sub>4</sub>/7 as a cone-induction treatment has now been demonstrated for at least 12 species representing four genera of Pinaceae (see references in Pharis et al. 1980, Ross et al. 1981). Auxins, and to a lesser extent cytokinins, can enhance the efficacy of GA<sub>4</sub>/7 in some species, although neither they nor other plant growth substances are particularly effective by themselves (Ross 1976, Pharis et al. 1980, Tompsett 1978).

Giberellin A4/7 has proved to be about the most effective and reliable flowering stimulation treatment for a wide variety of Pinaceae family conifers. Four- to six-fold increases in cone production are routinely achieved, with considerably greater responses not uncommon (see McMullan 1980, Ross et al. 1981). Rootpruning alone has elicited flowering responses of greater magnitude, but to our knowledge only for Douglas-fir (S.C. Cade et al., Weyerhaeuser Co., unpublished results). Although the hormone is most effective on sexually mature trees (see Ross 1976, 1978, Greenwood 1978), the age at which flowering can be induced is being continually reduced as research optimizes treatment conditions. Thus Brix and Portlock (1982) induced precocious flowering in potted western hemlock seedlings that were only two years old from seed by means of GA4/7 and water stress treatment — interestingly, this most responsive of all Pinaceae species also has one of the longest juvenile phases, 20-25 years.

Best results are usually achieved when the  $GA_4/7$  mixture is applied in combintaion with cultural practices, which by themselves may be ineffective in that particular instance. Both nitrate fertilization and girdling are effective in this regard (Ross and Pharis 1976, Ross <u>et al.</u> 1981), but the strongest synergistic effects have occurred with water stress (Ross 1978, Pollard and Portlock 1981). Preliminary indications are that  $GA_4/7$  plus rootpruning will be especially effective treatment combination, at least for Douglas-fir (Ross unpub.).

At present GAs have their greatest usefulness in inducing early flowering for breeding purposes. As with rootpruning, more costeffective application methods must be developed before hormonal treatment of large seed orchard trees can be considered practical, except on a limited scale (e.g. in Finland the several-fold increases in seed yield by GA4/7 in Scots pine were accomplished at a cost for hormone of about 0.2¢/seed -- not very much until one considers that 150 million seedlings are planted each year). Western hemlock and those species of Cupressaceae and Taxodiaceae that flower profusely in response to low-concentrations of aqueous GA foliar sprays are currently exceptions. But, for most Pinaceae species GA4/7 foliar sprays are relatively ineffective -- they are also costly, being quite wasteful of this still relatively expensive hormone (\$CDN 12.00/gram, 1981). Unfortunately, the more effective (in terms of hormone cost) stem- and branch-injection methods are laborious and not well suited for large trees (Pharis and Ross 1976). The prospects of developing cost-effective GA foliar sprays are good however. Special anti-evaporant oils and new ultra low volume spray (ULV) techniques have resulted in greatly enhanced biological activity from foliar-applied pesticides at only a fraction of dosage previously required with conventional aqueous sprays (Coffee 1979). Their use with GAs on conifers is currently being assessed in British Columbia. Further research is thus required to determine the best application techniques, the concentration of hormone, and the most effective treatment schedule for each species.

# Growth Control

How long until an orchard comes into commercial cone production appears to be a function of tree or propagule size, not age. Hence, the faster the early growth rate, the better. This is why seedling orchards become more productive sooner than clonal orchards, despite propagation of clonal orchards from already sexually mature individuals (Puritch et al. 1979). Seedlings characteristically grow much faster than vegetative propagules and they also have more branches (potential flowering sites) per unit of stem (Copes 1976). While it is true that poor flowering is normally associated with good growing sites, this is because the stress conditions required for enhanced cone-bud induction seldom occur at the proper time. However, it now appears that we "can have our cake and eat it too" through use of growth-acceleration techniques.

Although long known for woody angiosperms (Jackson and Sweet 1972), it has only recently been shown that subjecting conifer seedlings during their first year of free growth to extended photoperiods within the greenhouse can greatly hasten the onset of flowering following outplanting (Young and Hanover 1976, Cecich 1981).

This method of growth acceleration is much less effective on vegetative propagules where the pattern of slow and determined growth is already established. However, on mature scions growth rate can be maximized by using robust scion material and field grafting onto vigorous, well established seedling rootstock (Copes 1980). Although pot grafting has advantages from the standpoint of convenience, Copes (1980) has shown that their performance following outplanting is decidedly inferior, even in the absence of apparent pot-binding. Rooted cuttings require even more time to attain cone-production size (Copes 1976), and this method of orchard establishment can only be recommended for those species where rootstock-scion incompatibility makes the use of grafts too risky. Whatever the method of propagation, the importance of weeding, irrigation, fertilization and stocking control to minimize the time required for orchard trees to attain an optimal cone-production size cannot be over-emphasized. Seed orchard managers are often reluctant to accelerate growth since the trees will all too rapidly become too tall for economical cone harvesting and other management practices. Also, the view still prevails that height control in conifer seed orchards is neither practical nor effective. One method of overcoming this problem, annual leader removal (frequently also competing branches) beginning at a relatively young age (6-10 years) usually depressed seed yields, often for several years after pruning was discontinued (Copes 1973, Long <u>et al</u>. 1974). Furthermore, the check to height growth was only temporary, with vigorous upper-crown branches rapidly replacing the removed terminal once apical dominance had been interrupted.

The main reason why this method of height control has been generally detrimental appears to be that pruning was initiated before the tree crown had sufficiently developed. Working with radiata pine in Australia, Matheson and Willcocks (1976) found that a late, very severe top-pruning (pollarding) not only gave effective height control (3-5 years), but actually increased cone production. Flowering after pollarding of 22 m ramets to 8 m was increased greater than 70% over the next two years. Similar results were achieved by Neinstaedt (1981) in a 15-year-old grafted white spruce orchard by top-pruning the upper 33% of live crown. Pollarding of a Douglas-fir orchard has also given encouraging results in a preliminary trial by Master (1981). These studies only begin to indicate the potential that crown management offers for increasing the proportion of cone-producing branches. Research aimed at determining the optimum tree size to begin treatment and the method and severity of pruning, should be given the highest priority, with special concern toward making the application of the GA4/7 hormone treatment more effective.

## TREATMENT STRATEGIES

The question of optimum treatment strategy has recieved little research attention. However, there are some general guidelines, and we can indicate areas where further research in techniques is urgently needed in order to realize maximum cone-induction benefits.

- Treatments should be tailored for specific purposes. Thus, although neither GAs nor rootpruning has yet attained an operational, cost-effective status, their selective use to enhance seed production by the "genetically best" clones may be justified. Also, certain treatments (e.g. girdling/root-pruning) have a tendency to preferentially promote male flowering, and should be used for those clones or orchards where seed yields or genetic quality is being limited by inadequate pollen production.
- 2. The optimum treatment(s) will vary with the site (and with annual climatic conditions, but these can only be predicted "on the average"). Nitrate fertilization will not be particularly effective on sites where, during cone-bud differentiation, a high soil pH and cool, moist soil conditions favour its rapid reduction (Ebell 1972). Rootpruning may be absolutely essential on wet sites, with or without

GA4/7 treatment, if any flowering at all is to be realized. But, rootpruning could depress yields if used on an already stressful site. Unfortunately, we do not yet know how the various treatments influence flowering, and hence how they should be used to compensate for different limitations of site.

- 3. The optimum treatment(s) changes with age. This is another area where further research is urgently required, although in general we know that the older the tree, the less the stimulus needed. There is also some evidence that the severe stress necessary to induce flowering in young trees can depress cone and seed yields in older trees (Ross 1978).
- 4. There is an optimum tree size for initiation of treatments that stimualte maximum flowering per propagule. Most orchards are designed to concentrate seed production on a relatively few large trees, and crown development (and thus future yields) can be severely depressed if stress conditions are initiated too soon. Growth-acceleration techniques should be used to attain this optimum size (which remains to be determined experimentally) as rapidly as possible.
- 5. Biennial treatment--half the orchard one year the other half the next in an alternating manner--will result in greater accumulative seed yields than annual re-treatment of the entire orchard. Firstly, the trees will require at least a year to physically recover from rootpruning (or girdling) for re-treatment to be very effective. Secondly, the stress conditions conducive to cone-bud differentiation may result in increased cone and seed abortion. And thirdly, good growing conditions during the off-treatment year appear to be required for shoot recovery, and for the production of vigorous terminal buds having a high potential for differentiating cone-buds.

## NEW SEED ORCHARD CONCEPTS

Despite recent hormonal and cultural treatment developments in cone-bud enhancement and height control techniques, the traditional wind-pollinated seed orchard remains a slow, unreliable and generally inefficient method for production of genetically improved seed. Control over (or amelioration of) unfavourable environmental conditions will always be limited, and all the management problems associated with large trees can only be reduced, not eliminated.

Further, the lack of control over pollen parentage results in genetic gains considerably below those possible with contolled pollination. Two new seed orchard concepts have recently be proposed which we believe are deserving of serious consideration and further research. These are (1) the hedged, full-sibling orchard (Sweet and Krugman 1978) and (2) the indoor potted orchard (Haeussler and Ross 1981).

Sweet and Krugman (1978) describe a new approach to the production of full-sibling seed, which although specifically aimed at radiata pine, could be adapted to any species. What they propose is in essence a group of 2-clone orchards where ramets are grown in clonal "hedges" kept low by pruning, and in which pollen parentage is controlled through artificial pollination rather than by juxtaposition of clones. In addition to making artificial pollination practical, the low height of ramets (2-4 m) greatly facilitates many treatments that promote flowering, as well as the protection and harvesting of cones. The clonal-row design enables treatments to be custom tailored and optimally timed to the requirements and phenology of individual clones. It also makes for more efficient use of valuable orchard land. Inferior clones can be replaced with new selections, while retaining those of maintained genetic superiority, in what we call an in situ advancing-front design. This is possible because the hedged ramets in one clonal row are never allowed to reach a size where they will seriously affect flowering of ramets in adjacent rows.

The hedged orchard is managed for early and sustained high seed yields. Because production is diffused among many small ramets, rather than concentrated on a few large trees, as in conventional orchards, treatments to enhance flowering can be initiated much earlier. The method of crown training also differs substantially from the pollarding treatment previously described. It begins early and, in the case of radiata pine, is intended to favour the abundant production of vigorous shoots for seed cones and/or suppressed shoots for pollen production, to the exclusion of intermediate-vigor shoots which have low potential for differentiating cone-buds of either sex. For other conifer species it remains necessary to better characterize the types of shoots with high "sexual differentiation potential", than to develop the pruning techniques to promote their rapid production of small ramets.

Radiata pine breeding arboreta have been managed along lines similar to the hedged orchard concept for a number of years in New Zealand and Australia. Although seed yields per hectare have not been compared in relation to conventional orchards, they are expected to be higher. Crown training will enhance the potential for flowering, and cone enhancement techniques should also be more efficient (and effective) on the smaller ramets. Because trees are much smaller, one's ability to protect the developing cones and seeds is greater, and seed set can be icreased through artificial pollination which, in pine at least, will also reduce conelet abortion.

Much of the basic technology for artificial pollination exists now. The challenge will be to develop cost-effective methods for harvesting, processing and storing, and applying the large quantities of pollen required for high volume production of full-sibling seed. To facilitate pollen management we envisage the creation of separate orchards managed specificially for seed or pollen production. The female orchard should, so far as possible, be geographically isolated from sources of foreign pollen, although overhead sprinklers can be used to delay female receptivity and thus avoid serious contamination (Fashler and Devitt 1980). Pollen storage techniques have improved considerably in recent years, but fresh pollen is still preferred. Therefore, it will be desirable if the pollen orchard can be situated where pollen shed will predictably occur several weeks before seed cone receptivity, so as to allow sufficient time for pollen harvesting and processing. Part of the challenge must also rest with tree breeders to identify and develop parents that are not only genetically superior, but also have a high degree of male/female compatibility in pollination/fertilization if we are to justify the extra cost of producing full sibling progeny.

Indoor, Potted Orchards

The idea of culturing ramets indoors in pots to accelerate flowering for breeding purposes is not new (Pharis and Ross 1976, Greenwood <u>et al.</u> 1979), and we (Haeussler and Ross 1981) and others (Luukkanen 1980, Rottink<sup>1</sup> pers. comm.) are currently exploring its application for volume seed production.

The indoor, potted orchard has many advantages over soil-based orchards. Most important is the ability to reliably and precisely provide optimal environmental conditions for hastening the age at which cone-buds can be repeatedly induced, and cones matured, in large numbers per propagule, both over a sustained period of time. These conditions are seldom achieved simultaneously in nature, even on the best flowering sites. Potted stock is not tolerant of mismanagement, and the problems of high mortality of trees, cone-buds, and cones, together with poor seed set, that have been associated with container orchards are directly related to our ignorance of and/or lack of attention to proper horticultural practices.

Many studies have demonstrated the early and enhanced flowering of potted stock subjected indoors to inductive water stress and high temperatures at the appropriate time (Chalupka and Giertych 1977, Tompsett and Fletcher 1977, Luukkanen 1980, Ross, unpub.). The efficacy of GA4/7 and other induction treatments is also greatly enhanced (Ross 1978, Greenwood <u>et al. 1979</u>, Pollard and Portlock 1981, Brix and Portlock 1982). Additionally, there are other potentially highly effective induction treatments, such as out-of-phase dormancy (Greenwood 1981) and heat stress (Pollard and Portlock 1981), that can only be used on indoor, potted orchards.

There are also obvious advantages of working indoors with small potted propagules: ease of treatment application, pollination and cone harvesting; increased efficiency as a result of better working conditions; and relative freedom from foreign pollen. The fact that trees can be moved with minimal expense makes for efficient space

<u>1</u> B. Rottink, Crown Zellerbach, Wilsonville, Oregon.

utilization, as well as easy roguing and introduction of new clones. The ability to separate trees for special treatment is a particularly important consideration with respect to pollen management e.g. for forcing early pollen shed and delaying female receptivity.

Currently, high production cost appears to be the major disadvantage of indoor, potted orchards. However, increased seed yields and more efficient management techniques should reduce this cost (per superior seed) considerably. And, the technology of managing trees in pots for large-scale seed production is still relatively new and unproven, and management techniques must be made more cost-effective. There is also the question of how long orchard trees can be profitably maintained in pots. From the experience of commercial nurseries, 10-15 years with improved crown and root management does not seem unreasonable. By this age new, improved parental selections will be available for replacement, and the older trees could be outplanted to provide an immediately productive hedged or conventional orchard if regeneration needs could not be met from the potted seed production orchard of full sibling.

Western hemlock (see Haeussler and Ross 1981) and species of Cupressaceae and Taxodiaceae which are known to flower profusely in response to GA and/or water stress treatments are ideal candidates for the indoor, potted orchard. So too are those highly recalcitrant species (or provenances) for which a consistent seed supply is urgently required. The ability to rapidly respond to changing seed requirements also makes the indoor, potted orchard a highly suitable production method for so-called "minor species" whose potential value has yet to be determined. And, even for species that flower moderately well in the traditional seed orchard, there are the prospects for earlier seed production from desirable individuals, hence higher genetic gains. Further, in many areas prime seed orchard sites are becoming scarce and quite expensive. Potted orchards require only a fraction of the space of traditional orchards and they can be located on inexpensive and otherwise non-productive land.

It is axiomatic that progress in tree breeding remains little more than an academic exercise until the genetic gains are actually realized in better, faster growing forests. The two new orchard concepts discussed here are ways to ensure that these benefits are rapidly and fully realized. Others, such as clonal propagation through adventitious budding (via tissue culture) or rooting of needle fascicles (see Rauter and Hood 1981) may, in the future, offer the potential of multiplying each genetically superior seed into at least several hundred propagules. If so, then the potted orchard concept will become even more attractive.

Finally, despite its inherent limitations, the conventional wind-pollinated orchard, if it must be used, can become a more cost-effective production method if the recent developments (and future improvements) in cone production enhancement techniques are implemented.

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# POLLEN MANAGEMENT THROUGH PHENOLOGICAL CONTROL OF DEVELOPMENT

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# ABSTRACT

The general sequence of pollen cone and pollen development are described in 13 conifers native to British Columbia in relation to: (1) the time of winter dormancy; (2) the sequence of cell division in pollen development; and (3) the phenology of post-dormancy pollen cone and pollen development. The potential for altering the phenology of pollen cone and pollen development within a seed orchard is discussed in relation to the stages of development most likely to respond to cultural treatments.

# résumé

On décrit le processus général de développement des cônes de pollen et du pollen pour 13 conifères indigènes de la Colombie-Britannique aux points de vue suivants: la durée de la dormance hivernale, le processus de division cellulaire durant le développement du pollen et la phénologie du développement des cônes de pollen et du pollen après la dormance. On discute des possibilités de modifier la phénologie de ces développements dans un verger à graines en essayant de déterminer à quels stades du développement les traitements culturaux seraient le plus efficaces.

## INTRODUCTION

In seed orchards we must have viable pollen available when it is needed for pollinations. This requires the careful management of the pollen-cone crop. To do this we must understand the phenology of both pollen-cone and pollen development for each conifer species. From the outset we must realize that there are limitations in our ability to manipulate the phenology of pollen cone development. The duration of only certain stages of development can be altered significantly and in a seed orchard it is presently feasible only to increase the duration of these stages by cooling

The function of pollen is to provide a means for the transfer from the male cone to the female cone of the cell which forms the male gametes. We are aware of the many morphological differences between pollen of different conifers (Foster and Gifford 1972, Singh 1978). However, little is known about the phenology of pollen development for species growing in their native habitat and even less is known about the effects on phenology when we move a species into a seed orchard outside its natural range.

In this paper I would like to describe the general sequence of pollen cone development which occurs over two growing seasons and show the variation which occurs in: (1) the time of winter dormancy: (2) the sequence of cell division in pollen development; and (3) the phenology of post-dormancy pollen cone and pollen development in 13 native conifers. This should provide some insight into the potential for phenological control of pollen-cone and pollen development and the stages of development most likely to respond to cultural treatments.

## THE TIME OF WINTER DORMANCY

Pollen cones are initiated during the late spring or summer of the year before these cones shed their pollen (Owens and Molder 1978). All microsporophylls are initiated before winter dormancy but the stage of microsporangial development reached varies between species. Pollen cones of different species may become dormant, as measured by the absence of cell divisions: (1) soon after sporogenous tissue develops: (2) after pollen mother cells differentiate from the sporogenous tissue; (3) during meiotic prophase of the pollen mother cells; or, (4) after the pollen develops (Fig. 1).

Whether winter dormancy occurs at the sporogenous tissue stage as in Pinus (Kupila-Ahvenniemi et al. 1978, Owens and Molder 1977, 1981) or at the pre-meiotic pollen mother cell stage as in Abies and Picea (Owens and Molder 1977, 1979, 1980a; Singh and Owens 1981a, b) may make little difference to the ultimate pollen development. In these genera both meiosis and pollen development occur after winter dormancy. Ultrastructural studies of overwintering sporogenous cells of Pinus have shown that a true dormant period does not occur, rather nuclear and cytoplasmic changes occur in sporogenous cells throughout winter dormancy and this period is more correctly called a period of reduced activity rather than dormancy (Kupila-Ahvenniemi et al. 1978). Similar studies have not been made for Abies and Picea.

In Larix, Pseudotsuga, Thuja and Tsuga, meiosis begins in the fall then becomes arrested when pollen mother cells reach either the pachytene or the diffuse (diplotene) stages of meiosis (Owens and Molder 1971b). After dormancy, meiosis is rapidly completed followed by pollen development. As in Pinus, many changes occur in the pollen mother cells during winter dormancy. In <u>Pseudotsuga</u> chromosomes change from diffuse to granular, the nuclear membrane becomes more distinct and there is a great increase in the number of cytoplasmic organelles.

In Larix growing in Sweden, when pollen mother cells were induced to develop beyond the diffuse stage before winter dormancy, there occurred a higher incidence of pollen abnormalities than in trees in which pollen mother cells overwintered at the diffuse stage (Eriksson



Fig. 1 Stages of pollen cone and pollen development and the times when dormancy may occur in different species.

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1968). Consequently, trees moved to seed orchards in colder areas may have a higher incidence of pollen inviability or abnormalities because pollen mother cells may not have reached the "dormant" diffuse stage before cold weather occurs.

In <u>Chamaecyparis</u> and <u>Juniperus</u> meiosis and pollen development occur before winter dormancy (Owens and Molder 1974). Pollen cones overwinter containing mature dry pollen and no changes were observed, at the light microscope level, during winter dormancy. Pollen cones apparently require a sequence of short days and cold followed by long days before anthesis occurs, as has been shown experimentally in <u>Thuja</u> (Pharis et al. 1969).

Therefore, the time of winter dormancy in pollen cone development appears to be uniform within a species and attempts to alter this sequence may result in poor quality, inviable or no pollen. Exceptions may occur when pollen cones are initiated and pollen develops under unusual conditions in a greenhouse or growth chamber.

# PATTERNS OF CELL DIVISION DURING POLLEN DEVELOPMENT

Two patterns of cell division occur during pollen development in our native conifers. In <u>Chamaecyparis</u>, <u>Juniperus</u>, <u>Taxus</u> and <u>Thuja</u>, pollen is small, lacks sacci, is sculptured with orbicules, storage products are as oil droplets, and pollen is shed at the 1- or 2-celled stage. The sequence of development is shown in Figure 2. After microspores separate, the exine followed by the intime thickens, oil droplets form and orbicules from the tapetal cells are deposited on the surface of the exine. Either one or no cell division occur before the pollen is shed (Owens and Molder 1974, Owens et al. 1980b).

In Abies, Larix, Picea, Pinus, Pseudotsuga and Thuja pollen is large, sacci are present in some genera but not in others, storage products are in the form of starch and pollen is shed at the 4- or 5-celled stage. The sequence of development is shown in figure 3. As in the first type, after microspores separate and the exine followed by the intine thickens, then sacci form in some species and a characteristic sculpturing may occur on the surface of the exine. Unlike the first type, either three or four cell divisions occur before the pollen is shed (Owens and Molder 1971, 1975, 1977, 1979a, b, 1980a, 1981; Singh and Owens 1981a, b).

The sequence of cell divisions normally occurs just before the pollen is shed. In both types two non-motile male gametes form after the pollen reaches the seed cone and germinates. Variations may occur in the normal sequence of cell divisions but the frequency is usually not high and normally results in small amounts of inviable pollen.

# PHENOLOGY OF POST-DORMANCY POLLEN CONE DEVELOPMENT

The phenology of past-dormancy pollen cone development has been studied in 13 of our conifer species (Fig. 4). Within a pollen cone,



development is essentially synchronous in all pollen sacs and if differences occur it is in the distal pollen sacs of a cone where development may be slightly delayed.

Chamaecyparis nootkatensis, which forms pollen before dormancy, as do the junipers, has a brief post-dormancy stage of only 1 to 2 weeks during which time no changes have been observed in the pollen (Fig. 4) (Owens and Molder 1974).

Other native conifers have a post-dormancy period of pollen-cone and pollen development which may be as short as 5 weeks as in Larix (Owens and Molder 1979b) to as long as 12 weeks as in <u>Tsuga</u> <u>mertensiana</u> (Owens and Molder 1975) (Fig. 4). This is the time from the end of pollen-cone-bud dormancy (when cell divisions resume) to anthesis (pollen shed). Regardless of differences in the length of the postdormancy period, in different species, their pollen cones pass through five post-dormancy stages and the duration of each stage may vary between species.

Immediately following dormancy there is a pre-meiotic division stage during which either the sporogeneous cells divide to form pollen mother cells which enter meiotic prophase, or the pollen mother cells, which overwintered in meiotic prophase, rapidly resume meiosis. Because different species overwinter at different stages this period is variable between species, ranging from as little as 1 week in <u>Pseudotsuga</u> and <u>Larix</u> (Owens and Molder 1971a, 1979b) to 4 weeks in <u>Pinus monticola</u> (Owens and Molder 1977a, Singh and Owens 1981a) (Fig. 4). Increasing or decreasing temperatures during this time could significantly shorten or lengthen, respectively, the duration of this stage. However, because DNA replication, chromosome pairing, etc., may be occurring during this stage, temperature changes may cause deleterious gene or chromosomal mutations which may affect pollen development or appear after pollination.

The second stage, meiotic division, is uniformly short, lasting no more than 1 week in any species studied thus far (Fig. 4). Attempting to alter this stage would not significantly alter the length of the post-dormancy period and may result in meiotic irregularities causing reduced pollen viability.

The third stage, microspore development, varies in duration in different species from 1 week in <u>Pinus</u> monticola and <u>Thuja plicata</u> (Owens and Molder 1977a, 1980b) to 6 weeks in <u>Tsuga mertensiana</u> (Owens and Molder 1975) (Fig. 4). During this stage microspores within the tetrad enlarge and separate, the exine thickens, sacci (if present) form and starch accumulates. However, no cell divisions occur. Pollen cones usually swell noticeably at this time because of the increased size of the pollen sacs. Increasing or decreasing temperatures at this time could significantly alter the duration of this stage in some species without a high risk of genetic damage. However, pollen morphology and the amount of stored food may be affected and these may in turn affect pollen viability, germinability and vigor.

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Meiotic Division													
End of Dormancy until 1st meiotic division			Anthesis										
Total time from end of dormancy ( ) until anthesis	(early April) 7 wks	(late March) 8-9 wks	(early Arpil) l wk	(early March) 5-7 wks	(mid-April) 9-11 wks	(mid-April) 7-8 wks	(early March) 7-8 wks	(early April) 10 wks	(mid-March) 9 wks	(mid-April) 8 wks	(late Feb) 7-8 wks	(mid-Feb) 6-7 wks	(late March) 12 wks
Species	Abies amabilis	Abies lasiocarpa	Chamaecyparis nootkatensis	Larix occidentalis	Picea engelmanni	Picea glauca	Picea sitchensis	Pinus contorta var. latifolia	Pinus contorta var. contorta	Pinus monticola	Pseudotsuga menziesii	Thuja plicata	Tusga mertenslana

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Phenology of post-dormancy pollen cone development in 13 native conifers. Fig. 4

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The fourth stage is a period of cell division which is generally short. The duration varies from 1 week in Thuja plicata, where at most only one cell division occurs (Owens and Molder 1980b), to 3 weeks in some members of the Pinaceae where 3 to 4 cell divisions occur (Fig. 4). This period is greatly affected by temperature, which is often quite warm during this time. Moderate cooling or warming may slow or hasten the development. However, excessive cooling may arrest pollen-cone development and reduce pollen production, whereas, excessive warming may caused pollen to be shed prematurely. The effects on pollen viability are not certain. Since pollen is free within the pollen sacs and only some final touches of sculpturing occur during this stage, it is likely that pollen, if forced to be shed at the 2- or 3-celled stage in the Pinaceae would complete development normally once within the seed cone and viability would not be affected. However, this is a period when pollen becomes dry and forcing may prevent complete drying, resulting in a high moisture content and clumping of pollen which would adversely affect storage and dissemination. In the laboratory forcing at this time upsets the synchrony of cell divisions within a pollen cone. Consequently, the pollen may be shed at more variable stages of development.

The last stage, anthesis, involves an elongation of the pollen-cone axis causing microsporophylls to separate and opening of the pollen sacs. Opening of the pollen sacs in most species results from physical separation along a line(s) of dehiscence consisting of specialized cells differentiated in the pollen sac wall after dormancy. Anthesis appears to be a function of drying if the line of dehiscence has differentiated normally. Anthesis may be hastened by warming or delayed by cooling. Anthesis of an individual pollen cone usually occurs within a few days and often overlaps with later stages of pollen development. It would be difficult to manipulate this time enough to greatly alter the duration of post-dormancy development. Excessive cooling at this time may affect pollen moisture content and cause clumping as it does during the period of cell division. Forcing in the laboratory often causes the cone axis to elongate excessively and prematurely.

#### SUMMARY

Pollen production in seed orchards can be managed by manipulating the phenology of pollen-cone and pollen development (Fig. 4) within as yet unknown limits by modifying temperature. However, the potential for this control will vary between species and only certain stages of development can potentially be altered.

Generally, the longer the particular stage the greater the possibility of significantly altering the duration of that stage by changing the environment during which that stage occurs. At this time we do not know the relative importance of photoperiod and temperature in breaking dormancy of pollen cone buds. Sarvas (1962, 1965) has demonstrated the importance of temperature on post-dormancy pollen development, however, the effect of temperature on each of the stages of development has not be carefully studied. Caution should be used to ensure that phenological manipulations do not cause genetic or morphological damage to pollen which might affect viability.

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# STRATEGIES FOR CONTROL OF INSECT PESTS IN SEED ORCHARDS

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#### ABSTRACT

Seed orchard trees are susceptible to attack by the same complex of insects as nearby forest stands of the same or similar species. Culture practices, such as orchard site selection and cone harvest, can have pronounced effects on the levels of damage done by insects in seed orchards and on the strategies used in insect pest control. Insecticides are currently the only practical agents for insect pest control in seed orchards where need for control is immediate. In Canada, only one insecticide (dimethoate) is registered for use against cone and seed insects (excluding defoliators) and then only on one host (Douglas-fir). An expanded arsenal of insecticides is needed for use in seed orchards. The decision to apply a method of pest control must be based on the value of seed, crop size, expected losses and effectiveness of the control method. This decision requires that techniques for measuring crop size and for predicting seed losses to insects are available.

Strategies for applying insecticides are functions of the insects causing concern, which insecticides are registered for use against those insects, when applications can be made, how the insecticide is formulated, and orchard location. Insecticides should be used only when necessary and in such a way as to maximize the benefit/cost ratio of the treatment. Advantages and disadvantages of contact and systemic insecticides are discussed in relation to seed orchards, as are different methods of application.

# RÉSUMÉ

Les arbres des vergers à graines peuvent être attaqués par les mêmes insectes qui ravagent les peuplements d'espèces identiques ou semblables dans les forêts avoisinantes. Les méthodes de culture, comme le choix des stations et la récolte des cônes, peuvent avior une grande influence sur l'étendue des dégâts des insectes et les stratégies mises en oeuvre pour les combattre. Actuellement les insecticides constituent le seul moyen pratique de répression immédiate des insectes nuisibles. Au Canada, le seul insecticide homologué qu'on peut employer contre les insects (à l'exclusion des défoliateurs) des cônes et des graines c'est le diméthoate, et encore n'est-il efficace que chez le Douglas taxifolié. Il faudrait tout un arsenal d'insecticides pour les vergers. Avant d'avoir recours à une méthode de lutte contre les insectes, il faut prendre en considération la valeur des graines, l'abondance de la récolte, les pertes prévues et l'efficacité de la méthode; il faut aussi s'assurer de pouvoir disposer de techniques permettant de mesurer la récolte et de prévoir les pertes de semences dues aux insects.

Le choix de la stratégie de lutte à l'aide d'insecticides dépend des insectes en cause, de l'existence d'insecticides homologués contre ces insectes, de la période pendant laquell on peut en faire l'application, de la préparation insecticide à utiliser et de l'emplacement du verger. On devrait utiliser les insecticides seulement lorsqu'ils sont nécessaires et de façon à rentabiliser au maximum le traitement.

On discute des avantages et des inconvénients des insecticides de contact et systémiques relativement aux vergers à graines ainsi que des différentes méthodes d'application.

## INTRODUCTION

Seed orchard trees are susceptible to the same complex of insect pests as nearby stands of the same species. Orchards have characteristics that make them more suitable than forest stands for control of insect pests, namely: 1) establishment costs and crop values are high, 2) constant and close surveillance is possible and remedial actions can be taken quickly, 3) small areas are involved and there is easy access to each tree, and 4) a trained staff is available for diagnosis and treatment of problems (Dinus and Yates 1975).

Each orchard is subject to its own particular complex of insect pests, the complex being a function of the tree species and the location of the orchard. Choice of orchard location is an important consideration, since risk of attack by insects can be minimized or avoided with good orchard location. Orchards should be located on sites suited to good seed production and, if possible, isolated from stands of the same species or closely related species. The prevalence of potentially damaging insects and the probability of damage should be weighed against other factors. Insects of particular interest include cone and seed insects, defoliators and twig and shoot insects.

The importance of cone and seed insects varies among hosts. In B.C., hosts can be categorized by potential losses to cone and seed insects as follows:

Severe	Sporadic	Minor
Douglas-fir interior spruces true firs ponderosa pine	Sitka spruce western white pine western red cedar	hemlock larch lodgepole pine

Trees heavily attacked in forest stands will also be heavily attacked in

orchards, unless the orchards are isolated. The proportions of seed crops destroyed in orchards can vary dramatically from year to year and from site to site. Losses in Douglas-fir orchards in British Columbia have ranged from less that 10% to more the 90%. Cone and seed insects are rated as a top priority problem in producing Douglas-fir seed orchards in B.C. and in producing pine seed orchards in the southern United States (Overgaard et al. 1975).

Seed orchards present a different situation to cone and seed insects than do forest stands. Orchard trees are spaced to promote maximum cone production, a situation that also promotes infestations of these insects (Schenk and Goyer 1967; Kraft 1968; Mattson 1976). Stabilizing and increasing cone production in orchards may also promote increased insect populations (Mattson 1971, 1976). Cone crops are harvested whenever they occur in seed orchards, whereas in forest stands, only heavy and moderate cone crops are harvested and then only when seed from that particular forest site is needed. Most cone and seed insects remain in the cones until after harvest and are removed from orchards with each crop. Thus, these insects cannot overwinter on-site, and must migrate into orchards from adjacent stands to attack crops. A notable exception is the spiral spruce-cone borer, which leaves the cones prior to harvest.

Defoliators, such as spruce budworm and western spruce budworm, can affect seed production by attacking cones directly and through the effects of defoliation. These insects have been important seed destroyers in forest stands during outbreaks (Dewey 1970; Powell 1973; Schooley 1978). Some species of twig and shoot borers are important because they attack conelets as well as shoots (Yates and Ebel 1972).

## STRATEGIES FOR CONTROL OF INSECT PESTS

Strategies for controlling insect pests in seed orchards depend on the insect causing concern, its life history, habits and population dynamics, the tree species involved, the location of the orchard, and methods of pest control available for use. Developing a strategy for a particular situation consists of making a series of decisions.

## Is pest control necessary?

Decisions to apply pest control actions must be based on value of the seed, crop size, expected losses and effectiveness of control actions. The benefit/cost ratio must be great enough (at least 1) to economically justify taking a particular control action (DeBarr 1971; Yates 1977).

Crop inventory is an important factor in determining whether or not control actions should be taken because it is important to know the size of the crop to be protected. Thus, it is important to have a technique available for estimating the number of cones to be expected at harvest. Life tables are particularly useful in crop inventories because they project expected harvests from counts taken early in the development of cones and they point out key sources of seed loss. Life tables have been developed for cone crops of several species of pines (Shearer and Schmidt 1971: Ebel and Yates 1974: DeBarr and Barber 1975; Mattson 1978; Yates and Ebel 1978).

Insect pest populations should be monitored to determine the need for control actions. Monitoring must be done early enough for such actions to be taken, if necessary, before damage occurs. Two approaches are being developed for monitoring cone and seed insects; namely, egg sampling and adult trapping. The disadvantages of egg counts are that they are tedious and destructive (i.e., cones are removed). Adult trapping avoids both of these problems. Adult trap catches must be related to damage for this technique to be of use. Lights, sex pheromones and host attractants are potential lures for trapping. Light traps have been used to monitor lepidopterans in pine seed orchards in the southern U.S. (Yates 1973; Yates and Ebel 1975). Sex pheromones can be used to monitor population levels of codling moth in fruit orchards (Madsen et al. 1974; Riedl and Croft 1974; Madsen et al. 1975; Vakenti and Madsen 1976) and similar systems could be developed for use in seed orchards. Pheromones are involved in the mating behaviours of many cone and seed insects, including Dioryctria coneworms (Fatzinger and Asher 1971; DeBarr and Berisford 1981; Hanula et al. 1981), Douglas-fir cone moth (Hedlin and Ruth 1968; Weatherston  $\overline{\text{et al.}}$  1977), Douglas-fir cone gall midge (Miller and Borden 1981), spruce seedworm (Weatherston et al. 1977), and ponderosa pine cone beetle (Kinzer et al. 1972). The presence of attractants produced by the host has been demonstrated for a coneworm in southern pines (Asher 1970) and for ponderosa pine cone beetle (Kinzer et al. 1972).

What methods of pest control are available for use?

Insecticides are the only practical control agents currently available for cone and seed insects and other insect pests in orchard situations where need for control is immediate. However, cultural practices in orchards can have effects. The importance of orchard site selection has already been pointed out and the effects of cone removal on populations of cone and seed insects should not be underestimated. It is important to collect all cones in an orchard, including cones on graft rootstocks; otherwise, an on-site population will exist, resulting in higher losses. For example, in 1979, in a Douglas-fir seed orchard where cones on rootstocks were not collected in 1978, cone and seed insects destroyed 1.7 times more potential seeds than at another orchard less than 2 km distant where all cones were collected in 1978. Insectresistant clones have been identified in southern pine orchards in the United States (Merkel et al. 1965; Merkel 1967; DeBarr et al. 1972). Presence of resistant clones in orchards could reduce the dependence on insecticides. Unfortunately, a survey of two Douglas-fir seed orchards in B.C. indicated that clonal variation in susceptibility to several cone and seed insects was not of practical significance (Hedlin and Ruth 1978). Treating Douglas-fir with cold water to delay reproductive bud flush, for prevention of pollen contamination (Silen and Keane 1969; Fashler and Devitt 1980), has reduced damage by Douglas-fir cone gall

midge, but the effectiveness of the technique varies from year to year and cannot be relied upon.

The strategies of applying control actions depend on the type of action to be taken. The following is concerned specifically with application of insecticides since these are the only practical agents currently available for use in most situations.

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# Strategies for applying insecticides

Strategies for applying insecticides involve the following questions:

- 1) Which insecticide should be used?
- 2) How should it be applied?
- 3) When should it be applied?
- 4) Which tree should be treated?

The insecticide actually chosen will depend on the insect to be controlled, which insecticides are registered for use against that particular insect, when application can be made, and location of the orchard. The lack of registered insecticides for use against specific insects greatly restricts the strategies that can be developed for use. Only one insecticide (dimethoate) is registered for use against cone and seed insects in Canada (excluding defoliators that attack cones) and then only on one host (Douglas-fir). Orchard location can also restrict strategies, especially when an orchard is located near or adjacent to sensitive areas, such as residential areas, schools and reservoirs.

Insecticides can be grouped into contact insecticides and systemic insecticides. Each group has characteristics that affect the strategy of their use.

Contact insecticides must contact the insect to be effective. Thus, they must be applied when the insects are exposed. They are not effective against stages of insects that live within protected environments, such as cones. Timing of application is critical when controlling cone and seed insects, but not as critical when controlling insects that are constantly exposed, such as defoliators and aphids. In the case of Douglas-fir cone and seed insects, contact insecticides must be applied when strobili are open and adult insects are active to be effective and, therefore, can only be used as preventative sprays because there is no time to monitor for the need of pest control. Azinphosmethyl (Guthion<sup>®</sup>) is used in southern U.S. pine orchards to prevent infestations of coneworms (Dioryctria spp.) (Merkel et al. 1976), especially the webbing coneworm, one of their major pests. This insect overwinters as young larvae in sheltered niches, such as branch crotches, and infests cones once these larvae become active in the spring. The insecticide must be applied when the larvae become active but before they enter cones, a period of a few days.

Systemic insecticides, which are taken up by plant tissues, have advantages over contact insecticides for control of cone and seed insects; namely, that timing of application is not as critical and that systemics are less susceptible to wash-off by rain. Use of a systemic in Douglas-fir orchards allows time to monitor orchards for the need of pest control. A disadvantage of systemic insecticides is their relatively high toxicities to nontarget organisms, including trees. Operational applications of dimethoate in Douglas-fir seed orchards have shown some clones to be sensitive to, i.e., severely damaged by, a concentration of 0.5% active ingredient. The range of concentrations used in orchards for effective control of cone and seed insects is 0.5 to 1.0%.

Spraying is the only method of applying contact insecticides. Systemic insecticides can be applied as foliar sprays, paint-ons, injections, granules incorporated into the soil, and soil drenches, depending on formulation. Only foliar sprays and soil-incorporation of granular formulations have been developed adequately for operational use.

Sprays can be applied with hydraulic sprayers, mist blowers or airblast sprayer. Hydraulic sprayers, the type used in Douglas-fir seed orchards in B.C. for cone and seed insect control, apply high volume, low concentrate sprays which can be selectively directed to cone-bearing portions of tree crowns, resulting in good coverage. Good coverage is important if systemic insecticides applied as foliar sprays are to be effective against cone and seed insects (Hedlin 1966; Johnson and Zingg 1967) because, although systemics are taken up by plant tissues, they are not translocated far. Mist blowers and airblast sprayers apply low volume, high concentrate sprays. These sprayers can apply a spray to an orchard more rapidly than can hydraulic sprayers, but the sprays contain more concentrated active ingredient and are more susceptible to drift because of the small droplet sizes produced. Mist blowers and airblast sprayers are used in southern U.S. pine orchards for application of contact insecticides for control of webbing coneworm and other seed pests. These sprayers are often more efficient than hydraulic sprayers for control of defoliators and other exposed insects.

Aerial applications of contact insecticides for controlling orchard pests are being tested in the southern U.S. and show promise, but development of this technique is not complete (Barry 1981). A problem of aerial applications is the poor spray distribution that often occurs.

Timing sprays of systemic insecticides is a function of the tree species involved. The optimum time for treating Douglas-fir is when the conelets are closed and turning down, but before they reach the pendant position. Sprays applied before or after this period are not as effective. The optimum time for spraying spruce is after the conelets have closed and are just starting to turn down, but before they reach the horizontal position. Optimum spray times for other conifers have not been determined.

Granular insecticides are used operationally in the southern

pine orchards, primarily for control of seed bugs and tip moths (Merkel and Hertel 1976; DeBarr 1978; Nord 1978). Single applications of granular insecticides can be as effective as several sprays in reducing damage by these pests (DeBarr <u>et al.</u> 1972; Neel 1980). These insecticides, which are applied in the spring when the sap begins moving in the trees, give season-long control and are particularly useful against insect pests that produce several generations a year. A disadvantage of granular insecticides is their high toxicities to nontarget organisms, including mammals and especially, birds. Because granular insecticides are applied before insect attacks take place, they can only be used as preventative measures. In the southern U.S., they are used in orchards that have had histories of seed bug or tip moth infestations.

The effectiveness of treating orchards with single sprays are often adequate for insects, such as defoliators or aphids; but for control of cone and seed insects, the effectiveness of single sprays depends on the variation of reproductive bud flush. Variation in strobili development in Douglas-fir can range up to 9 days on a single tree (Allen 1943). Cones on one tree may be pendant while on another they may still be open. Two or three applications, spraying each tree only once, when conelets are at the optimal stage of development, may be necessary to ensure an effective treatment.

Treatment should aim only at producing trees, and possibly only at the heaviest producing trees, depending on seed value. It is not uncommon for 20% of the producing trees to produce 80% or more of the cones, especially in young orchards that are just beginning to produce cone crops. Treating only moderate and heavy cropped trees maximizes the benefit/cost ratio for the insecticide application by reducing the amount of insecticide used and the amount of labor required to apply the spray while protecting the bulk of the crop. This is the approach currently used in Douglas-fir seed orchards in B.C., and has been suggested as a good approach for use in pine orchards in the southern U.S. (Yates 1977).

## CONCLUSIONS

Insecticides are currently the only practical agents for controlling insect pests in seed orchards where need for control is immediate. An expanded arsenal of insecticides for use against cone and seed insects in seed orchards is needed because only one insecticide is registered for use against cone and seed insects (excluding defoliators) and only for use on one host. The strategy used for control of seed orchard pests will vary among orchards, depending on the location of the orchard, on the insects causing damage, on which insecticides are registered for use against the insects of concern and on how these insecticides are formulated. Techniques for measuring crop size and for predicting seed losses to insects must be developed for the judicious use of insecticides.
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WEYERHAEUSER'S SEED ORCHARD PROGRAM

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## ABSTRACT

A description of Weyerhaeuser's Douglas-fir orchard program on the West Coast is presented. Emphasis is placed on genetic considerations, management philosophy and flower stimulation. The program objective is to maximize genetic gain per unit time. Therefore, the orchard type chosen was clonal; the design a randomized complete block. The importance of proper spatial distribution of the orchard, and of breeding zones and ramets within are discussed, as were the problems of clone number and roguing levels. Concerning management, three phases, establishment, growth and production are discussed. For establishment, the major issue is the cost of delays. In approach, with the advent of compatible rootstock, field grafting offers a time and growth advantage, since rootstocks can be developing root systems in the field while decisions on scion source are pending. The growth phase emphasizes maximum height growth and crown volume, not only to reach production targets quickly and maximize production, but in preparation for height control. In addition to developing crown volume, culturing for maximum internode length maximizes long-term yield by allowing greater light penetration, a key element of any height control procedure. Other components of the growth phase are also discussed. The focus of the discussion of the production phase is flower stimulation. Examples of recent Weyerhaeuser data illustrate the stimulatory effect of fertilization, girdling, root pruning and gibberellins. For each, yield increases of 2.5, 2.1, 5.2 and 3 times, respectively, were observed.

# RÉSUMÉ

On présente une description du programme de vergers à graines de Douglas taxifolié de la compagnie Weyerhaeuser sur la Côte Ouest. L'accent est mis sur les aspects génétiques, les concepts d'aménagement et l'induction florale. L'objectif de ce programme est de maximiser l'amélioration génétique par unité de temps, et, pour cela, il faut un verger de type clonal entièrement constitué de blocs aléatoires. On discute de l'importance de la disposition du verger, des zones de reproduction et des ramets qui s'y trouvent, ainsi que de la question du nombre de clones et de la quantité de rebuts de sélection. Pour ce qui est de l'aménagement, on analyse trois des étapes: l'établissement, la croissance et le rendement. Le principal problème de l'établissement est le côut d'attente. Un façon d'y rémédier, maintenant qu'il est possible d'obtenir des porte-greffes compatibles, est de faire le greffage au champ; cette méthode est avantageuse du point de vue temps et croissance parce que les racines des porte-greffes peuvent se développer en attendant le choix de la source des greffons. En ce qui regarde la croissance, c'est la hauteur maximale et le volume de la couronne qui priment, non seulement pour atteindre rapidement les niveaux de rendement visés et obtenir un rendement maximal, mais aussi pour pouvoir contrôler la hauteur. En outre d'augmenter le volume de la couronne, la culture visant à obtenir la plus grande distance internodale laisse pénétrer la lumière davantage, ce qui porte à son maximum le rendement à long terme et constitue un élément essentiel de toute méthode de contrôle de la hauteur. On discute aussi d'autres sujets relatifs à la phase de croissance. L'exposé sur la phase de production porte surtout sur l'induction florale. Des résultats obtenus récemment par la compagnie Weyerhaeuser montrent l'effet stimulant de la fertilisation, de l'annélation, de l'élagage des racines et des gibbérellines, avec des rendements accrus de 250,210,520 et 300% respectivement.

### INTRODUCTION

When I was asked to discuss Weyerhaeuser's Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) seed orchard program on the west coast, it seemed that our approach to design, establishment and management of seed orchards was not unlike that of many organizations. Therefore, what should the focus of this paper be? There is not time to discuss the specific details of each and every aspect of the program. Instead, I have chosen to describe our management philosophy and discuss the reasoning behind it. Also, since flower stimulation techniques are one of our most important management tools, it is appropriate to focus on this aspect of the program as well. To that end, examples of Weyerhaeuser data for the four major stimulation techniques (fertilization, girdling, root pruning and gibberellins) are discussed. Overall, the objective of this paper is simple. That is, to present a point of view, stimulating questions and discussions, that will help in developing an orchard program. Emphasis is on the first generation only.

Any given management approach is based on a set of objectives and an ability to meet those objectives. Therefore, before reviewing Weyerhaeuser's approach, some background information is helpful. Our tree improvement programs on the west coast headed into full swing in 1965. The objective was to obtain additional product value through optimal selection of species, seed source, families and individuals within families. The system chosen to meet this objective was genetic recurrent selection. In 1967, the initial first-generation seed orchard ramets were planted at Rochester, Washington and Turner, Oregon. In 1973, additional acres were established at Sequim, Washington. Today, Weyerhaeuser manages 69.2 hectares of Douglas-fir orchards, producing seed for 11 breeding zones. The regeneration requirement through 2004 is on the average 16,200 hectares per year across 1.13 million hectares in Washington and Oregon. The average age of the oldest orchard is now 13 years. In terms of meeting planting stock requirements, there should be an abundance of seed for some breeding area; for others a potential shortage.

The objective of our orchard program is basically two-fold. That is, to produce large quantities of seed, and to maintain the proper genetic quality control to assure predicted genetic gains become realized gains. The latter is by far the more important; yet, the most difficult to achieve. Therefore, in describing our philosophy and approach it seems fitting to quickly touch on the genetic considerations before delving into management practices.

## GENETIC CONSIDERATIONS

Preliminary planning is an extremely important phase in the development of a seed orchard program. Several questions need to be answered. For example, when is the seed needed? What is the production capability? What is the planting stock requirement by breeding zone; perhaps seed zone or elevation band? Once these questions have been answered, important design questions need to be considered. The first question generally asked concerns the type of orchard -- seedling or clonal? The type selected depends on the situation. Our choice was clonal because the approach offers the following advantages:

- 1) Parents are of known combining ability.
- 2) Roguing or other spacing adjustments can be made when needed.
- 3) Inbreeding should be less.
- 4) Offers a means to preserve genotypes.
- 5) Orchards can be placed on sites conducive to seed production, etc.
- 6) Orchards can be cultured for seed production.
- 7) Flowering generally occurs earlier.

We have opted to keep the testing and seed production functions separate. By so doing, and with the clonal approach we expect to produce seed capable of maximum gain.

The design question is usually the next issue. Giertych (1975) in the text Seed Orchards, edited by Faulkner, offers a number of design options. There are many suitable designs. However, only those designs which minimize selfing and favor panmixis should be considered. Hence, our choice of the randomized complete block design, which meets both criteria. Also, it lends itself to valid clonal comparisons and to performing replicated experiments. Once the site has been selected, orchard layout questions need to be resolved. The major issue is pollen contamination. All too often we have seen examples of orchard blocks established on unsuitable sites, or blocks representing different breeding areas placed too closely together. The reasoning has been either to save space or because the acres were not available. We have our own examples of poor layout, but it is not the way it should be done. Seed orchards can become a costly embarrassment if predicted gains are not realized. Therefore, our approach will be to do the best job we can to minimize pollen contamination through proper spatial distribution of

orchard blocks and isolation of the orchard itself. Our philosophy is -it's better to be safe than sorry. Until we have strong evidence that pollen contamination is not a serious problem, or have consistent treatments to minimize its effects, like bloom delay and supplemental pollination, we will consider dollars for isolation well spent. The generally accepted width of an isolation strip is 122 meters. Some evidence suggests this is ample; some does not. It goes without saying that the distance between ramets of the same clone needs to be as large as possible. This applies to individuals within families as well. Again, the generally accepted standard has been 27 meters.

The last issue discussed will be that of clone or genotype number. The size of the breeding and production populations is completely different. The breeding population carries all genotypes required to move through time without unduly narrowing the genetic base. The production population does not. Since orchard management is costly, carry only enough clones to meet the following objectives:

- 1) To provide a representative sample size (selection) capturing the genetic diversity of the breeding area and later gain through roguing.
- 2) To provide a representative sample of the breeding area (after roguing) from which production and later performance will be based (reasonable genetic base).

So, what should the number of clones be in the final production population? Some feel 10 is ample; others feel more comfortable with 30 or 40. For now, it is still a good question. Our current thinking is that 20 is ample, but it is still based somewhat on professional intuition.

Concerning roguing levels, based on an examination of our progeny test data definitely plan for at least a 50 percent rogue. However, do not put yourself into a box during the design phase. Plan for a high roguing level. It is much nicer to have the option to remove clones, than wishing others were available. For example, it is less costly to build an "elite orchard" through roguing than by establishment. In the same vein, by not establishing enough ramets per clone, to allow for silvicultural thinning, or by limiting spacing, you can again put yourself into a box. Progeny test information seems to notoriously lag behind orchard development. Roguing to maintain ramet productivity in the future without the benefit of progeny test information can also be a costly embarrassment. Our choice would be to initially increase the number of ramets per clone, allowing for a silvicultural thin, and reaping the benefits of early production. However, each situation is different. Nevertheless, two key words are flexibility and box. You can keep yourself out of boxes by maintaining flexibility. It is good to keep in mind that sound selection, breeding and testing buy you nothing in terms of realized gain if your orchard program is not sound.

# ORCHARD MANAGEMENT

There are three phases of orchard management: establishment, growth and production. The approach to each is to discuss them separately with emphasis on the production phase; specifically, flower stimualtion. Also, the intent is not to get bogged down with nitty-gritty, but to focus on the overall philosophy.

### Establishment Phase

Generally, the establishment phase lasts one to four years. The thinking being that a tree planted later than that would be too far behind to compete successfully from a production point of view -- at least at current orchard spacings. With the use of compatible rootstock, there is some truth to this line of thinking; with wild rootstock, not so. Graft incompatibility creates holes in orchards. With these holes also comes the opportunity to move in ramets of top performing clones. It never fails, these ramets always seem to find themselves next to each other in the orchard. To rogue them means a loss in production and genetic gain; to leave them would mean considerably less yield among all competing ramets. The cost of a transplanting operation would quickly be recovered in terms of increased seed and genetic gain. Again, it points out the critical relationship in timing between the progeny test and orchard. Although the competition issue offers interesting debate and opportunity, the real issue is the cost of delaying establishment. Each year establishment is delayed means a delay in getting improved stock to rotation.

There are two common establishment techniques used. In the first, grafts are made on 1- to 2-year-old potted rootstock. Outplanting follows in the fall or the next spring. In the second, grafts are made on field-grown rootstock 2 to 3 years after planting. Our efforts with the potted rootstock approach have been successful. With this approach high grafting success is assured and establishment flexibility maintained. A drawback of the potted system is that if grafts become pot-bound, poor performance can result. Growth rate is reduced, plagiotropism seems to be accentuated and, later, wind firmness may be affected. Nevertheless, it is our preferred method of establishment.

We are, however, looking very hard at grafting on field grown stock. There are two major reasons why this approach is appealing. First, grafting on stock with well-developed root systems should offer a growth advantage. This fact is well established. One spin-off of this increased growth should be earlier flowering. Secondly, there is a time advantage. Rootstocks can be growing in the field while decision on scion source are pending. The technique is well suited to a breeding orchard situation, where growth, flowering and time are considered important. Weyerhaeuser is currently using the approach in its breeding orchard at Sequim, Washington, and is planning its use in advanced generation orchard establishment. The major drawback to this sytem would have to be increased risk of poor graft survival due to the chance of unfavorable climatic conditions during grafting. To date, however, this has not been a significant problem with Douglas-fir on the west coast.

Growth Phase

Although flowering is limited during the growth phase, there is opportunity to culture for maximum growth. Three advantages quickly come to mind. These are:

- 1) To reach full production targets as quickly as possible.
- 2) To develop a crown capable of maximum cone production (long internodes), and
- 3) To develop a crown that will minimize reduction in yield following height control (again, lengthy internodes).

The third advantage may be more important than many realize. Harvesting cones from tall trees is costly. Results from Weyerhaeuser research on height control at our McDonald orchard indicated no difference in yield ( = 0.05 level) between control ramets and those height controlled, for both the 1978 and 1980 crops (Masters, unpublished data). The paired-plot study involved 12 clones with one ramet per clone per treatment, chosen for their similarities in height and crown volume. At the time of height control, the average height of control ramets was 13.7 meters, of those height-controlled, 6.7 meters. Although the study was small, the redistribution of flowering seen on height-controlled ramets was responsible for the comparable yields on those ramets. Larger studies have been installed. Therefore, in addition to developing crown volume, culturing for maximum internode length maximizes long-term yield by allowing greater light penetration, an important element of any height control procedure.

Still, there are many unanswered questions about how to maximize the growth of Douglas-fir. Fertilization is obviously an important treatment. A Weyerhaeuser technical report "The principles and practice of nutrition in Douglas-fir seed orchards" (Masters and Webster 1980) summarizes the state of the art on Douglas-fir nutrition for growth. The information in this report offers guidelines on monitoring nutrient status as well as developing the fertilizer prescription. Overall, our objective is to maintain nitrogen, phosphorus and sulfur at high levels and the other micronutrients at medium levels. Also, the micronutrients are not allowed to reach critical levels. Irrigation is another treatment that can be used to improve growth. Some sites require it; others do not. Concerning a specific prescription, we have none. When our soils dry we water to field capacity. Our most frequently used monitoring device is the Pressure  $Bomb_{\perp}^1$ . Other cultural practices have been used from time to time, depending on the situation -- viz. subsoiling and weed control. Subsoiling improves aeration of heavy soils or those heavily compacted. Weed control, again depending on the situation, can reduce competition for light or moisture. It can also provide some rodent protection.

<sup>&</sup>lt;u>1</u> PMS Instrument Company, Corvallis, Oregon

Before moving on to the production phase, another question that must be asked -- when does culture for growth shift to production? There is no specific point at which the shift should occur. The decision should be made based on ability to meet planting stock requirements. This means pooling information on orchard stocking levels, site productivity and response to stimulation treatments. For some, it might be at the point Douglas-fir begins producing significantly, which is generally between the ages of 10 and 12. These ages will, of course, vary and depend on site and the successful culture for growth. Others, and Weyerhaeuser currently fits into this group in some situations, may feel the need to wait until larger crown volumes are attained before beginning a stimulation program. The concern is that reduced height growth (a characteristic of flower stimulation treatments) will foster development of compact crowns reducing future yields. Production then occurs only on the outside edges of the crown because of poor light penetration. Still others may favor high density plantings, practicing stimulation early to obtain early yields. We are working toward this position in the future. We want our best material into the field quickly. Also, we have placed ourselves into enough boxes in the past. We want the flexibility to manipulate genetic gain and we want to keep our trees low. Whether we are talking about harvest, supplemental mass pollination or insect control, small trees are less costly to manage.

## Production Phase

"Production phase" to us means flower stimulation. And we are nearing this phase of our management. However, graft incompatibility, changing planting stock requirements and poor orchard site selection in one case, make it essential to carefully consider what we do. Our concern at the moment is that intensive flower stimulation too early will reduce growth and future yields. There is one exception. We do fertilize to stimulate flowering but only because the rates we use do not negatively impact growth. So currently, our focus is to learn as much as we can about what our flower stimulation practices should be. Therefore, the discussion of this section will revolve around examples of recent Weyerhaeuser data collected on each of the four major flower stimulation treatments: fertilization, girdling, root pruning and gibberellins.

## Fertilization

The practice of fertilizing Douglas-fir to promote flowering has been with us for some time. Various rates and types have been used. Generally, rates have ranged from 224 to 448 kg N/ha, with the nitrate form of nitrogen being the type most commonly used. Success has been varied, with fertilizer rate and type, site and tree age (maturation) all being important variables. Weyerhaeuser has not done any fertilization research since the mid-70's when the operational recommendation of 224 kg N/ha calcium nitrate was made. More is planned in the future because we do not feel we have the best prescription. Nevertheless, significant responses in flowering, even at low rates are possible. The data represents an operational check of the prescription and is based on individual production.

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Table 1 illustrates the effect of calcium nitrate fertilization at 224 kg N/ha on the 1980 crop at Turner, Oregon (Masters and Dotter, unpublished data). Half the Coos Bay and Springfield low-elevation blocks received fertilizer in 1979. As a result of this treatment, the difference between fertilized and control groups was striking. Significant increases in yield can be seen for all production traits (Table 1). However, the most striking difference was in the total cones. The percent increase in total cones for the 12-year-old Coos Bay block and the 11-year-old Springfield block was 145 and 59 percent, respectivly. In terms of actual numbers, the Coos Bay block produced an additional 69,498 cones; the Springfield block, 44,427 cones. Not only did the treatment increase the number of trees producing, but also the yield on those destined to flower. Had the size of the 1980 crop been predictable in the spring of 1979, and the whole orchard fertilized rather than half, an additional 3.3 kg/ha of good seed would have been produced in the Coos Bay block alone. Thus, a total yield for Coos Bay of 16.5 kg/ha would have been a very respectable yield for a 12-year-old orchard.

Table 1. The effect of calcium nitrate fertilization (224 kg N/ha) on cone production at Turner,  $Oregon \frac{1}{2}$ .

Trait	Coos Bay Bl	ock (CB)	Springfield B	Percent		
	Fertilized	Control	Fertilized	Control	Increase	
	(N=494)	(N=495)	(N=650)	(N=650)	СВ	SP
Total Cones	117,472	47,947	119,989	75,562	145	59
Producing Trees	243	162	285	217	50	31
Cones/Prod. Tree	483	296	421	348	63	21
Cones/Tree	238	96	184	116	148	59

 $\frac{1}{2}$  1980 Data: Coos Bay age 12; Springfield, 11.

### Girdling

Girdling should be considered a viable flower stimulation tool in seed orchards. Based on past Weyerhaeuser research and that of others, yield increases of 1.5 to 2 times are not unreasonable. In 1979, a pilot girdling trial was initiated at Turner, Oregon, and Rochester, Washington. Its purpose was to determine flowering effectiveness on a large scale, and to help determine long-term application strategies.

The study was designed to compare ramets treated with an overlapping half-circumferential saw girdle (main stem) to ungirdled (control) ramets. The distance between the girdles was set at 1.5 times the diameter of the stem. Eight rows in each orchard were selected for girdling, and an additional 8 were treated as controls (= 250 ramets/ treatment/orchard). All study trees selected were relatively uniform with respect to growth with no signs of graft incompatiblity. Included in the study were plans to assess the effect of yearly girdling and alternate year girdling. First-year results (1980 crop) were again striking (Masters and Ross, unpublished data). Yield increases in total cones produced were 78 precent at Turner, Oregon, and 115 percent at Rochester (Table 2). Increases in yield seemed equally split between increases in total producing trees as well as in cones per producing tree. In addition, significant increases in male production were noted (not shown).

	Turner		Rochester (LV)					
Trait	Girdling	Control	%	Girdling	Control	%		
	(N=256)	(N=255)	Inc.	(N=276)	(N=271)	Inc.		
Total Cones	34,405	19,322	78	26,807	12,526	114		
Producing Trees	117	86	36	92	54	70		
Cones/Prod. Tree Cones/Tree Cone Effic. (%)	$294+39^{2}$ 134+19 66+6	225+50 76+18 70+10	31 76	291 <u>+</u> 53 97 <u>+</u> 20 88 <u>+</u> 3	232+52 46+12 80+4	25 111 —		

Table 2. The effect of girdling on cone production at Turner Oregon and Rochester, Washington  $\frac{1}{2}$ .

 $\frac{1}{2}$  1980 data: Turner age 12; Rochester, 11.

 $\overline{2}$  Standard error.

## Root Pruning

Root pruning with a Vermeer tree spade or subsoiling has become a standard flower stimulation treatment in many orchards. Examination of the state of the art shows the potential exists to at least double yields. In fact, a quadrupling of yields is not unreasonable. For example, in 1974, a study involving two root pruning treatments and a control was initiated on 7-year-old grafted Douglas-fir at Rochester, Washington (Masters et al. 1981). Root pruning was achieved by fully extending all four blades of a 762-mm Vermeer tree spade without lifting the tree. An early treatment (April 19, 1974) was timed to correspond with the beginning of vegetative bud swell; the late treatment (June 26, 1974), to the end of rapid shoot elongation. In all, each treatment involved an average of 2.5 ramets from each of 20 clones. The results indicate that 74 percent of the early root-pruned clones produced female cones and 54 percent produced male buds (Table 3). The percent of clones flowering in the control group was 22 and 20 percent for female and males, respectively. Early root pruning significantly (0.05 level) increased the number of female cones per cone-bearing ramet, female cones per ramet and male buds per ramet 5, 34 and 9 times respectively. Filled seed per cone was not affected by treatment. Based on the evidence, root pruning has been recommended as a flower stimulation treatment in breeding and seed orchards. However, work continues on a more cost

efficient approach to this treatment -- subsoiling.

	Percentprod	Clones ucing	Female Cones/ producing ramet		Female Cones per ramet		Male Buds per ramet	
Treatment	Females	Males	n	x	n	x	n	x
Early root pruning Late root	74 ·	54	22	120a <sup>2</sup>	41	68a	41	520a
pruning	43	37	8	4ъ	41	1Ь	41	5b
Control	22	20	15	23ъ	196	2ь	196	60ъ

Table 3. The effect of root pruning on the production of female cones and male buds in the Longview block at Rochester, Washington<sup>1</sup>

 $\frac{1}{2}$  1975 data; graft age 8

 $\frac{1}{2}$  Values with the same letter do not differ significantly ( = 0.05)

# Gibberellins

The research on gibberellic acids (GA) to promote flowering in Douglas-fir and other species has been extensive. The literature on this subject is ample. The work at Weyerhaeuser was pioneered by S.D. Ross, and the results have been successful. A testimony to that success is our use of stem-injected  $GA_{4/7}$ ,  $GA_{4/7}$  + girdling and  $GA_{4/7}$  in combination with other treatments operationally in our breeding orchard. When these treatments have been applied to young ramets (3 to 4 years old), they have made the difference between having a crop and not having one.

Our concern now is to expand this technology for use on large production orchard trees. Research on the "cut-branch" method of injecting GA into large trees has been successful (Masters, unpublished data), but the method is labor intensive and has other drawbacks as well. Foliar application of GA is our goal. The initial work at Weyerhaeuser by Ross (1979) was successful. Individual branch treatments to 9 year old Douglas-fir grafts resulted in 27 percent of the branches yielding females, and 15 percent males. Controls bore no flowers of either sex.

In 1978, in support of Ross' work, I initiated additional work on foliar application of GA. The objective was to confirm the response obtained with individual branch sprays by treating whole trees. The study, a clonally balance paired test, involved 10 weekly applications of foliar GA4/7, and a control. The treatments were applied to 8 clones and 4 ramets per treatment per clone, in the 8-year-old Cascade block at Rochester, Washington. Both clone and treatment sources of variation were significant at the 0.01 level. The control mean was  $81 \pm 45$  (S.E.) flowers and yielded a total of 2352 harvested cones. For the spray treatment, the mean was  $246 \pm 79$  flowers, producing a total of 6942 harvested cones. The response was clearly, a 3-fold increase (Table 4). The data are self-explanatory. The most significant impact was in the number of clones and ramets flowering. However, there was also a significant increase (62 percent) in the number of cones per producing tree. Also, no significant difference in cone or seed efficiency was observed. It is acknowledged that improvement in the time and duration of treatment is needed to make large-scale foliar spray applications less costly. Also, work on method of application is needed. Some of this work is ongoing. It is clear that foliar application of GAs in seed orchards is near at hand.

Table 4. The effect of GA foliar spray on cone production in the Cascade block at Rochester, Washington  $\frac{1}{2}$ .

Trait <sup>2</sup>	Control (N=32)	Foliar Spray (N=32)	Percent Increase		
Total Cones	2,352	6,942	195		
Producing Trees	11	20	82		
Percent Producing Cones	63	100	59		
Cones/Producing Tree	241+112	347+98	62		
Cones/Tree	74+41	217+68	193		
Cone Efficiency (%)	91				

 $\frac{1}{2}$  1979 data; graft age 8.

 $\frac{2}{2}$  Treatments were significantly different at the 0.01 level.

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# STRATEGIES

# FOR

# TREE IMPROVEMENT

Chairman:

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# DECISION MAKING AND STRATEGY OPTIONS FOR TREE IMPROVEMENT

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### ABSTRACT

Procedures for tree improvment are examined in relation to the common management activities of planning, implementation, and control. Planning calls for a clear and acceptable enunciation of purpose, a decision on how to select strategies, identification of strategy options and their subsequent evaluation, and a consideration of risks associated with the chosen pathway. Implementation is effected through training, although it is expedited if planning procedures are properly explained to all parties when several organizations are involved. Similarly, control is favoured by commonly recognized objectives and a sense of mutual commitment.

# RÉSUME

On étudie les méthodes d'amélioration des arbres en considérant les étapes normales de l'aménagement: la planification, la mise en oeuvre et la conduite de projet. La planification exige que le but soit exposé de manière claire et acceptable; il faut décider de la façon de choisir les stratégies, déterminer lesquelles on peut employer, en faire l'évaluation et calculer les risques que comporte le choix qu'on fait. La mise en oeuvre se fait par l'apprentissage, bien qu'elle puisse être accélérée si les méthodes de planification sont bien expliquées à tous et chacun lorsque plusieures organismes sont en cause. De même, la conduite du projet est facilitée si tous s'entendent sur les objectifs et considérent qu'ils font partie d'une équipe.

## INTRODUCTION

The word "strategy," stripped of its original military meaning, can be defined as a plan for the skillful management of any enterprise. At first glance, tree improvement appears to require only a simple plan. On further consideration, as the complexities of gene pool formation, biology of seed production, uncertainties of cost and benefit, and problems of long-term commitment are unveiled, we see that there are many possible strategies for this complex enterprise. Choices among options become necessary as does the need to organize information in ways that facilitate decisions.

Subsequent speakers will present some specific strategies. In preparation for those discussions, I have chosen to emphasize management of the process by which strategy options might be evaluated. Management is often symbolized by the sequence of activities shown in Figure 1. Let's consider how the way in which strategy options are chosen might influence the success of those activities.

# PLANNING

At a recent meeting of tree breeders, a silviculturist remarked that there is an attitude of "true belief" among breeders; an attitude sometimes undaunted by economic realities. Our symposium reflects the view that tree improvement starts at the indicated point in Figure 2. It should be pointed out, however, that tree improvement has a better chance of maintaining the required long-term commitment if the choice to develop a program has been made after a comprehensive review of options in intensive forest management. Challenges to preceding steps in the path leading to a tree improvement program are immensely frustrating.

In planning skillful management, I see five general questions to be asked:

- 1. What is the purpose of a particular tree improvement program? A few forestry managers seem to still accept a reply of "to achieve genetic gain." Increasingly, however, an answer of "to develop an investment opportunity that compares favorably with alternative investments" probably will be more acceptable in both public and private organizations.
- 2. How shall we choose what to do? Here I refer to the process of decision making. Although the basic phases of selection, propagation, and orchard establishment are reasonably obvious, variations on the general strategy of tree improvement are numerous and can be complex.

One way to choose a tree improvement strategy is to follow the leader. This often appears to be the choice of forest industry and probably is optimum where the leader has a good strategy which matches the needs of followers.

At levels of greater participation in tree improvement planning, more careful analysis is required. That analysis should begin with the identification of which factors are important in evaluating alternative strategies. Gain per year, years to seed yield, progeny test acreage, total cost, etc. are examples of criteria by which to measure alternatives. Having a common set of negotiated criteria does much to reduce arguments from disparate points of view.

3. What are the strategy options? Many of us do a less-thancomprehensive survey of alternatives in choosing a tree improvement strategy. Despite the fact that we usually are constrained by inherited programs, there are some non-traditional options that might be of value in some programs. Table 1 lists a few rarely considered possibilities, each of which is more or less technically feasible at



Fig. 1. Activities in management



Fig. 2. A decision tree in forest management

present for some species or areas. Current rapid progress in cell biology research may soon open options that we easily dismiss today.

- 4. Having decided which criteria are important, and having arranged tree breeding options, the choice of which option to implement involves evaluating each option for each criterion. A variety of formal analytical techniques exist for this purpose. They include systems of numerical weighting, probabilistic decision trees, and matrices where only data (as contrasted to arbitrary scores) can be entered. Figure 3 shows portions of a criteria/alternatives matrix used to guide a choice of seed orchard type and location. Each of these techniques leads, in a systematic way, to the identification of a preferred alternative.
- 5. What might go wrong if the chosen alternative is followed? If risk is not included among the criteria by which alternatives are evaluated, an estimate of risk for the preferred option should be made. Risks in a high cost-high benefit approach, for example, would include chances of decreased funding at critcal times.

Perhaps the intially chosen option will be seen to carry too much risk and a more conservative option will be chosen.

Table 1. Some non-traditional options for tree improvement.

A. Bulk population breeding: Establish plantations with a desirable

- A. Bulk population breeding: Establish plantations with a desirable genetic base, ignore pedigree, rogue on basis of individual performance, utilize as a seed orchard.
- B. Multiple Index Selection: Develop replicate populations, choose trees for seed production within that population which has the best combination of traits.
- C. F<sub>2</sub> selection from wide crossing: Cross provenances, induce early flowering, produce an  $F_2$ , screen for exceptional segregants, propagate vegetatively or by seed.
- D. Cell selection: Expose cultured tissues to selective forces, regenerate surviving cells, propagate vegetatively or by seed.

CRITERIA	Field O (4 loca owners combina A B		Orcha ation ship ation C	ard n- ns) D	Potted Orchard (l location- ownership) E	Potted Field (5 location- ownership combinations) F G H I			
SEED PRODUCTIVITY POTENT Mean maximum temperatu Mean moisture deficit	IAL re								
FACILITIES COST Irrigation Growth system									
ORCHARD TREE COST Propagation Root Control Irrigation Fertilization Monitoring Protection Weather					- ·				
SEED PRODUCTION Chemical induction									
GENE DILUTION									
GAIN PER UNIT TIME									

Fig. 3. Abstract of a criteria/alternatives matrix for choice of a seed orchard type and location.

# IMPLEMENTATION

Implementation in tree improvement is largely a matter of training where a resident tree improvement staff exists. More challenging is the case where implementation requires persuasion of people in other organizations. It seems to me that presentation of the process by which a particular tree improvement strategy was chosen could be useful in gaining support of those who implement the plan as well as those who provide administrative approval.

# CONTROL

Control is an activity which varies widely in degree among different organizations. Where a tree improvement strategy is implemented within one organization only, control ought to be fairly simple. By contrast, in cooperative programs, the range of knowledge and commitment among different partners would seem to require some standardization of critical activities. On-site inspection by a central tree improvement staff has been effective in some programs. Publication of standards for principal program activities has been useful in others. Perhaps the key elements here are related to those which have made Japanese industrial production the recent envy of the world, namely, a sense of common objectives and mutual commitment. Perhaps here again, formal processes of choosing options, openly presented, can be useful.

### CONCLUSION

Our next speakers will be discussing some specific strategies in tree improvement. I hope that my introductory comments will have been useful in helping us to relate those strategies to our own tree breeding programs.

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# INTERIM SEED SUPPLIES BEFORE SEED ORCHARDS ARE PRODUCTIVE

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# ABSTRACT

For most species in Canada, seed production in orchards falls short of the seed required for reforestation. Some measure of genetic control or gain is nevertheless attainable through appropriate choice of seed sources. Designation of seed zones or site regions is an important preliminary step in controlling seed movements.

The role and limitations of local provenances, tested provenance, tested stands, seed collection areas, seed production areas, and selected trees are discussed.

# RESUME

Dans le cas de la majorité des essences d'arbres au Canada, les vergers ne produisent pas assez de graines pour répondre aux besoins des programmes de restauration forestière. On peut quand même obtenir un certain degré de contrôle génétique ou un certain gain génétique en faisant aun choix judicieux des origines des graines. Pour contrôler les déplacement de graines, il est important d'indiquer qu préalable les zones au les régions d'où elles proviennent.

Cette communication discute du rôle et des limites des provenances locales, des semences et des peuplements certifiés, des zones de production et de récolte des semences, de même que des arbres sélectionnés.

## INTRODUCTION

Various tree improvement programs have been or are being developed all over Canada. One of the objectives of these programs is to develop improved genetic material that will be reproduced in production seed orchards.

For some species, a certain amount of improved seeds is already available. But for most species, it is expected that improved seeds from the orchards will be available in a certain number of years from their establishment, usually not before 10 years. Meanwhile, seeds and good seeds are needed by the billions to meet the requirements of the various artificial regeneration programs throughout the country. It is imperative to get the best seeds possible for these programs because the small genetic gain achieved on one single seedling will become most important when repeated millions and millions of times. Various means of getting these seeds until seed orchards yield their full quota are suggested hereafter.

#### SEED ZONES

One of the preliminary steps towards getting better results from artificial regeneration is to divide the province into seed zones or site regions (Ontario) based on climatic data or other factors affecting tree growth. In those zones or sites, the genetic characteristics of a given species are relatively uniform.

Unless there is strong evidence that seeds collected in one zone will perform satisfactorily in another zone, no seed movement between zones should be allowed. Seeds collected in one zone should then be used within the same zone or site region.

Most of the seeds actually needed in artificial regeneration programs are collected this way. That is, cones are picked from phenotypically good stands and kept separated by zone or even by some other subdivisions within the zone. Large seed lots are identified by stands within zone while smaller lots are bulked at extraction time, at least in Quebec. Non-identified seeds brought in by pickers should not be accepted at all.

## LOCAL PROVENANCES

A common conclusion from any provenance test is that "local seeds are best". This is so because trees have become adapted to the climate and environment in which they are growing through generations of natural selection. However, as for most rules there might be and in fact there are some exceptions. For example, other provenances than the local might survive and grow better when planted on the same site (e.g., the white spruce provenance from Beachburg, Ontario). If one is not aware of the extent of seed movement or if no research has been done in a given area or for a given species, the safe rule should be "collect locally". In that case, "local " seeds might be referred to as seeds collected in a township, an administrative unit, a small seed zone or any other convenient subdivisions of a territory.

Exact identification of the provenance should follow each seed lot from collection through extraction, seedling production and plantation in the field for future references. Here again, non-identified seeds should not be accepted.

# TESTED PROVENANCES

Geneticists have been actively engaged in provenance testing for many years now. They have shown what type of variation (clonal or ecotypic) can be expected throughout the range of a species. They have also identified some provenance that will outperform the local one.

If the testing has been conducted over many years and if the original stand(s) tested is or are still available, large quantities of seeds can then be collected and be used with the local or instead of the local ones. Such stand(s) should also be reserved and managed for future abundant crops.

In that respect, as soon as a provenance gives some clues that it will be a good one, the stand should be saved from exploitation until more definite results are available. Too many good stands or provenances disappear during the lag period of testing.

### TESTED STANDS

Some provenances have tested or are testing better-than-average stands in order to provide an immediate source of well-adapted seeds. These tests are conducted at different locations in a province or part of a province. They will show which stands provide the best seeds for a given area. Seeds collected from many trees in these stands will be bulked and used either locally or at some other locations depending on the results of the tests.

Seeds collected from these stands will also provide valuable information as to seed movement within or between zones. The best stands so tested can be reserved and managed as seed production areas or seed collection areas. A greater genetic gain can also be expected if seeds are collected only on the best phenotypes in these tested stands.

## SEED COLLECTION AREAS

Seed collection in these areas is suited to such species as black spruce and jack pine which naturally occur in large, pure, even-aged stands and for which large quantities of seeds are needed annually for the artificial regeneration programs.

They are phenotypically good stands and they will provide large amounts of well-identified seeds with no or with a small genetic gain depending on the original quality of the stand. They may or may not have been tested.

Cone collection is generally done by felling a portion of the stand during a good seed year. It is generally recommended that a portion of the seeds be returned to the cut area in order to preserve the gene pool. Little or no management for increased seed production is generally done in these seed collection areas.

# SEED PRODUCTION AREAS

Seed production areas are phenotypically good natural stands or plantations of known origin in which some management practices have been conducted in order to increase their quality and their seed production. If poor phenotypes are removed, genetic gains up to 10% might be obtained. Usually, these stands have been or will be tested. They are established in rather young but sexually mature stands in order to respond better to the cultural treatments.

Seeds may be collected from standing trees or from felled trees when the stands have become too old or too difficult to climb.

The tested seed production areas will provide the best seeds for artificial regeneration programs until improved seed is available from seed orchards. Such species as white spruce, white and red pine are best suited to this approach.

## SELECTED TREES

In an extensive plus-tree selection program as for black spruce and jack pine, a large number of phenotypically superior individuals are selected in various superior stands. These trees will be progeny-tested and the best families will be kept in a first-generation seed orchard. Since the selected trees are generally felled to ease cone collection, all cones can then be collected.

A portion of the seeds obtained from each of these can be taken, bulked and used for plantations. Usually, the amount of seeds available by that means will be rather small but they are another good source of well-identified superior seeds. Moreover, the plantations established with these seeds will provide, after being thinned of the poor phenotypes, and being managed for abundant seed crop, a future source of well-identified superior seeds.

## PURCHASING OF SEEDS

Purchasing seeds from commercial dealers can be tricky. Each agency needing seeds should have its own seed collection program. Nevertheless, if seeds must be purchased, make sure that you can trust the dealer or that you buy only certified seeds as to their quality and exact provenance.

### CONCLUSION

Many seed orchards have already been established for many species throughout the country and others are being set up every year. Many are still too young to produce seeds, do not produce enough seeds yet or do not flower properly. Meanwhile, large amount of seeds are needed annually.

For those organizations now working without seed orchards and that will continue to do so for many years, large amount of good seeds could be collected from seed production or collection areas, depending on species, established in each seed zone. If good provenances have been identified by proper experiments, seed should also be collected from those original stands if still available. If no seed production or collection areas have been established or if reliable results from the provenance tests are not available, seed collection should be confined to the best phenotypically local stands in each zone and if possible, to the best trees in these stands.

Finally if a tree improvement program is underway for an origanization, trees must have been or will be selected. Smaller quantities of good quality seeds can thus be obtained from these trees and used as partial fulfillment of a regeneration program.

## USES FOR ROOTED CUTTINGS IN TREE IMPROVEMENT PROGRAMS

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## ABSTRACT

This paper presents a summary of the uses for rooted cuttings in various phases of a tree improvement program, namely breeding orchards, cutting orchards, production seed orchards, research plantations and production plantations. It also mentions some of the concerns regarding rooted cuttings as well as some of the problems that need solutions.

# RÉSUMÉ

Ce document résume l'usage qu'on peut faire des boutures racinées au cours de différentes étapes d'un programme d'amélioration des arbres, en particulier dans les vergers de reproduction, les verges de bouturage, les vergers de production de graines, les plantations de recherche et les plantations de rendement. Il fait également état de quelques points concernant les boutures racinées ainsi que de quelques problèmes à résoudre.

## INTRODUCTION

Vegetative propagation has long been employed in tree improvement programs, principally in the form of grafting. Much attention has been focused on the promise of tissue culture, but considerable development is still necessary before the promise can be fulfilled. Rooted cuttings are a third form of vegetative propagation, and the one on which this paper will concentrate. Although several of the hardwoods, such as the Euramerican poplars (<u>Populus x euramericana</u> (Dode) Guinier), have been commonly propagated by rooted cuttings (Zsuffa 1976), <u>Cryptomeria japonica</u> (L.F.) Don is the only coniferous species propagated by this technique on a significant scale (Toda 1973). Recently there has been a pronounced increase in the use of rooted cuttings as a tool in tree improvement research and also as regular planting stock. The objective of this paper is to review the uses that rooted cuttings may serve in the various phases of tree improvement.

## BACKGROUND

In the late 1930's and early 1940's, several Canadians worked on the rooting of various coniferous species (Grace 1939, Griffith 1940, Farrar and Grace 1942). Although they did have some success, their programs were unfortunately discontinued due to World War II. In the 1960's, there was renewed interest in rooting in several species and in several countries throughout the world (Thulin & Faulds 1968, Rauter 1971, Kleinschmit et al. 1973).

This interest continued to grow and by the 1970's, it was felt that there was a role for rooted cuttings in tree improvement programs, provided that some major problems could be overcome. Two areas of major concern were: 1) determining the factors that influenced each species' rooting ability, and 2) the subsequent field performance of the rooted cuttings.

During the 1970's, symposia were held to discuss the success of rooting programs, to identify questions that needed answers and in some cases to provide answers to questions that had been asked. Two of the symposia, one in New Zealand in 1973, and one in Sweden in 1977, dealt entirely with the vegetative propagation of forest trees. (See references under 'Symposia'.) Many of the questions have since been partially answered, and many more are currently under investigation. Now, during the 1980's, a serious effort should be made to effectively incorporate rooted cuttings into tree improvement program.

## USES FOR ROOTED CUTTINGS

The uses of rooted cuttings can be assigned to five major areas on the basis of various objectives and procedures of research and management. The areas are: 1) breeding orchards, 2) cutting orchards, 3) production seed orchards, 4) research plantations, and 5) production plantations. The role of the traditional 'clone bank' is filled by both the cutting orchard and the breeding orchard.

## Breeding Orchards

The breeding orchard, as outlined by Rauter (1980), is designed to provide a source for producing new combinations of genes that will be suitable for advanced-generation programs. The trees in the breeding orchard may be representative of one or several of the following objectives:

- 1) A reserve of clones occurring in the seed orchards for insurance against destruction by such agents as wind or fire;
- 2) Controlled pollinations to produce families for progeny testing and/or advanced-generation breeding;
- 3) A reserve of phenotypes that are not currently in the production orchard, but represent traits that may be useful in the future;
- A reserve of plus tree selections of species that do not currently have a sufficiently large regeneration program to merit a production orchard;
- 5) Selections from certain exotic species as a source of pre-adapted genes for specific environmental conditions or with resistance to a given pest (Rauter 1980);
- 6) Samples of given gene pools that require conservation.

Although a clonal breeding orchard is normally established with grafted material, rooted cuttings can provide a viable alternative particularly when graft incompatibility is a problem. Since the number of ramets required per clone is small -- many fewer than for a production orchard -- good rooting ability is not important. Also, growth and form are not very important in a breeding orchard, thus cuttings do not have to be taken from young seedlings, but can be taken from older trees.

The management objective for the breeding orchard is to produce flowers for controlled pollinations. The trees should be subjected to flower inducing treatments such as fertilization, drought stress and hormone application. Since open pollinated seed is not utilized, the layout can be simple and systematic to facilitate the crossing work. Isolation from contaminating pollen sources is also not critical.

Cutting Orchards

The cutting orchard is designed to provide vegetative propagules of selected genotypes for current or future programs. The objectives may be the same as many of those listed above for breeding orchards. However, the management objective is to encourage <u>vegetative</u> growth and to promote ease of rooting through whatever technology is available.

The source material in the cutting orchard may consist of rooted cuttings, seedlings or grafts. Since the prime objective is to produce good quality cuttings for as long as possible, each cutting donor should be hedged, re-rooted or otherwise manipulated to retard maturation of the donor (Libby 1979, Libby and Hood 1976). The number of ramets per clone can vary from a few, when serving a clone bank function, to many when serving as a source of rooted cuttings for an artificial regeneration program. This latter function assumes that a species has sufficiently good rooting ability in a juvenile state to make a production cutting operation efficient. The same advantages in terms of layout and location discussed for breeding orchards also apply to cutting orchards.

## Production Seed Orchards.

The production orchard as outlined by Rauter (1980) is established to produce genetically improved seed that will fulfill the seed requirements of an artificial regeneration program. Seed from the orchard should produce seedlings that are suitable to the environment in which they will be growing. To meet this criterion, most orchards are established with material selected from the same geographic source or site region to which the seed or resultant seedlings will be returned. However, there are instances when a foreign source is superior to that of the local material. The selected genotypes that are placed in a production orchard have some or all of the desired traits currently required in a tree at harvest time.

Most clonal production orchards are established with grafted material, but rooted cuttings can provide the same viable alternatives as described under the previous section for breeding orchards. The selected individuals should root sufficiently well to produce the number of ramets required to satisfy the proposed planting plans for the production orchard. As in the breeding orchard, juvenile material is not necessary since flower production rather than growth rate is the main concern.

There are some programs considering the use of rooted cuttings for clonal production orchards. For example, workers in Sweden feel that rooted cuttings can be justified because the cost is 1/20th that of grafting, they can see no advantage of grafting over rooting, and they require much larger areas of seed orchards to be established than they have been able to plant to date through grafting (Werner 1977). The Texas Forest Service has experienced problems with graft incompatibility in slash pine (Pinus elliottii Engelm.) and loblolly pine (Pinus taeda L.). Rooted cuttings of clones selected for a wide range of compatibility and a positive influence on flowering will be used as rootstock for clonal production orchards (Bower 1981).

# Research Plantations

The primary intent of research plantations with rooted cuttings is to obtain more precise genetic information than could be obtained with seedling experiments. The theoretical advantages of this approach include gains in selection efficiency (accurately identifying good genotypes), and more accurate estimates of genotype-environment interactions (Libby 1964, Burdon and Shelbourne 1974). Further, if heritability is low, the clonal trial will allow a smaller and more economical experiment to obtain a given level of precision (Burdon and Shelbourne 1974). These advantages also make rooted cuttings attractive for use in genetic architecture studies (Hood and Libby 1980). Rooted cuttings can also be used to supplant the conventional seedling progeny trial (Libby 1969, Rauter 1980). Normally, wind-pollinated or control-pollinated seed is collected from individual clones, and seedling progeny tests are planted to evaluate the parent material. By rooting cuttings from the progeny, it is possible to multiply each seedling several-fold and to establish clonal trials rather than seedling trials. To establish a clonal trial the same size as the usual seedling trial, fewer seeds are needed per cross, thus the pollination effort can be reduced and the start of the testing program hastened.

Rooted cuttings can also be more efficient than seedlings in experiments designed to study growth rate, form, wood properties, fertilizer response, response to various treatments for induction of flowering, and similar types of physiological and genetic experiments. In certain experiments, the genetic variation within seedling families complicates the results. Conversely, the ability to partition variation in response to a treatment between and within genotypes, allows a cleaner interpretation of the results.

Since juvenile material is used for rooting, many if not most coniferous species are suited to this approach. Work currently under way in Ontario with such species as white spruce (Picea glauca (Moench) Voss), black spruce (Picea mariana (Mill.) B.S.P.), white pine (Pinus strobus L.) and tamarack (Larix laricina (Du Roi) K. Koch.), indicates that rooting ability of juvenile seedlings and the cuttings taken from first and second cycle cuttings is very high. Subsequent growth and form is comparable to if not better than seedling performance. Black spruce and tamarack are particularly amenable to this approach as they produce a great number of lateral branches when topped. Under contolled conditions, 100 cuttings per seedling donor have been obtained within a 12 month time span (Perez de la Garza 1977).

However, white spruce and white pine do not produce laterals as readily and the number of cuttings cannot be expanded as rapidly. Webb1 (pers. comm. 1981) is investigating a variety of chemicals and environmental conditions and he has been able to increase several-fold bud differentiation and lateral branch development in white spruce.

## Production Plantations

Production plantations are established to regenerate lands and to provide the next crop of trees. Conventionally, plantations are established with either seed or seedlings. Some exceptions were the planting of either rooted or unrooted cuttings of several <u>Populus</u> and <u>Salix</u> species throughout Europe and North America, as well as <u>Cryptomeria</u> in Japan. Within the past ten years, several countries have incorporated rooted cuttings into their regeneration program. Lower Saxony, West

<sup>1</sup> Dr. D.P Webb, Great Lakes For. Res. Centre, Sault Ste. Marie, Ontario

Germany has been able to produce one million rooted cuttings of Norway spruce (Picea abies (L.) Karst.) annually (Kleinschmit and Schmidt 1977). In this program, the cuttings were obtained from superior seedlings of selected provenances. The objective was to produce 30 to 40% of the total planting need with rooted cuttings. Juvenility of the selections was maintained through serial propagation and hedging. Several thousand rooted cuttings of Norway spruce have been planted annually in Finland. Their material originated from the best seedlings from their best families (Lepisto 1977). New Zealand planted tens of thousands of rooted cuttings of Monterey pine (Pinus radiata D. Don) (Libby 1976). Ontario has planted several thousand rooted cuttings of black spruce (bulk seedlot origin) and will be enlarging its program substantially within the next year or two. Finally, an Eucalyptus program in Brazil has recently started to use rooted cuttings on a large scale in its operational plantings (Zobel pers. comm. 1981).

The advantages of using rooted cuttings in production plantations are many, and chief among them is the greater gain than with conventional seedling plantations. With the seedling approach, the breeder is able to utilize only a portion of the genetic variance, while with rooted cuttings, the breeder may capitalize on all of the genetic variance. Rooted cuttings can also allow capture of more of the additive genetic variance within families, which makes the breeding program more effective (Libby 1977).

Uniformity of product is another advantage of regeneration with rooted cuttings, making operations more simple and efficient for both raw material consumers and forest managers. Uniformity of clones can also allow a fine tuning of specific clones to specific sites to a much greater degree than is possible using open-pollinted families from seed orchards.

Regeneration with rooted cuttings can alleviate some of the problems of large fluctuations in the periodicity of cone crops. In Ontario, good seed crops occur in black spruce and tamarack infrequently. Even with extensive management, it is expected that this periodicity will occur to some extent in seed orchards as well. In order to cope with the seed shortages, plans call for the clonal reproduction of seedlings. Obtaining regeneration stock from cutting orchards would alleviate the problem of seed shortages and provide sufficient stock to fulfill regeneration targets.

Interspecific hybrids are difficult to produce on a mass production basis. Either inefficient open-pollinated orchards or expenseive large control-pollination programs are necessary. Rooted cuttings are an obvious solution to this problem (Duffield 1981). The most successful hybridization program to date in forestry has been with poplars, and there, vegetative propagation is the rule rather than the exception. In Ontario, the interspecific hybrid spruce program is being de-emphasized, but a few promising combinations are being considered for vegetative propagation. Approximately 4,000 rooted cuttings from 33 clones of a Picea rubens Sarg. x Picea omorika (Panic) Purkyne hybrid will be planted in a prodution trial in 19821.

Finally, the use of rooted cuttings for regeneration can reduce the period between test results and planting improved stock (Libby 1969, Zobel, 1981). By keeping some ramets of a clone hedged in a cutting orchard while other ramets are being field tested, many cuttings can be produced as soon as superior clones are identified. Thus the period between results and full production will be less than the corresponding period in a seed orchard program.

## CONCERNS WITH USING ROOTED CUTTINGS

We have described in the above sections the many advantages of using rooted cuttings in various phases of tree improvement. However, as with most frontiers and changes in technologies, there are some concerns. For many of the advantages discussed above, we assume that rooted cuttings will grow better than or at least as well as seedlings. In some coniferous species this assumption is still questionable. We further must assume that if rooted cuttings cannot be produced as cheaply as seedlings, then the gain in product and economies of management will more than offset the higher production costs.

Another concern often expressed about clonal plantings is the fear of monoculture, and the potential for disaster with genetic uniformity. Libby (1981) recommended from 7 to 30 as a safe number of clones in a given production plantation, the exact number depending on several variables such as acceptable risk levels, intensity of management, plantation size, and rotation age. Further, a mosaic of clones, rather than a mixture of clones, was recommended as a management system that may even have advantages in pest resistance over conventional plantations of open-pollinated families with their mixtures of full- and half-sibs (Libby 1981, Zobel, 1981).

In genetic tests a disadvantage of clones is the loss of selection differential, given that the number of trees that can be planted and measured has an upper limit. A further problem is the bias, associated with genetic parameters, arising from common environmental effects ("C" effects).

# PROBLEMS THAT STILL NEED SOLUTIONS

Since, for a large number of our important tree species, only juvenile material roots easily and grows well, maintaining this physiological condition is a necessity. Hedging and repropagation have been used to retard, but not halt, maturation. An expected benefit of tissue culture research will be a method to effectively rejuvenate mature tissue.

Technological development is needed to produce a management

<sup>1</sup> Material obtained from Dr. A.G. Gordon, Ont. Min. Nat. Res.

system, with associated equipment, for large scale collection and rooting of cuttings.

## POTENTIAL IMPACT ON TREE IMPROVEMENT PROGRAMS

If rooted cuttings are used to any extent in the various areas described in this paper, a totally different look must be taken at conventional breeding strategies and approaches to breeding programs. For example, if the production plantations utilize rooted cuttings, production seed orchards can be phased out and replaced with smaller, more genetically diverse breeding and cutting orchards. It will be much cheaper to manage a clonal cutting orchard than extensive acres of production seed orchard. Since we are able to capture the best genotypes through vegetative propagation, yield per unit of time should be substantially superior to that produced from even good qualtiy seedling stock.

Although there are still some problems to be resolved, there is great potential in using rooted cuttings. For some species and some programs, this potential can be realized immediately. The challenge is ours to take advantage of what is known and to transmit this knowledge into practice.

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# POTENTIAL IN JACK PINE SEEDLING SEED ORCHARDS

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## ABSTRACT

Jack pine improvement programs, whose ultimate goals are to produce high quality, genetically improved seed in seed orchards, are underway throughout much of the commerical range of jack pine in Canada and the United States. Information is presented on the early seed production potential needed for planning, establishing and managing such orchards. Seedling rather than clonal orchards are recommended primarily because clonal orchards cost more to establish and produce less seed. Cost of establishing and managing seedling orchards is low and generations can be turned over rapidly in breeding populations to create improved trees for subsequent orchards. Significant amounts of seeds are produced by age 6 and within the first 8 years 2.9 million filled seed per hectare of orchard can be produced. Costs of thinning and other cultural treatments to prolong orchard life beyond 10 years of seed production probably cannot be justified because additional genetic gains can be made by proceeding to new orchards based on progeny tests and breeding done in the interim. Seed losses due to abortion, insects, and squirrels continue to be problems that need more research. As these problems are solved and cultural and hormone treatments are further improved resulting in even earlier and more prolific seed production, we can expect that useful life of a given generation jack pine seedling seed orchard will be even shorter. Future seedling seed orchards should be located for maximum production of high quality, genetically improved seed, perhaps south of the natural range of the species.

## RESUMÉ

Dans la plus grande partie de l'aire d'exploitation du pin gris au Canada et aux États-Unis, des programmes d'amélioration de cette espèce sont en oeuvre, et leur objectif est d'arriver à produire, dans des vergers, des graines de haute qualité, génétiquement améliorées. On présente de l'information concernant les possibilités de production

précoce de graines, information utile pour la planification, la mise sur pied et la gestion des vergers de ce genre. On recommande des vergers à graines de familles plutôt que des vergers de clones, principalement parce que ces derniers sont plus coûteux à mettre sur pied et qu'ils produisent moins de graines. Le coût d'établissement et de gestion de vergers à graines de familles est faible, et les générations qu'ils produisent peuvent être rapidement transformées en populations reproductrices d'arbres améliorés qui seront utilisés à leur tour pour d'autres vergers. Les sujets de 6 ans produisent déjà un nombre important de graines et, dans les huit premières années d'exploitation, un verger peut produire 2,9 millions de graines pleines par hectare. On ne peut probablement pas justifier les coûts des éclaircies et des autres traitements sylvicoles destinés à prolonger la production de graines du verger au-dela de 10 ans parce qu'on aura pu obtenir entre-temps des améliorations génétiques supplémentaires en mettant sur peid d'autres vergers à partir de tests de descendance et de croisements. Les pertes de graines dues à des avortements, aux insectes et aux écureuils sont toujours des problèmes et appellent encore de la recherche. À mesure que ces problèmes seront résolus, que les traitements sylvicoles et aux hormones seront améliorés et qu'on obtiendra ainsi une production de graines plus précoce et plus abondante, on peut s'attendre à ce que la vie utile d'un verger à graines de familles de pins gris sera de plus en plus courte. Pour une productin maximale de graines de haute qualité génétiquement améliorees, les futurs vergers devraient peut-être être établis au sud du domaine naturel de l'espèce.

#### INTRODUCTION

Jack pine (Pinus banksiana Lamb.) improvement programs are underway throughout much of the commercial range of jack pine in Canada and the United States (Rudolph and Yeatman 1982) and vary widely in extent, intensity, and investment. Examples of extensive programs to produce large quantities of improved seed, required primarily for direct seeding, are the seed production stands developed near Baskatong Lake in Western Quebec (Lamontagne 1980) and in the Gogama District in Central Ontario (Oldford et al. 1979). Among more intensive improvement programs is one begun in the Lake States that combines both short- and long-term breeding and improvement objectives and is based on the Coordinated Population Concept (Kang 1980). The base population selected within a breeding zone is randomly divided into subsets of index or research populations and breeding populations, which will be used to develop production populations or seed orchards.

All of these programs are based on the best available provenance test information for delineating breeding zones and seed zones. The research results obtained from the index populations in the Lake States program will be used to predict the average performance of the breeding populations and to develop general breeding prescriptions for subsequent generations. Emphasis in the index populations is on rapid generation turnover so that various breeding schemes, selection methods, and other breeding activities may be evaluated as quickly as possible. Advantage is taken of rapid generation turnover based on evidence that age-age correlations for growth, although not exceptionally high when young ages are involved, are sufficient to assure selection of most "winners" by age 5 (Lambeth 1980; Rudolph and Yeatman 1982). These evaluations will provide opportunities for manipulating the breeding populations to develop production populations or seed orchards for mass producing genetically improved seeds to meet regeneration needs within the breeding or seed zone.

All jack pine improvement programs, whose ultimate goals are to produce high quality seed in seed orchards, need information on the early seed production potential of seed orchards. Although information is limited on seed production from the few currently producing seed orchards, scattered information from other research provides some insight on what might be expected from future orchards. Here I will bring together information on early flowering and seed production that will be useful for planning, establishing, and managing jack pine seed orchards. We need to recognize that a given improvement program may have more than one type of population or orchard managed for different purposes. Breeding and research populations, for example, would be managed as progeny tests and to facilitate controlled breeding and not necessarily for mass producing seed. However, after seedlings for the next generation seed orchard have been produced by breeding of the selected trees, the breeding population may be used as an interim seed source in the early stages of a multi-generation, long term improvement program. A production population or orchard, on the other hand, would be managed for producing large quantities of high quality seed in the shortest possible Thus, because the purposes of breeding and seed production time. populations are different, it is important that they be considered as separate functions in an improvement program. The information presented here will be useful for managing both breeding and production populations but emphasis is on seed production populations or orchards.

# WHY SEEDLING SEED ORCHARDS IN JACK PINE?

Jack pine has numerous characteristics that favor the seedling rather than the clonal seed orchard approach (Wright 1964). It frequently occurs over large areas in relatively pure, even-aged stands that lend themselves well to selection of large numbers of trees at low cost (Rauter 1980). Candidate trees can be compared with many trees growing in the immediate vicinity so that differences due to site can be minimized. Current information, although not definitive, suggests that phenotypic selection for height growth may not be very effective in jack pine (Canavera 1975) so large investments in selecting superior trees in natural stands probably cannot be justified because the expected gains from such selection are small. Thus, a low selection differential should be used but, because of the low cost of selection, a large number of trees can be included in an improvement program.

The seedling seed orchard approach in jack pine improvement is further enhanced because the species has rapid early growth, normally produces seeds at young age, flowers consistently year after year, and usually has serotinous cones so seeds may be temporarily stored on the trees if necessary (Rudolph 1979b, Yeatman 1979, Rudolph and Yeatman 1982). Thus, the small number of cones produced in the first several years in an orchard can be held on the trees until total production makes collection economically feasible.

Grafting is the only practical method at present to establish clonal orchards of jack pine from selections made in natural stands. However, grafted jack pine trees have several disadvantages compared to seedlings: (1) they are slow to develop large, cone-bearing crowns, (2) they cost more, and (3) graft incompatibility may eliminate some genotypes entirely (Rudolph and Yeatman 1982).

Clonal orchards may have a place in subsequent generation orchards based on the results of progeny tests. However, the higher costs of clonal orchards may outweigh the small additional short-term interim gains these orchards may make possible compared to selection and improvement facilitated by rapid turn over of seedling generations.

The early flowering and seed production results discussed below support the seedling seed orchard approach and indicate the rate of progress that can be anticipated in proceeding to advanced generation seed orchards.

## EARLY FLOWERING AND SEED PRODUCTION POTENTIAL

Under favorable growing conditions in the greenhouse and nursery, a small percentage of jack pine seedlings can be induced to produce female strobili as early as 12 months from seed (Rudolph 1979a). In other populations under these conditions, the percentage of trees producing female strobili increased to 23 percent at 17 months and 62 percent at 23 months (Table 1). The average number of strobili per tree ranges from one to two and they are usually borne on the main stem. The percentage of strobili maturing into cones and the number of filled seeds per cone are reduced, probably due to the lack of pollen production at this age (Rudolph 1966). However, controlled pollinations on the young seedlings resulted in cone set and filled seed percentages similar to pollinations on older trees.

An average of 17 percent of trees from various Lake State provenances grown in a nursery near Rhinelander, Wisconsin, flowered at 17 months (Table 2) (Jeffers and Nienstaedt 1972). Differences among provenances in proportion of trees flowering were small on the average and ranged up to 30 percent. Thus, although some differences in age for initiation of first flowering are evident among Lake State provenances, they are minor and probably of little significance when combining selections from this broad breeding zone into a coordinated base population for an improvement program.

Seedling	% of trees with female strobili	No. of female strobili per tree	% of cones maturing	Ave. No. seeds per cone	% seed germination
17 Months	23	1.34	10	25.9	36
23 Months	62	2.08	50	26.4	77

Table	1.	Female flowering and seed production on 17- and 23-month
		old jack pine seedlings (adapted from Rudolph 1966)

A major hindrance in taking advantage of such early female flowering is from the 3 to 4 year lag in male strobili production. Pollen production is probably not adequte for complete pollinations until the fifth or sixth year (Rudolph 1966, 1979a,b, 1981). A low cost supplemental pollination using artificially applied pollen from other selected trees could be considered to increase cone set and filled seed production in jack pine orchards younger than 6 years.

Table	2.	Female strobili production on 17-month-old jack pine seedlings
		by provenance of female parent (adapted from Jeffers and
		Nienstaedt 1972)

Provenance	% trees with female strobili	No. females per flowering seedling
Cass Co., MN	17	1.16
Forest Co., WI	18	1.14
Manistee Co., MI	16	1.13
Douglas Co., WI	19	1.14
Marinette Co., WI	14	1.21
Wood Co., WI	12	1.19
Mean	17	1.15

Jeffers (1976) projected seed yields in a hypothetical seedling seed orchard at age 6 years based on actual seed production in a 5-year nursery test. His orchard was designed to permit heavy rogueing. In this scheme, families would be planted in replicates of 2- to 4-tree row plots with a 0.5 m spacing between trees within rows and a 2.5 m spacing between rows. The seed orchard would initially contain 8,000 trees per hectare. The first thinning, (probably no later than the fourth year) would be based on performance measurements and would remove more than half of the trees and retain 3,200 trees per hectare. Based on female strobili counts in the fifth year and assuming 50 percent loss of strobili before cone maturity and 25 filled seeds per cone, he projected production of 266,800 filled seeds per hectare in the sixth year. Assuming 80 percent of the filled seed would yield plantable seedlings, 213,400 seedlings could be produced per hectare of orchard.

Using a somewhat different approach to orchard establishment than that of Jeffers, Rudolph (1979b) determined <u>actual</u> cone and seed production in the first 6 years in a seedling seed orchard (Table 3). The planting was established from a single local stand seed collection and was typical of a seed orchard scheme in which no rogueing or thinning would be done in the first 10 years. Thus, no selection was imposed and the overall quality of the trees was undoubtedly lower than in Jeffers' seed orchard in which more than 50 percent of the poorer families and trees were rogued. Therefore, one might expect early seed production to also be lower than in Jeffers' orchard, assuming that faster growing trees have higher early seed production. Greenhouse and nursery culture of the two orchard populations were similar and the field plantings were in the same general area but Rudolph's orchard was at a much wider spacing (2.44 m x 2.44 m) resulting in about one-half as many trees (1,683) per hectare.

Age	% of trees with cones	No. Cones per tree	No. Seeds per tree	No. filled seed per tree	l % of seed filled	No. filled seeds per hectare at 2.44 x 2.44 m spacing
4	16	0.3	2.8	0.6	23	1,085
5	47	1.1	11.6	8.0	69	13,415
6	93	10.1	221.2	166.7	75	280,491
Total	filled	seed per	hectare pro	oduced in firs	st 6 year	s - 294,991

Table 3. Mature cone and seed production of jack pine trees 4, 5, and 6 years old from seed (adapted from Rudolph 1979b) Contrary to what was expected, the actual yield of filled seed per hectare in the sixth year in Rudolph's orchard was slightly higher (280,000) than the projection (267,000) in Jeffers' orchard. The difference in spacing between trees in the two orchards would probably not yet be an influencing factor on early seed production because even at the narrower spacing in Jeffers' orchard, crown competition would not have occurred.

Adding the number of seeds produced in the fourth and fifth year in Rudolph's orchard to those of the sixth year gives a total of 295,000 filled seeds per hectare and, assuming that 80 percent would produce plantable seedlings, 236,000 seedlings. Noteworthy is the increase from less than one-fourth of the seed being filled in the fourth year to three-fourths in the sixth year. This is likely due to the increase in pollen production after the fourth year noted earlier.

Cone production data are not available for Rudolph's (1979b) orchard in the seventh year. However, conelets on the trees in midsummer of the seventh year were counted to project seed production in the eighth year (Table 4). An average of about 43 conelets per tree were produced. Allowing for 10 percent additional cone loss in the second year of cone maturation and assuming 25 filled seeds per cone, 1,619,000 filled seeds per hectare would be produced. Assuming production in the seventh year would be midway between the sixth and eighth year, 950,000 filled seeds per hectare would be expected. The actual production for the first 6 years (Table 3) plus that projected for the seventh and eighth years (Table 4) results in 2,863,000 filled seed per hectare produced in the first 8 years. If 80 percent of the filled seed produces plantable seedlings, 2,290,000 seedlings per hectare of seed orchard can be produced within the first 8 years from about 1,700 trees.

Although information on seed production in the above-described orchard after the eighth year is not available, general observation indicated that cone production continued to increase rapidly for the next several years until crown closure became a limiting factor. At that time, thinning may be necessary to keep the crowns in the open if the orchard was to be continued. Removing the top two to three "whorls" of crown would also help keep the height at which cones are produced within more easily collectible reach. Considering the production of 1.65 million filled seeds per hectare in the eighth year, subsequent annual production could be expected to be more than 2 million -- yields that should make management of seed orchards for early seed production worthwhile.

However, the cost of thinning and other cultural treatments to prolong the life of the orchard may not be justifiable because of the low cost of establishing and managing such a jack pine orchard in which the only treatments were to prepare the site with a herbicide and mow between rows for the first 2 years. Instead, considering the opportunities by the time an orchard is 10 years old of advancing to the next generation orchards because of rapid generation turnover in the breeding population in the interim, investments should be made in new orchards with the objective of achieving additional gains. Seedlings for the new orchards would be selected based on the early performance of controlled breeding progenies from the progeny test breeding population. The costs of using this approach for the continuing production of genetically improved seed will add little to the total cost of artificial regeneration and plantation management to tree harvest, and the gains to be achieved can be expected to yield a good return on the investment (Lundgren and King 1965, Carlisle and Teich 1975).

Table 4. Seed production in the first 8 years in a jack pine seedling seed orchard at a 2.44 x 2.44 m spacing (adapted from Rudloph 1979b)

Total filled seed production per hectare through age 6 294,991
Average number of conelets per tree in summer of seventh year - 42.75
Number of cones per tree maturing in eighth year assuming additional 10 percent cone loss 38.48
Number of cones per hectare in eighth year at 2.44 x 2.44 m spacing (1,683 trees) 64,753
Number of filled seeds per tree in eighth year assuming 25 filled seeds per cone 962
Number of filled seed per hectare in eighth year at 2.44 x 2.44 m spacing (1,683 trees) 1,618,806
Number of filled seed per hectare in seventh year assuming mid-point bewtween sixth and eighth year 949,647
Total filled seed production per hectare through age 8 2,863,444

## LOCATING ORCHARDS FOR BEST SEED PRODUCTION

As soon as results from progeny tests made in the breeding zone are available, and seedlings for the next generation orchards are produced by controlled pollination on selected trees in the breeding population, seed orchards should be located for maximizing seed production and quality, possibly outside the breeding zone.

Seed yield per cone and seed quality from trees in 15 provenances at 5 plantation locations showed striking differences due to plantation location (Rudolph and Cecich 1979). Trees in a plantation at Plattsmouth, Nebraska, which is far south of the natural range of jack pine, produced more filled seeds per cone and more plantable seedlings per cone than trees of the same provenances in four Lake States plantings (Table 5). More than three times as many filled seeds per cone were produced in Nebraska as in a planting at Black River Falls, Wisconsin, which is within the natural jack pine range. The planting at Black River Falls is apparently on a poor site although natural jack pine stands are found there. Another planting on a better jack pine site, at Lake Tomahawk in northern Wisconsin approached the seed yield and quality of the Nebraska planting. These results, although preliminary, suggest that seed orchard site selection for maximum production of high quality seed must be carefully considered and that location of orchards outside of the breeding or seed zone and south of the natural range of jack pine in longer growing season areas cannot be dismissed. Additional research on optimum seed orchard location for early and high seed production in jack pine is now underway by the North central Tree Improvement Committee (NC-99) (Nienstaedt 1981).

Table 5. Seed yield and seed characteristics of trees in 15 provenances at 5 plantation locations (adapted from Rudolph and Cecich 1979)

	······	Cone and	seed chara	acteristi	cs <u>-</u>
Plantation location	No. trees	No. seeds per cone	No. seeds per cone	% seeds filled	% total seed germina- tion
Plattsmouth, NB	88	33.4	23.9	70	67
Kellogg Forest, Ml	72	20.6	10.3	46	43
Black River Falls,WI	100	20.6	7.0	33	31
Lake Tomahawk, WI	144	24.2	21.3	88	85
Grand Rapids, MN	70	21.8	18.4	84	82
TOTAL	474				
MEAN		24.2	16.7	66	63

<u>1</u> Differences among locations are significant at the l percent level for all characteristics.

PROBLEMS IN ORCHARD MANAGEMENT FOR EARLY SEED PRODUCTION

Design and spacing are major concerns when establishing seedlings seed orchards (Rauter 1980). Many different designs, spacings, and rogueing approaches have been proposed (see review in Rudolph and Yeatman 1982). Designs will vary with total orchard size and shape, the number of genotypes, whether rogueing will be done, and the selection method used in rogueing. All designs should include random placement of trees or families in replicated blocks.

In seedling seed orchards containing material that has already been progeny tested and no further rogueing or thinning is planned for at least 10 years, spacing for maximum seed production during the period should be 2.5 m x 2.5 m to avoid crown closure and competition and to maximize potential cone producing crown surface. If rogueing is planned at age 4 or 5, row plots of no more than four trees per plot should be used. Spacing between trees within rows can be close initially, e.g., 1.5 m, to allow for the rogueing. Spacing between rows should be 2.5 m, so grasses and herbaceous vegetation can be mowed for the first several years.

Cone abortion continues to be a serious problem (Cecich 1979) and its causes in young seed orchards are unknown. Seed yields in jack pine may be low in many instances due to low seed potential (2 x number of fertile scales) and resulting low seed efficiency (number of filled seeds/seed potential) (Bramlett 1974). It may be possible to increase seed yields in young orchards by selecting for high seed efficiency rather than high cone production (Polk 1966, Todhunter and Polk 1981).

Cone and seed insects cause serious losses in seed production on young jack pines (Rauf <u>et al.</u> 1981, Rudolph 1981). For example, the jack pine budworm (<u>Choristoneura pinus pinus</u> Freeman) destroyed 12 percent of the conelets in a planting in northeastern Wisconsin. A mirid (<u>Platylygus luridus</u> Reuter) was observed piercing into conelets as well as shoots and needles and was apparently responsible for severe but unknown conelet losses that may previously have been considered as abortion due to other causes. Numerous other insects are responsible for lesser amounts of damage (Rauf <u>et al.</u> 1981). Losses due to insects and abortion can reach more than 90 percent of a seed crop during heavy insect infestations (Rudolph 1981). Clearly, control of cone and seed insects and prevention of abortion in jack pine seedlings seed orchards are problems that must be solved if the early flowering and seed production potential is to be used to advantage.

Red squirrels (<u>Tamiasciurus hudsonicus</u> Allen) destroy cones and consume seeds (Rudolf 1965, Rudolph and Cecich 1979, Rudolph and Yeatman 1982). Losses to squirrels can be minimized by carefully timing cone collection so that cones are taken as soon as seeds are viable and before squirrels begin to harvest them (Cecich and Rudolph 1982). The following indicators of cone and seed ripeness proved to be best for northeast Wisconsin: 75 percent of the cone was brown, inside surfaces of the cone scales were reddish brown, seeds were dark brown or black, and cone moisture content was less tha 42 percent of fresh weight. These indicators of cone and seed ripeness coincided with the beginning of cone harvesting by squirrels (Cecich and Rudolph 1982).

Although most jack pine trees bear serotinous cones, some bear

cones that open soon after they mature resulting in potential seed losses in orchard production. Such losses may be most serious in young orchards in which the small cone crops are retaind on the trees for the first several years of production until the accumulated crop reaches levels that are economically feasible to collect. The serotinous cone character is highly heritable so selection for it can be effective (Rudolph <u>et al</u>. 1959, Teich 1970, Sittman and Tyson 1971). Therefore, if other tree characteristics of potential selections for orchards are equal, the serotinous cone habit should be favoured (Rudolph and Yeatman 1982). Straight cones also should be preferred for orchard selections because they yield more seeds than curved ones (Jeffers 1972, Baker 1980, Rudolph and Yeatman 1982).

## FUTURE PROSPECTS

The future is bright for obtaining earlier and higher production of genetically improved seed from jack pine seedling seed orchards than is presently possible. Although many problems remain to be solved, research advances are expected on the following fronts: (1) time to first flowering will be further shortened by cultural manipulation of photoperiod, temperature, moisture, and nutrients, particularly during the intial stages of seedling development; (2) flowering will be increased by effective hormone applications such as gibberellin A4/7 (Cecich 1981); (3) economically feasible application methods will be developed whereby entire orchards can be treated; (4) methods of controlling cone and seed insects and other damaging agents will be improved; and (5) causes of conelet abscission and abortion will be identified and losses due to these causes will be prevented.

Because all of these developments permit an even more rapid generation turnover in jack pine breeding, opportunities will be provided for earlier evaluation of various breeding schemes, selection methods, age to age performance correlations, and other breeding activities. This points to a decreasing practical life for a given generation jack pine seedling seed orchard in the future. Clearly, a useful orchard life of no more than 10 years is in sight. One combined progeny test-seedling seed orchard established in 1974 by the Potlatch Corporation in north Central Minnesota will soon be phased out and the second generation orchard will be established (Schantz-Hansen 1981). Within 6 years of establishment, this orchard produced almost 7 kg of high quality seed from 1,700 trees. The nursery manager that grew the seedlings from the orchard seed noted that the seed was much larger than seed from natural stands used previously and that the performance of the seedlings in the nursery was better than that from any previous natural stand collections.

As additional demonstrations of gains are produced from other jack pine orchards, managers and administrators of reforestation programs will increasingly realize that the cost of producing gentically improved seed in orchards adds little to the total cost of reforestation and forest management until harvest. The potential for genetic gain in jack pine is present—it needs to be developed and applied in reforestation programs.

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ONE GENERATION OF LOBLOLLY PINE TREE IMPROVEMENT: RESULTS AND CHALLENGES

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## ABSTRACT

Intensive first generation tree improvement programs in the southern United States with loblolly pine (Pinus taeda L.) and slash pine (Pinus elliotti Engelm.) are reaching maturity. Yields from first generation seed orchards are now approaching the demand for improved seed. Genetic gains for height growth of loblolly pine in the N.C. State-Industry Pine Tree Improvement Cooperative appear to be remaining stable at about 3% through 12 years of age in progeny tests. Extrapolation to later ages through the use of yield tables shows that the impact of a 3% height increase on percent volume improvement depends upon stand age and management practices. Percentage cubic meter volume gains in unthinned plantations are greatest before the oneset of intense competition and mortality in the stand. Greatest percentage gains in cubic meter volume will result through shorter rotations or thinnings to salvage mortality.

Challenges and opportunities in first generation improvement programs do not end as breeding programs focus on second generation activities. Additional gains in the genetic quality of first generation planting stock may be realized through family block plantings, mass propagation of full sib families, and super intensive roguing of seed orchards based upon complete progeny test information. Small increments of gain can mean a large difference in profitability.

RESUME

On est en voie d'atteindre les objectifs des programmes intensifs entrepris dans le sud des États-Unis pour améliorer les arbres de la première génération dans le cas du pin à encens (<u>Pinus taeda</u> L.) et du pitchpin américan (<u>Pinus elliotti</u> Engelm.). Le rendement de la première génération d'arbres des vergers à graines suffira bientôt à la demande de graines améliorées. D'après les tests de descendance, le gain génétique de croissance en hauteur semble avoir été de 3% par aunéepour une arbre de 12 ans à la N.C. State-Industry Pine Tree Improvement Cooperative. Si à l'aide de tables de rendement on extrapole pour un arbre plus vieux, on voit que l'effet d'un gain de 3% en hauteur sur le pourcentage d'amélioration du volume dépend de l'âge du peuplement et des methodes d'aménagement. En pourcentage, le gain de volume en mètres cubes dans les plantations non éclaircies est le plus élevé avant que la compétition et la mortalité ne commencent à se manifester dans le peuplement. Ce gain sera à son maximum si l'on diminue l'âge d'exploitabilité absolue ou si l'on éclaircit la plantation pour faire décriotre la mortalité.

Il reste encore des défis à relever et des points à améliorer dans les programmes pour les arbres de la première génération même si l'on oriente les programmes de reproduction vers la deuxième génération. On peut encore améliorer la qualité génétique du matériel de reproduction de la première génération par la plantation de familles en blocs, par la sélection massale des fratries et en éliminant des vergers à graines tous les rebuts de sélection en se fondant sur les résultats complets des tests de descendance. Des gaines minimes peuvent être très profitables.

#### INTRODUCTION

Intensive genetic improvement of forest trees began during the 1950's in a number of countries throughout the world. In North America, programs dealing with loblolly pine (Pinus taeda L.) and slash pine (Pinus elliotii Engelm.) have been particularly active, and have reached a stage where members of the three largest cooperative improvement programs in the southern United States are able to meet all or part of their annual planting needs with improved  $stock^1$ . Initial activities with these species involved intensive selection of superior phenotypes in natural stands, followed by establishment of clonal seed orchards and extensive progeny testing. Major breeding efforts are rapidly turning to the second generation of improvement (Talbert 1979; van Buijtenen and Lowe 1979).

Most emphasis in the North Carolina State University-Industry Pine Tree Improvement Cooperative is on loblolly pine. The approach taken was one of superior tree selection within geographic regions. Each Cooperative member was originally responsible for selection of 20-30 trees in natural stands. Trees were selected for growth, stem straightness, pruning ability, wood density, crown and branch characteristices, and selections had to be free of any fusiform rust (<u>Cronartium quercum Bech Mizobe f. sp. fusiforme</u>) infection. Estimated selection intensities varied from about i = 1.89 (7 in 100 individuals saved) for volume to i = .97 (40 in 100 individuals saved) for fusiform rust resitance, where the disease is a problem (Porterfield, 1973). Trees selected for each orchard were progeny tested utilizing a factorial mating design, where 4 or 5 clones were chosen as testers and mated to

<sup>1</sup> The three cooperatives are the Western Gulf Tree Improvement Program, Texas A & M University; Cooperative Forest Genetics Research Program, University of Florida, and the N.C. State University-Industry Pine Tree Improvement Cooperative.

the other trees in the orchard. An attempt was made to test each full sib family in two different environments in each of three years. A randomized complete block design has been used with families planted in ten tree row plots in each block. Included in each block are plots of one or more unimproved seedlots. The same tests serve as a base population for selection of second generation parents.

Breeding efforts for first generation loblolly pine selections are now complete, with the final tests scheduled for establishment in the field in 1983. Test measurement is currently a major activity in the Cooperative with over 750,000 individual trees measured each year. Tests are measured after four, eight and twelve growing seasons in the field. For some orchards we have considered progeny test information sufficiently complete (most tests 8 years or older) to rogue them to their final clonal composition. Developmental work in the breeding and testing phase of the Cooperative is now focused on second generation tree improvement.

First generation seed orchards in the Cooperative are reaching full productivity. Cone crops have been heavy three out of the last four years, (Table 1) and some organizations have enough seed in storage to meet their needs for several years. We anticipate a record cone crop in 1981.

Harvest Year	Kilograms of Seed	Potential Regeneration $(ha.)^{\underline{1}}$
1977	22,500	220,000
1978	21,300	209,000
1979	25,100	246,000
1980	7,200	70,000

Table 1. Seed yield for N. C. State Cooperative loblolly pine seed orchards for the past four years.

<u>1</u> Assumes a 2.4 x 2.4 m spacing, and 17,000 plantable seedlings per Kilogram of seed.

While most orchards have been genetically rogued, there is opportunity for a further increase in the genetic quality of seeds produced, especially as supplies of improved seed become plentiful and maximum production is no longer a constraint in orchard management. Most of the challenges we currently face in the genetic aspects of first generation tree improvement involve seed orchard practices to upgrade the genetic quality of seed.

The N.C. State Cooperative is at a turning point in both its applied and developmental phases. While much effort is now given to second-generation activities, a number of first generation tests are at least 12 years old, and some trends in the performance of improved stock The N.C. State Cooperative is at a turning point in both its applied and developmental phases. While much effort is now given to second-generation activities, a number of first generation tests are at least 12 years old, and some trends in the performance of improved stock are beginning to emerge. The first generation program can be described by the gains which are being achieved, and by the challenges which we are encountering as orchards and genetic tests reach maturity.

## GAINS FROM ONE GENERATION OF TREE IMPROVEMENT

Gains from tree improvement activities ultimately reside in the improved productivity of forest lands. Determination of realized gains in productivity, especially those in yield per unit area, usually involve establishment of long-term studies with large block plots comparing improved and unimproved planting stock. Since in most programs selections for the next generation are made well before rotation age, breeding activities will have advanced to the second or third generation before realized gains from first generation orchards are accurately known. For planning purposes, however, economic and silvicultural decisions involving management of plantations from first generation stock must be made early in the program. Consequently, estimates of gain from tree improvment must often be made from studies not designed specifically for that purpose.

The N.C. State Cooperative's first generation genetic tests were established primarily for progeny testing and selection purposes. The row plots utilized do not permit direct comparisons of yield among families or between improved stock and unimproved check lots. However, many tests have now been measured at four, eight, and twelve years of age and trends are evident in the relative performance of improved and unimproved stock over time. Extrapolation results to rotation age indicates that tree improvement will have important implications for forest management.

Average percentage gains in height growth for first generation loblolly pine progeny compared to unimproved checks are shown in Table 2. Gain figures were computed by determining average gain for each loblolly pine seed orchard in the Cooperative, and then averaging across all orchards. Each orchard was treated as an independent estimate of gain. Percentage gains for any individual orchard may be biased to the extent that the tester mating system used does not represent what would be obtained with random mating in the seed orchard, and to the extent that the unimproved check does note accurately represent unimproved planting stock1. However, when averaged across a number of orchards, these effects should average out.

In the first generation, each Cooperator was responsible for furnishing his own unimproved check. We know that unimproved checks of Cooperators in the same area differ in their performance. effects should average out.

	Δα.	0	
	4		
Percent Gain $\frac{2}{}$	3.14	4.06	2.84
Standard Error	•45	.52	65
Range	-2.18 to 7.54	79 to 8.00	-3.49 to 6.89
No. Orchard	33	30	16

Table 2.	Average percentage height gains for first generation lobiolity	y
	pine seed orchard stock at different assessment ages	

<u>1</u> Gains are calculated as average performance of progeny test seedlings in comparison to improved check lots.

2 Percent Gains at all ages are significanty greater than 0 (p < .01). Gains at different ages are not significantly different from each other.

Percent gain estimates for height appear to be remaining constant at 3-4% regardless of test measurement age (Table 2). Individual orchards differ widely in their performance, but combined gain figures are all significantly greater than 0 (p < .01) and are not significantly different from each other.

Interpretation of percentage gains in young tests, and extrapolation to later ages is a matter of some debate. Cannell (1978) has questioned estimates of gain in yield from selection because genotypes are selected for individual growth rate, often at very young ages before intense tree to tree competition begins, and not for their ability to produce more wood per unit of land. An alternative argument is that yield per unit area can be partitioned into components due to carrying capacity and growth rate (Lambeth 1978). Carrying capacity is defined as the total amount of biomass that can be produced by a unit of land in a period of time. In forestry terms, it can be expressed as the number of stems of a given size that can occur on a particular unit of land at a given plantation age once full stocking is reached. Changes in carrying capacity in agricultural crops (total biomass) as a result of genetic improvement are generally considered to be minimal (Evans 1980). A nursery bed study with loblolly pine could not detect any family variation in carrying capacity (Wearstler 1978). But, even if we assume that carrying capacity for a given site is not subject to genetic manipulation, yields can still be increased by improving growth rate, for which there is substantial genetic variation in nearly every tree species that has been studied (Wright 1976). Improvement in growth rate will result in more rapid stand development which can decrease the time until

. . . . .

the stand reaches a certain harvestable size, or result in more merchantable volume at a given rotation age, packed onto fewer stems because of mortality.

If one assumes the percentage gain figures for height shown in Table 1 will remain constant at about 3% over time, then gain from selection can be expressed as a change in site index, or the expected height of the dominant and co-dominant trees in a stand at a base age. For example, if site index for improved stock is 60 feet (18.3 meters) (base age 25), then an equivalent site index using improved stock from unrogued orchards would be 1.03 x 60 ft. = 61.8 ft. (18.8 m). If one further assumes that through selection we have improved growth rate (stand development) and not carrying capacity, then changes in yield resulting from tree improvement can be obtained through use of growth and yield models. These models predict yield based upon initial plant density, site index, and plantation age or dominant tree height.

Predicted cubic meter volume yields in unthinned plantations for unrogued and rogued first generation loblolly pine seed orchards at various ages on site index  $60_{(25)}$  land are shown in Table 3. Unrogued orchard stock was assumed to grow 3% faster in height than unimproved stock, changing site quality to an equivalent of site index  $61.8_{(25)}$ . Stock from rouged orchards was estimated from progeny tests to grow 7% faster in height than unimproved stock changing site index to an equivalent of  $64.2_{(25)}$  (site index figures were rounded to 62 and 64 respectively). If an orchard were rogued strictly on height, estimated gains would be greater than 7%. In reality orchards are rogued on a number of characteristics, including cone production, which reduces effective selection intensity for height. The 7% figure is probably realistic for many orchards.

Predicted percentage gains in cubic meter volume decline dramatically with increasing age in the unthinned stand depicted in Table 3 (Figure 1). Gains for rogued orchard stock fall from 20% at age 15 to just under 5% at age 35. At age 25, a common rotation age on land of this site quality, percentage gains in cubic foot volume are 6.4% for plantations from unrogued orchards and 12.7% from rogued orchards, with no salvage of lost mortality by thinning. Absolute gains in volume appear to be remaining nearly constant with time after a plateau is reached at about age 20 (Table 3).

One of the reasons for decreasing percentage gains in volume is an increasing volume figure on which the percentage is based (Table 3). Examination of the stand data shows that another reason is increased mortality in stands planted with seed orchard stock, because of more intense tree to tree competition resulting from more rapid stand development. When the trees are in a "free to grow" situation, there is little mortality and percent improvement in cubic meter volume resulting from small changes in site index are large. Gains fall as competition sets in, more quickly on the better sites, and mortality begins to occur. Much of the loss in percentage gain can be recaptured if mortality is salvaged by thinning.

Table 3. Stand densities and cubic meter volumes in unthinned loblolly pine plantation for site index 60, 62 and  $64_{(25)}$  at various ages <u>1</u>.

	60	ft.	62 ft.		64 ft.	
Age	Trees/ha.	m. <sup>3</sup> /ha	Trees /ha.	m. <sup>3</sup> /ha.	Trees/ha.	m. <sup>3</sup> /ha
1	1480		1480		1480	
15	1462	105.4	1457	116.1	1447	126.7
20	1380	206.4	1356	224.2	1329	241.4
25	1218	307.1	1178	326.8	1139	346.1
30	1015	359.6	973	378.3	909	398.1
35	830	392.7	790	402.8	758	410.4

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Differences in yield for small changes in site index were calculated utilizing models developed by W.L. Halfey and W.D. Smith, Southern Forest Research Centre, Department of Forestry, N.C. State University (as yet unpublished). I gratefully acknowledge their assistance.

 $\frac{2}{2} \text{ site index } 60_{(25)} = \text{unimproved stock}$ site index  $62_{(25)} = \text{unrogued orchard stock}$ site index  $64_{(25)} = \text{rogued orchard stock}$ All volumes are total tree inside bark.

Changes in percent volume gains with increasing stand age have important implications for forest management. If the best potential percentage gains from tree improvement are to be realized, stands must either be harvested before intense competition and associated mortality begin, or stands must be thinned to salvage mortality. In stands that are to be thinned operationally, the time of first thinning will come at a younger age when improved stock is used (Switzer and Shelton 1981).

Gains in volume production from genetics can be utilized by the forest manager in two ways. One would be to harvest timber when it reaches a given size, and genetic improvement would be realized as a



Fig. 1. Influence of age on percentage cubic meter volume gain in unthinned loblolly pine plantations utilizing first generation orchard stock.

reduction in rotation age. If this were the case, and rotation length for unimproved stock on site index  $60_{(25)}$  land were 25 years, then use of periodic annual increments generated from Table 3 would show that rotation could be reduced to 24 years with unrogued orchard stock, or to 23 years with rogued orchard stock. Gains in cubic meters of wood from tree improvement would simply be 4.1% (25/24-1) for unrogued orchards, and 8.6% for rogued orchards. A reduction in rotation age can substantially improve profitability by decreasing the number of years that plantation establishment costs must be carried (Lambeth 1978).

Alternatively, the manager could decide to grow the stand for the same rotation length, and enjoy the benefit of harvesting more volume per acre, concentrated on fewer but larger, more valuable stems. Gains in estimated dollar value for 25 year rotation on site index  $60_{(25)}$ land with this alternative are shown in Table 4. Unrogued orchards yield an 18% increase in dollar value at age 25, while a 32% increase in value results from use of stock from rogued orchards, given the assumptions listed in Table 4. The large increases in value associated with small gains in cubic meter volume are the result of more trees in the larger diameter classes.

Table 4. Improvements in value in unthinned plantations at stand age 25 utilizing unrogued and rogued seed orchard seed on site index  $60_{(25)}$  land.

Type Stoc	k Value (Dollars,	/ha.) % Gain
Unimprove	d 4152	
Unrogued	4891	18%
Rogued	5476	32%
Assumptions:		
Value of	trees < 23 cm dbh =	\$12/cord
Value of	trees $23-31 \text{ cm dbh} =$	\$40/cord
Value of	trees 31+ cm dbh =	\$60/cord
l cord =	2.56 cubic meters of	solid wood

Increases in stumpage values shown in Table 4 are probably conservative. Growth rate was the only trait considered, and improvment in quality characteristics have been ignored. Test data shows that genetic improvements in quality have been large, especially in stem straightness, and that variation in these characteristics have a marked impact on yield of both solid wood and pulpwood products (Blair <u>et al</u> 1974). The improvements in quality undoubtedly have an impact, especially in stands harvested at young ages where quality characteristics play a large role in determining whether a log is of pulpwood quality or whether it could be used for solid wood products. Research is currently underway to more fully elucidate the relationship between the crown and straightness scores used in N.C. State Cooperative and product yeild.

Genetic gains have also been made in other characteristics. Wood specific gravity is a highly heritable trait in many species, including loblolly pine (Otegbye and Kellison 1980; Dadswell <u>et al</u> 1961; van Buijtenen 1965; Zobel <u>et al</u> 1972). Based upon parent-offspring correlations, we have estimated that with one generation of light selection for increased wood specific gravity (1 in 2 individuals saved), improvement has been on the order of 9.6 kilograms per cubic meter of dry wood in 12 year-old trees (Jett and Talbert 1980).

Improvements in fusiform rust resistance appear to be resulting largely from progeny testing and orchard roguing. There is considerable genetic variation in fusiform rust resistance in loblolly pine (Kinloch and Stonecypher 1969). In progeny tests, however, unimproved check lots have performed nearly as well, on the average, as progeny of selected trees. This has happened even though a requirement for first generation selections was that they be free of rust. Many selections were made in stands with low to intermediate rust infection, so there was a low selection intensity for disease-free trees. It has been shown that substantial gain can be made in rust resistance in slash pine by selecting rust-free trees in heavily infected stands (Goddard and Schmidt 1979). Where fusiform rust resistance is of over-riding importance, specialty loblolly pine seed orchards composed of proven rust-resistant parents have been established (Zobel et al 1971).

There is no longer any doubt that substantial genetic gains can be made in forest trees in one generation of selection. Changes in the genetic composition of the forest stand will have a large impact on forest management strategies (Zobel 1979). It is important that the tree breeder and forest manager realize that gain figures for volume, stem straightness, or any other characteristic must be interpreted in relation to their effects on stand development and associated management activities. Gains for any trait, expressed in biological or economic terms, can and will change dramatically during the life of the stand, and with different management practices.

## CHALLENGES IN FIRST GENERATION LOBLOLLY PINE TREE IMPROVEMENT

Although substantial gains have been made in one generation of selection, progeny testing, and orchard roguing, there are opportunities for further increases in productivity of first generation plantic; stock. These arise primarily because of two factors. First, an excellent data base exists for performance of both half and full sib families in progeny tests that were established for first generation orchards. Second, seed production in orchards has exceeded expectations, and several seed orchards are now producing quantities of seed far in excess of what is needed for regeneration purposes for the organization involved. Some opportunities can be taken advantage of almost immediately; others are very much in the experimental arena.

### Planting by Half Sib Family

Progeny tests have shown that seed orchard parents differ widely in general combining abilities. This information has been used extensively to rogue seed orchards, but the genetic quality of seed can be improved further by collection of seed only from those parents which have the highest combining abilities. Orchard clones can be divided into groups according to the gain that will be obtained from their use. For example, families which have shown excellent resistance to fusiform rust could be collected separately and used in areas of high rust incidence. Taken one step further, seed collection could be kept separate by clone, and sown in the nursery and planted in the field in a similar manner. An immediate benefit of this practice is increased seedling quality and uniformity in the nursery; another is that half-sib families can be planted and managed for their most appropriate end product. One organization has been planting in half-sib family blocks for several years (Gladstone 1981). With the record cone crop anticipated in 1981, we expect several companies to collect cones by clone or groups of clones

this fall.

Mass Production of Full Sib Families

In almost every testing program, occasional full sib families prove to be excellent performers in every important characteristic. An example of one such family is shown in Table 5. The use of several fully progeny tested families like 1-11 x 5-33 in a regeneration program would result in excellent improvements in growth, form, and rust resistance. Use of some specific crosses would result in estimated height gains of 25% or more. Mass production of full-sibs through control-pollinations is not economical, but several technological developments on the horizon may lend themselves to production efforts.

One possibility for production of full-sib planting stock is two-clone seed orchards. However, there are problems with establishment and management of two-clone orchards. The two clones must be similar in phenology (flowering time) so that cross-pollination will occur in the orchard. Additionally, at least one of the two clones must either not produce filled seed upon selfing, or must produce selfed seed of good genetic quality. Several two-clone orchards have been established, but they have yet to become productive and their ultimate utility is unknown.

		Trait		Fusiform	
	Height	Volume	Form	Rust Resistance	
Performance Level $\frac{1}{2}$	76	71	72	87	
Rank (out of 83)	4	7	19	1	

Table 5. Performance of family 1-11 x 5-33: A case for mass propagation of full siblings.

<u>1</u> Performance levels are calculated on a 0-100 basis; 50 is approximately average.

A more likely alternative for mass production of full siblings, at least in the near future, is through supplemental mass production (SMP). Results to date with SMP have been variable. An attempt to mass produce the hybrid pitch pine (Pinus rigida Mill.) x loblolly pine produced an average of 10.7% hybrid seedlings (Bridgwater and Trew 1981). In a study designed to determine its effectiveness in increasing seed set in young seed orchards, SMP was beneficial in a year of poor orchard pollen production, but ineffective in a year of good production (Bridgwater and Bramlett 1981). Problems encountered with SMP have included determining the appropriate amount of pollen to apply, and adapting equipment to forest tree seed orchard situations (Bridgwater and Trew 1981). Studies are currently underway to determine the effectiveness of SMP in increasing the quantity of seed from specific crosses in mature loblolly pine seed orchards.

Another way to mass produce full sib families would be through vegetative propagation. Vegetative propagation methods receiving most attention are rooted cuttings and tissue culture. Ideally, vegetative propagules would be derived from mature, fully progeny tested genotypes, but success thus far with loblolly pine has been with juvenile material (van Buijtenen et al 1975; Mott et al 1977). Rejuvenation techniques such as those used by the AFOCEL group in France may hold promise for allowing rooting of mature genotypes (Franclet 1979). Work is underway to propagate mature loblolly pine trees with tissue culture (Mott 1981). If exisiting propagation methods for juvenile material could be made cost effective, it would be possible to mass produce full siblings by rooted cuttings or tissue culture. Results are not yet available from well-designed long-term studies comparing the performance of vegetative propagules and seedlings for loblolly pine, but the several now underway should give good answers. This information is needed before large scale regeneration programs with vegetatively propagated material begin.

## Super-Intensive Roguing of First Generation Orchards

In the N.C. State Cooperative, seed orchards are rogued several times during their development. They are usually rogued to a final composition of 12-15 clones, and final density is on the order of 15-20 trees per acre. A constraint has always been to rogue lightly enough to maintain full seed production, but as excess quantities of seed become available, this is no longer a requirement. Additional genetic gain could be obtained if orchards were rogued to only the few best clones, at the expense of reducing seed yields.

While super-intensive orchard roguings appear favorable from a genetic gain standpoint, there are potential difficulties which may influence optimal clonal compositon in mature orchards. One obvious concern is the possible reduction in genetic variation through roguing to only a few clones. This has been a topic of much debate among forest geneticists for many years and the debate will likely continue for many more (Libby 1981; Zobel 1981). Electrophoresis studies with loblolly pine have shown that much allelic variation exists in seed orchards for loci that can be studied using this technique (Hunter 1977; Adams and Joly 1980). While the relationship of variation patterns at these loci and those for loci which influence adaptability traits are unknown, we do have studies underway to determine what might be the reduction in genetic variation at these loci from super-intensive roguing.

Another concern involves phenology. Lack of synchronization in flowering in orchards that have few clones could reduce potential gains through selfing and outside pollen contamination, and could further reduce genetic variability. Even with synchronization, pollen supply in the orchard could be reduced to a level where outside pollen contamination becomes a much bigger problem than in a fully stocked orchard. Orchard roguings of this intensity are experimental at this time. One slash pine orchard with which we work has recently been rogued operationally to eight clones. Experiments are underway in a loblolly pine orchard to compare the effects of roguing to final densities of four, eight and twelve of the best clones.

#### SUMMARY

Significant gains: in growth rate, wood density, stem quality, and fusiform rust resistance have been made in one generation of genetic improvement of loblolly pine. The size of gains which will be realized at harvest depend upon rotation age, stand management, and type of product.

Challenges and opportunities in first generation improvement programs do not end as complete progeny test information becomes available, and seed orchards reach full production. Aggressive, ongoing programs will have shifted much of their developmental efforts toward the next generation but additional short-term gains in first generation programs may be possible. For organizations with large regeneration programs, small increments of gain can mean a large difference in profitability.

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# STRATEGIES FOR ADVANCED GENERATION ORCHARDS

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#### ABSTRACT

The overall purpose of advanced generation breeding is to maximize the amount of genetic gain per year. To achieve this gain, one has to optimize the mating design, develop a good strategy to manage inbreeding, and shorten the breeding cycle by the use of flower induction and early selection procedures. The design of advanced generation seed orchards is, in principle, very little different from that of first generation orchards, but will require extra care to minimize crosses among related individuals.

# RÉSUMÉ

Le but principal de la reproduction précoce est de porter à son maximum le gain génétique annuel. Pour atteindre cet objectif, il faut optimiser le schéma d'hybridation, prendre les bons moyens pour éviter la consanguinité et comprimer le cycle de reproduction à l'aide de l'induction florale et de la sélection précoce. Le concept des vergers à génération précoce est peu différent de celui des vergers de première génération, mais il faut prendre plus de précautions afin de réduire au minimum les croisements entre individus apparentés.

## INTRODUCTION

Advanced generation orchards are considerably more complex than first-generation orchards and present a number of new problems and requirements. An advanced generation breeding system needs to be a stable system that can be recycled from generation to generation using the same procedure. In doing so, the genetic base will be narrowed and we are faced with the problem of managing inbreeding. There are several ways of doing this, which will be discussed in detail in the paper. Because of the inbreeding problem there is also a need for compatibility between the breeding procedures and the seed orchard layout, since the physical arrangements of the selections on the ground affects the degree of inbreeding of the resulting wind-pollinated seed. Finally there is a need for a means of adding new material into the system even after several generations of gentic improvement.

In the following paper, I am not proposing a specific system

that will solve all problems, but instead I shall explore some approaches to solving these problems. There are many possible solutions and the preferred solution will differ by species and region.

BREEDING STRATEGIES FOR ADVANCED GENERATION ORCHARDS

Coals

The overall goal for breeding for advanced generation orchards is to obtain the maximum amount of genetic improvement per unit of time.

This goal is to be achieved by appropriate mating designs, progeny test procedures and accelerated breeding procedures.

Mating Designs

Several objectives may be pursued when developing advanced generation mating designs. The most important ones are to develop families from which 1) the GCA can be determined for specific parents; 2) the SCA can be determined for specific pairs of parents; and 3) the breeding population for the next generation can be selected.

A summary of mating designs is given in Table 1 together with some of the advantages and disadvantages. A theoretical review of the merits of the different mating designs (Namkoong and Roberds 1974; van Buijtenen 1976) is beyond the scope of this paper, but there are some practical considerations that are worth pointing out. To effectively determine GCA, it is important that each parent is involved in several crosses. It is usually best if the design can be arranged in small sets of crosses. A small set of crosses can be completed in a relatively short period of time and such a group can be kept together in the field. In looking at the designs, it is obvious that some designs such as disconnected factorials, disconnected diallels, and partial diallels can do a fair job of satisfying the principal objectives. Other designs such as the polycross or the circular mating designs each satisfies merely one objective. One has the alternative of settling on one design that will satisfy all the objectives or following a proposal made by the French several years ago to utilize a number of complementary mating designs each of which is quite simple and does the best job of satisfying a single objective.

Progeny Test Designs

Progeny tests may have any number of goals such as early evaluation, ranking of families at the sampling stage, ranking of families at rotation age, evaluating specific traits such as disease, drought, and cold resistance, or evaluating actual growth and yield under operational conditions.

A summary of progeny test designs is given in Table 2. The physical layout of single tree plots and non-contiguous plots in the field is very similar. The main difference is that in non-contiguous plots several trees, even though they are not adjacent to each other, are considered as one plot.

	Objectives				
Mating Design	Cost	Served Well <u></u>	Efficiency		
Nested	Low	sca	Low		
Factorial (e.g. 4 tester scheme)	Moderate	gca, sca	Moderate		
Completed diallel	High	gca, sca, sel	Low		
Disconnected diallel	Moderate	gca, sca, sel	High		
Disconnected factorial	Moderate	gca, sca, sel	High		
Incomplete diallels	Moderate	gca, sca, sel	High		
Circular matings	Low	sel	High		
Single pair matings	Low	sel	High		
Polycross	Low	gca	High		

Table 1. Mating designs and Their Usefuline	Table	1.	Mating	designs	and	Their	Usefullr	ies
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 $\frac{1}{2}$  gca = determination of general combining ability.

sca = determination of specific combining ability.

sel = provide population in which to make advanced generation
selections once gca is known.

Single tree plots, non-contiguous plots, and row plots are rather good at evaluating seedlings at an early age, about to the sapling stage, but once competition sets in, rankings may be different from rankings obtained in block plots where trees are competing with their siblings. For that reason, there is some question about their ability to evaluate families well at rotation age. Block plots can be used well for all purposes. However, their statistical efficiency is low, since very large tests are required and usually a great deal of site variation is encountered.

In order to obtain growth and yield data under operational conditions, it is necessary to put sample plots in operational plantings. As far as I know, no data of this sort are available yet and not much is known about the statistical precision of such a procedure. One can expect it to be rather low because of the amount of site variation encountered and the uncontrolled nature of operational plantings. A problem that we have run into repeatedly in summarizing progeny test data is the difficulty of summarizing data across tests when each test contains a partial set of crosses with varying degrees of overlap among tests. It can be done but the statistical precision of the results is somewhat less than desirable. For that reason it would be advantageous to match the progeny test design and the mating design in such a way that entire sets of crosses can be field planted at the same time.

#### Management of Inbreeding

In a recurrent selection and breeding system, inbreeding eventually becomes unavoidable. It is therefore necessary to develop a strategy for the management of inbreeding. It is important to distinguish between the various populations involved in a breeding program. These populations are theoretically distinct, although in practice some of them are often combined. For this purpose, it suffices to consider the breeding population, the progeny test population, and the production population.

Progeny Test Design	Complexity	Cost	Well Served <sup>1</sup> Objectives	Efficiency
Single Tree Plots	High	Low	esp, sap	High
Non-contiguous Plots	High	Low	esp, sap	High
Row Plots	Low	Moderate	esp, sap	Moderate
Block Plots	Low	High	esp, sap, rot	Low
Sample Plots in Operational Plantings	Low	High	yield	Low

Table 2. Progeny Test Designs and Their Usefulness

<u>1</u> Abbreviations used: esp = early selection procedures sap = evaluation at sampling stage rot = evaluation at rotation age yield = growth and yield data.

The breeding population is composed of the trees and the progeny that are used to produce the selections for the next generation. The progeny test population is composed of the trees that are used to evaluate the parents from which they are derived. They may or may not be used to generate new selections. The production population consists of the seed and seedlings that are derived from the operational seed orchard. In the seed orchard seed, it is desirable to minimize or completely eliminate all inbreeding since inbreeding results in a loss of vigor. However, in the breeding population it is possible to tolerate a certain degree of inbreeding, and under certain circumstances it might even be desirable. In the progeny test plantations, inbreeding needs to be managed very carefully since it tends to be confounded with general combining ability. If all progenies in the test are equally inbred there is no particular problem. As a matter of fact, it might make it easier to distinguish the desirable progenies. However, if some are inbred more than others they might be unfairly penalized.

Maintaining a large genetic base is one means of slowing down the rate of inbreeding. This conflicts, however, with the overall goal of maximizing the gain per unit of time, which requires the maximum selection intensity possible and would result in narrowing the genetic base and increased inbreeding. This is a situation that is in principle unresolvable. One needs to arrive at a compromise solution, balancing the need for immediate gain against the need to minimize inbreeding and retain the maximum number of genes in the population to insure long-term gentic gains. It is also important to preserve genes that may be needed in the future to meet unexpected requirements such as changing market demands or resistance to new diseases.

## Effect of Mating Designs

Cockerham (1970) did some work several years ago on this and found that mating designs that avoid inbreeding as long as possible will begin to show rapid inbreeding once inbreeding starts. Other designs which allow some inbreeding right from the beginning will accumulate less inbreeding eventually. A circular mating design is one of those designs which falls in the second category.

#### Use of Co-Ancestry Matrix

A co-ancestry matrix (Falconer 1960) is a table which shows the degree of inbreeding to be expected when crosses are made among the parents included in the table. It is somewhat difficult to visualize the relationships since one has to look back two generations, a situation somewhat analogous to looking two moves ahead in a chess game. The method lends itself well to computer analysis, however, and can be a great help in planning crosses and determining the degree of inbreeding expected in progenies. The use of such a matrix enables one to carefully control the degree of inbreeding within the feasible limits.

## Use of Breeding Groups

By subdividing the population into independent lines, limiting all crosses for breeding purposes to within group crosses, it is possible to have an inbred breeding population, but assure that the production population referred to earlier is entirely outcrossed. This seems to be a very nice way to have one's cake and eat it too (van Buijtenen and Lowe 1979). Another major consideration in advanced generation breeding and one aimed specifically at increasing the gain per unit of time is the development of accelerated breeding procedures. There are two aspects to this, the breeding cycle can be reduced both by inducing earlier flowering and by reducing the length of time needed to evaluate the progenies.

## Flower Induction

In several species such as <u>Cryptomeria japonica</u>, Douglas-fir, and loblolly pine, it has been possible to induce early flowering by a variety of techniques. Some of the main techniques in use currently are a) application of gibberellins, particularly in combination with water stress (Pharis 1975; Greenwood 1977); b) heavy fertilization; c) out of phase dormancy (Greenwood 1980); d) branch girdling, particularly to induce male flowering (Greenwood 1977); and e) the use of specially selected understock (Holmes 1981; Wright 1981). All of these methods have worked under certain circumstances and in combination can serve to reduce the flowering age by several years.

#### Early Testing

Less progress has been made on early evaluation of families. In general, correlations between early height and diameter measurements and subsequent growth have been rather weak. Some recent experiments (Cannell <u>et al</u> 1978; Waxler 1980), however, show promise that some traits such as shoot-root ratio may be of value in selecting families at an early age for growth rate. Other traits such as rust resistance and drought resistance can easily be evaluated at an early age.

How to Blend in Accelerated Breeding with Conventional Testing

Little thought has been given to this problem so far. It is obvious that it will not be possible to replace seed orchards at very short intervals every time a generation has been completed. It seems reasonable to assume that if accelerated breeding becomes a reality, one may go through several cycles in quick succession before incorporating the selected material into the main line program. A possibility for integrating the various methods might lie in a stepwise screening procedure. One might, for instance, begin by screening a large number of trees with early testing methods, then screening the most promising families with conventional progeny tests for a duration of about half the rotation age, and finally screen a very small number either as orchard mix or open-pollinated families to full rotation age in operational plantings. To my knowledge, no one has ever thoroughly evaluated such a procedure, but this may be the general direction in which we are moving.

DESIGN STRATEGIES FOR ADVANCED GENERATION ORCHARDS

In a first-generation orchard one only needs to be concerned
with maximizing the crossing among clones and trying to minimize the pollination that may occur between ramets of the same clone. In advanced generation orchards one also has to be concerned about the relatedness among different clones in the orchards and the need to minimize or avoid mating between related clones. Similar designs can be used in advanced generation orchards and in first-generation orchards. They fall into two major categories: systematic designs and random designs.

### Systematic Designs

In Figure 1, a design is shown that is used extensively within the Western Gulf Forest Tree Improvement Program. It is very convenient for first-generation orchards and also works well with advanced generation orchards. In this case, each of the ten positions in the design indicated by the numbers 1 to 10 is identified with a breeding group rather than with an individual clone. In such a case not only can members of the same breeding group be included in the same orchard, but it is also rather easy to include members of different generations in the same orchard. It is, for instance, not uncommon to mix some of the very best first-generation selections in the same orchard with some untested but promising second-generation selections. The main disadvantage of the systematic design is that, if two or three trees are rogued from the orchard in adjacent positions, rather large holes will occur throughout an entire orchard block.

1	2	3	4	5	6	7	8	9	10
8	9	10	1	2	3	4	5	6	7
5	6	7	8	9	10	1	2	3	4
2	3	4	5	6	7	8	9	10	1
9	10	1	2	3	4	5	6	7	8
6	7	8	9	10	1	2	3	4	5
3	4	5	6	7	8	9	10	1	2
10	1	2	3	.4	5	6	7	8	9
7	8	9	10	1	2	3	4	5	6
4	5	6	7	8	9	10	1	2	3

Fig. 1. Systematic seed orchard design used by Western Gulf Forest Tree Improvement Program.

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Random Designs With Use of Breeding Groups

One can randomize the breeding group numbers and assign trees from breeding groups to the appropriate positions. Again it is possible to mix the generations. Experience shows, however, that even in randomly designed orchards very large holes can occur during roguing because of chance occurrences of trees that need to be removed from the orchard.

### Random Designs Without Breeding Groups

These are a nightmare to work with. It is almost impossible to design such an orchard by hand without making several mistakes. One needs a computer program to assign the positions and analyze the relatedness of the trees to be included in the orchard. One does need a rather large number of unrelated parents to complete such an orchard and the problem will become more severe in further generations.

# SUMMARY AND CONCLUSIONS

In the following few paragraphs I would like to summarize the preceding, really giving in to my personal biases.

- a) One of the promising approaches to the development of mating designs is the use of complementary mating designs using very simple mating schemes each of which serves a single objective very well.
- b) The most promising approach to managing inbreeding seems to be the use of breeding groups, allowing one to get inbreeding within the breeding population without getting inbreeding in the production orchard. If co-ancestry matrixes are used while planning crosses within a breeding group, it is possible to very closely control the amount of inbreeding in the breeding groups.
- c) It may be possible to blend in accelerated breeding methods with conventional ones, by the use of a stepwise screening procedure. This should result in considerable savings in the cost of progeny testing.
- d) Either systematic or random seed orchard designs can be used for advanced generation seed orchards. If they are used in combination with breeding groups, neither one is particularly difficult. If used without breeding groups, it is virtually a necessity to develop a computer program to assign the trees to their positions.

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# FIELD EXCURSION

# SAANICH PENINSULA SEED ORCHARDS

# ILLUSTRATING:

Capital Development Phase Mount Newton Seed Orchard

Establishment Phase Lost Lake Seed Orchard

Production Phase Saanichton Seed Orchards

# MOUNT NEWTON SEED ORCHARD S.W. Lorimer Crown Zellerbach Canada Ltd., and D.E. McMullan British Columbia Forest Products Ltd.

### INTRODUCTION

The site is being managed as a joint venture between British Columbia Forest Products Limited and Crown Zellerbach Canada Ltd. The 40 hectare property was purchased in 1979 with BCFP owning an undesignated 60% (24 hectares) and Crown Zellerbach 40% (16 hectares). The majority of the site is being managed as part of the Coastal Tree Improvement Council cooperative B.C. Forest Service-Industry tree improvement program. BCFP is responsible for the management of orchards 29 (Abies amabilis) and 20 (western hemlock), while Crown Zellerbach looks after orchards 34 (Douglas-fir), 38 (yellow cedar) and 40 (western red cedar). A small orchard supplying Douglas-fir seed for the private lands of both companies will also be established over the next few years on a portion of the site.

### MANAGEMENT

Direct supervision of the orchard is the responsibility of the Seed Orchard Supervisor, Brian Stretch, who reports directly to a Management Committee which is composed of the chief forester, silviculturist and an accountant from each company. Back-up supervision and assistance in site development is provided by a salaried employee. Annual and monthly operating financial statements are prepared by the accountant at the Crofton Logging office of BCFP.

Advice concerning orchard management and layout design problems is being provided to both companies by Don Lester, Ph.D., consulting geneticist, employed by Crown Zellerbach Corporation of Oregon. Other specialist advice is being sought as projects develop.

#### CAPITAL DEVELOPMENT PROGRAM

Since purchase of the site in 1979, general site improvements have included installation along the total perimeter of a chain-link fence, perimeter and some internal drainage, construction of access roads, upgrading and expansion of the small house to provide a residence for the orchard supervisor, structural repairs and re-roofing of the barn, rough construction of the holding site and service area, replacement of the power line along the access road, construction of an office and meeting room complex within the barn, and construction of a 43 million litre reservoir and lower sump as the first phase of the irrigation system. The majority of the required capital development projects are to be completed by mid-1981.

### ORCHARD DEVELOPMENT

The sites for the orchards are located as indicated on the attached map and were assigned on the basis of species/site suitability.

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Outplanting of the various orchards is scheduled to start in 1982 and be completed by the end of 1985. Planting spot preparation will be undertaken prior to field establishment. Selections of the parents is being undertaken through the cooperative selection program of the CTIC with propagation being undertaken at the Mesachie Lake Propagation Centre of the B.C.F.S. Cultural practices for the first few years will concentrate on vegetative growth in order to ensure successful orchard establishment.

### GENETIC IMPROVEMENT

Breeders employed by the B.C.F.S. are working towards developing information which would permit eventual roguing of the fir and hemlock orchards. No breeders have yet been assigned to the balsam, cedar and cypress programs. Parental selections for all orchards is based largely on parent tree quality and the need for obtaining a good geographic distribution.

### ORCHARD SUMMARY

Orchard	Area Under	Establishment	No. of	Estiamted Annual
No.1 Species	Orchard	Goal	Parents	Seed Yields
29 Balsam (A. amabilis)	7.7 ha	1984	100	1,380,000 by 1994
30 Western Hemlo	ck 8.2	1984	100	2,350,000 by 1991
34 Douglas-fir	5.2	1983	80	2,340,000 by 1994
38 Yellow cedar	1.2	1985	120	670,000 by 1991
40 Western red cedar	0.6	1984	100	420,000 by 1988
	22.9 ha			

The orchard size, numbers of parents, seed needs and estimated yields through time were determined by members of the Technical Planning Committee of the Coastal Tree Improvement Council

1 Orchard planting zo	nes
Orchard No.	Planting zone
29 30 34	Johnstone Strait, Western Vancouver Island Western Vancouver Island Johnstone Strait Johnstone Strait, Northern Vancouver Island
40	Western Vancouver Island, Eastern Vancouver Island Johnstone Strait, Eastern Vancouver Island, South Coast Mainland

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### MOUNT NEWTON SEED ORCHARDS



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LOST LAKE SEED ORCHARD

### W.L. McMullan

### Western Forest Products Limited

### INTRODUCTION

Western Forest Products is a large forest industrial company whose basic forest management policy is to maximize the quality and quantity of the annual allowable cut. However, the acreage base that is so essential for growing the forest crop has been slowly diminishing through losses to highways, gravel pits, parks, hydro lines, and environmental constraints. To provide for the future wood requirements of our manufacturing plants it will be necessary to produce more wood on less acreage. This will be imperative if only to maintain our current level of supply, but more so if we propose to provide our future increased wood demands.

To overcome future wood deficiences, Western Forest Products formulated plans for an Intensive Forest Management Program in 1971. The key element of this program is the production of genetically improved seed in the amounts necessary to fulfill all company reforestation requirements.

#### OBJECTIVE

The objective of the Western Forest Products Tree Improvement Program is to meet all planting requirements with genetically improved stock by 1985. The only practical method of achieving this objective is to develop an all-species seed orchard on a site that can be intensively managed for the production of gentically improved seed used to grow nursery stock for outplanting on company managed lands.

### BACKGROUND

In 1973, the Lost Lake Seed Orchard site was acquired on the Saanich Peninsula. Until recently, the WFP efforts have been completely independent from both governmental and industrial programs. However, in 1979, WFP joined the recently formed Industrial/Governmental Coastal Tree Improvement Council. To date, four of our seven seed orchard units are part of this co-operative tree improvement program. A summary of the WFP program is as follows:

....

Unit	STATUS	SPECIES/PROVENANCE	SIZE(Ha)
1	Co-operative	WII, N. Island. Low	3.66
2	Independent	WRC, N. Island, Mid	0.85
3	Independent	SS, N. Island, Low	0.48
4	Independent	WH. O.C.I., Low/Mid	1.09
5	Co-operative	SS, Q.C.I., Low	2.28
6	Co-operative	WH, N. Island, High	2.38
7	Independent	WRC, N. Island, Mid	0.58
, 7A	Co-operative	WRC, N. Island, Mid	1.05
7 21	oo operative	Total:	12.37

### PROGRESS TO DATE

- 1973 27.44 hectare seed orchard site purchased on the Saanich Peninsula.
- 1974 8,300 meters of drain tile installed. - propagation facilities constructed.
- 1975 conversion of old farm structures into workshop, storage areas, office and staff quarters.
  - landscaping, upgrading power supply and water lines.
- 1976 paving entrance road and parking lot.
  - construction of additional propagation facilities.
- 1977 installation of irrigation system initiated
- 1978 installation of 2,000 meter chain link fencing initiated. - farm tractor and accessories purchased.
- 1973 1980 over 700 plus/parent trees selected, cuttings collected and propagated by rooting.

### PROPAGATION

Over the yars, a total of 182,756 cuttings were set in the rooting beds. To date, 19,229 cuttings have rooted.

Propagation Techniques

- Cuttings are collected during the winter months in wild natural stands from trees selected for their superior growth and form characteristics.
- 2. These are shipped to the Lost Lake Seed Orchard and treated by the techniques developed and recommended by H. Brix and H. Barker of the Canadian Forestry Service:
  - a) Needles stripped from the base of each cutting for 2.5 cm.
  - b) Cuttings given a 24 hour basal soak in Indolebutyric acid and Benlate.
  - c) Rooting medium a mix of equal parts peatmoss, washed sand, and perlite.
  - d) Temperature regime: W.H. - W.R.C. - cold air, cold soil. S.S. and D.F. - cold air, warm soil.
    e) Rooting time: W.H. - 6 months - 24 months. W.R.C. - 3 months - 18 months. S.S. - 6 weeks - 12 months. D.F. - 3 moths - 12 moths.

# LOST LAKE SEED ORCHARD

C	RCHARD		
	REG.		
UNIT	NO .	SPECIES	PROVENANCE
1	26	W.H.	N. Island, low
2		W.R.C.	Q.C.I., mid
3		S.S.	N. Island, low
14		W.H.	Q.C.I., mid
5	42	S.S.	Q.C.I., low
6	27	W.H.	N. Island, high
7		W.R.C.	N, Island, mid
7A	28	W.R.C.	N, Island, mid

# Site Organization Showing Orchard Locations



### SAANICHTON SEED ORCHARDS

### Anita Fashler

### Pacific Forest Products Limited

### INTRODUCTION

At Pacific Forest Products we tend and harvest trees on self-regulated crown granted lands. These lands were purchased from the Esquimalt and Nanaimo Railway Co. and others starting in 1962. Our objective in conducting our forestry business is to manage our private forest land base to yield the highest possible return on our investment consistent with a continuous supply of wood.

The company manages 127,500 ha of privately owned forest (0.24 of British Columbia's forested area), most of which is located on the south east side of Vancouver Island, with additional supplies of crown lands on the west side of Vancouver Island as well as on the mid coastal Mainland.

The forest management policy of P.F.P. involves an intensive forest management program based on forest site classification. Forestry activities include prompt reforestation, spacing, fertilization, commerical thinning, protection and tree improvement. The Saanichton Douglas-fir seed orchards illustrate the company's commitment to intensively manage our private forest lands.

#### OBJECTIVE

The objectives of the seed orchard are: a) to produce improved seed for reforestation, and b) to generate advance generation populations through control crossing. The HE and LE orchards are designed to provide 25 kg of seed per annum at age 15 years. Similar productivity is expected from the FS seed orchard.

#### BACKGROUND

The 26 ha property was purchased in 1965. The site characteristics of summer drought and 2000 plus hours of annual sunshine appear to be responsible for frequent heavy cone crops in the area.

At this time, 11 of the 26 ha are developed in Douglas-fir. All orchards are privately owned and are designed to provide improved seedlings for reforestation on company lands. Some statistics on current seed orchard status are given below:

### Current Seed Orchard Status

Orcha	rd Type	Status	Species/Provenance	No. Clones or Crosses	Acre (ha)
HE	o.p seedling/clonal	private	F/high elev. <sup>2</sup>	63	3.4
LE	o.p seedling/clonal	private	F/Low elev.	72	1.3
FS	c/c/ seedling <sup>3</sup>	private	F/low to mid	145	6.0

 $\frac{1}{2} \text{ o.p. } - \text{ open pollinated} \\ \frac{1}{2} \text{ F} - \text{Douglas-fir} \\ \frac{3}{2} \text{ dc.c.} - \text{ control cross}$ 

The high elevation and low elevation seed orchards were grafted between 1966 and 1968; the open pollinated seedlings were 2 + 0 plugs planted in 1971. The full-sib seedlings were planted in 1975 as 1 + 1transplants. Just over 100 crosses are represented in the FS orchard to date.

### PRODUCTION INFORMATION

Cone and seed production at the Saanichton Douglas-fir seed orchards from 1976 to 1980 is given in Table 1. The 1980 seed crop of 26.55 kg has a projected seedling production of approximately 2.0 million. Cone crop estimates for 1981 predict a lower yield. This is consistent with the pattern of cone production established in the Saanich Peninsula seed orchards, namely a good crop about every 2 years.

Table 1. Douglas-fir Seed Orchard Cone and Seed Production

Year	Seed Orchard	Cone Production in HL	Seed Production in Kg	Seed Yield in Kg/hL
1976	high elevation	29.77	15.85	0.40
1977	high elevation		2.12	
1978	high elevation	57.9	22.37	0.39
	low elevation	3.6	0.96	0.27
1979	high elevation	45.0	11.6	0.26
1980	high elevation	49.14	25.0	0.50
1700	low elevation	1.8	0.6	0.33
	full-sib	2.16	0.95	0.44

#### MANAGEMENT INFORMATION

A special feature at the orchard is the solid set irrigation system used to delay flower bud opening past the local flowering period so that contamination from local pollen will be minimal. The system was applied to the 1976 and 1978 seed orchard cone crops. In both years phenological and pollen flight data showed that the cooling treatment kept the female reproductive buds unopened through the major portion of the local pollen flight period in approximately 76% of the Douglas-fir clones in the orchard. Cooling followed by bulk pollination is estimated to give 85-90% control over contamination.

Results of the seed and cone insect control study (Heath, 1980 Pacific Forest Products Internal Report) carried on at the seed orchard in 1980 are presented in Table 2. The objective was to assess the efficacy of an insecticide spray in comparison to and in conjunction with the irriagation cooling system to reduce seed losses due to insect damage. It was estimated that the application of an integrated pest/irrigation cooling system control program would protect over 1 million seeds annually in periods of heavy infestation.

### Table 2. Impact of <u>Contarinia</u> <u>oregonensis</u> on Seed Production at the Pacific Logging Seed Orchards

Treatment	Mean No. Filled Seeds per cone	Mean No. Seeds Destroyed per cone	% Seed Destroyed
Insectcide & Delay	19.96	0.09	0.46
Delay Alone	19.13	1.24	6.40
Insecticide Alone	11.43	0.33	2.80
Control	15.84	1.88	11.90

Standard orchard management procedures include reproductive bud delay, frost protection, irrigation, booster and control pollination, weed control and insect control. Several orchard surveys are undertaken throughout the year to improve management, assist planning and develop a data base for all clones in the seed orchard.

#### FUTURE PROJECTS

Emphasis on the Douglas-fir tree improvement program will be continued with specific interest in high elevation seed production. A tree improvement program will be developed for dry site western hemlock on company lands on east Vancouver Island. In addition, a Sitka spruce seed orchard is planned with the cooperation of the B.C. Ministry of Forests.



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# SEED TECHNOLOGY FOR SEED ORCHARDS

Chairman:

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George Edwards Canadian Forestry Service Victoria, B.C.

# CONE COLLECTION AND HANDLING FOR SEED ORCHARDS

### B.D. Haddon

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#### ABSTRACT

A wide variety of strategies and equipment is available for the collection of cones and seeds. Some are well suited to application in seed orchards while others do not meet the constraints inherent to seed orchards. The seed orchard manager can choose between manual and mechanical techniques and between harvesting before and after seed dispersal. Improved technology is not as important in cone handling as attention to logistics and administrative procedures.

# RÉSUMÉ

Il existe une grande variété de méthodes et d'équipement pour la récolte des cônes et des graines. Certains conviennent aux vergers à graines tandis que d'autres ne satisfont pas aux contraintes qu'on y trouve. Le directeur du verger a le choix entre des techniques manuelles et mécaniques et peut récolter soit avant, soit après la dispersion des graines. Pour la manutention des cônes, les nouvelles techniques ne sont pas aussi importantes que la logistique et les méthodes de gestion.

### INTRODUCTION

In a discussion of cone collection and handling for seed orchards, it seems logical to first consider the unique features and the constraints to seed orchard cone collection and handling. Among those features unique to seed orchards is the fact that the trees are extremely valuable as are the seeds to be collected from them. There are both clonal and seedling seed orchards, a fact which may affect cone collection and handling. It seems likely that accessibility to the trees will be greater in seed orchards than in natural stands.

A number of constraints, which are not necessarily unique to seed orchards, limit the options available for cone collection and handling for seed orchards. Damage to the trees cannot be tolerated because they are so valuable. Because the seeds are so valuable, no loss can be tolerated. Terrain can vary tremendously among Canadian seed orchards. Seed dispersal dates vary among individual parent trees in an orchard. A potential limiting factor is the availability of labour during the cone collection period and one is always faced with the vagaries of weather during the collection period.

# CROP ASSESSMENT

Before committing resources to cone collection, and hence every phase of handling and seed processing subsequent to collection, the seed orchard manager must decide whether a cone crop warrants collection. He must take account of genetic considerations; was flower production adequate for an acceptable genetic mix in the resultant seeds? He must take account of insect damage; are there actually sufficient quantities of sound seeds in the cones to warrant the commitment of resources for collection from a particular orchard?

The determination of seed development and the probable time of seed maturation are part of crop assessment. Only when all the biological factors are accounted for and a collection strategy worked out that takes into account such factors as availability of labour and equipment can the seed orchard manager determine the optimal scheduling of cone collections.

#### COLLECTION

Before seed dispersal

Manual cone collection

Any method of cone collection prior to seed dispersal offers the possibility of maintaining seedlot identity with respect to mother trees.

Many foresters will attest to the value of tree-climbing for cone collections (Yeatman and Nieman 1978, 1979). Topography presents no problem to this technique. However, it is unlikely that damage to trees can be kept to acceptable levels when they are climbed every year. A high level of training and skill is necessary for tree-climbing to be a safe and efficient technique.

Ladders, particularly tripod ladders, are useful tools (Yeatman and Nieman <u>ibid</u>.). Terrain would have to be very rough to restrict their use and trees are not subject to damage. However, ladders are restricted in height and are rather cumbersome. They must be moved around each tree to yield access to the entire cone-bearing crown.

"Cherry-pickers" or bucket booms can be mounted on a variety of vehicles. They offer greater maneuverability around tree crowns than ladders, but their use is restricted by terrain and the spacing between trees. They could damage trees through abrasion and soil compaction, especially as the larger the boom, the larger the vehicle required on which to mount it. A number of self-propelled aerial lift platforms are marketed for work in fruit orchards and light industrial settings, and have been used to advantage in British Columbia seed orchards. Innovations and improvisations have included such things as mounting scaffolding on the back of a truck (D.A. Skeates, Ontario Ministry of Natural Reosurces 1981, pers. comm.). Dooley <u>et al</u> (1981) have reported on a study of man positioners applicable to the manual collection of cones and have recommended a complement of man-lift equipment.

Seal (1957) reported a technique which may have application with mature, large crowned trees. For work in species with small cones, such as <u>Thuja</u> and <u>Tsuga</u>, the collector makes use of a triangular "Tree Net", usually 36 feet (11 metres) across the base and 40 feet (12 metres) high, made of Italian hemp with a 12 inch (305 mm) by 12 inch mesh. The apex of the net is run up into the crown by a carriage block on a guy line and, by means of guys from the base of the net, it is spread so as to partly envelope the crown. The collector lies in the net and picks the small cones by hand, putting them in a shoulder bag.

### Mechanical cone collection

A variety of machines have been developed for the separation of cones from slash, a feature which precludes their use in seed orchards, but at least one company has developed equipment for the collection of cones from standing trees.

Fandrich Cone Harvesters (Dr. H. Fandrich, Fandrich Cone Harvesters Ltd., Clearbrook, B.C. 1981, pers. comm.) are designed to collect seed bearing cones with the aid of a helicopter or crane. Generally, the harvester is lowered over the top 3-5 metres of the tree and then raised to collect the cones which fall into a bin surrounding the harvester head. When full, the bin is dumped at a central loading site. The Fandrich Balsam Rake was developed for cones larger than 40 mm in diameter, using specially designed fingers to strip cones from branches. The Fandrich Rotorake has rotating fingers that knock the cones from branches into a holding bin. The two rotating drums to which the flexible fingers are fastened are powered by a gas engine. The company claims that because damage to trees is minimal, Rotorakes can be used with a crane in seed orchards.

### Other concepts

Top pruning or "topping" seems to be a controversial topic. It has been considered both as a general collection technique (Slayton 1969) and for crown management in seed orchards. Although biological constraints preclude its use for some species, such as <u>Pinus</u>, other species such as white spruce (<u>Picea glauca</u> (Moench) Voss), seem well suited to this treatment (Nienstaedt 1981). The objectives of the treatment when used for crown management are to keep crowns low for easy cone collection and to increase cone yield.

Artificial ripening has been successfully applied to a number of species (Winston and Haddon 1981) and could be applied to any cone collection technique (before seed dispersal). Artificial ripening can give the seed orchard manager a longer collection period, facilitating the deployment of labour and equipment and possibly reducing squirrel depredation. In some cases it serves to precondition seeds in that the requirement for stratification is eliminated, even after regular seed storage (Haddon and Winston 1982).

After seed dispersal

Mechanical seed collection

Mechanical collection of seeds after dispersal reduces labour costs and eliminates extraction costs. The collector is assured of seed ripeness but cannot usually maintain seedlot identity.

Mechanical tree shakers, either self-propelled or mounted on a tractor or truck, have been developed and tested. Many consider this technique of cone removal unsatisfactory (Hallman and Casavan 1979), while others view it as practical (Moini and Miles 1981). Although tree shakers have usually been used for cone collection before seed dispersal, a variation has been reported in the USSR (Gukov 1973), wherein the trees are shaken by a hand-held modified power saw to hasten the dispersal of seed from open cones. The trees are shaken during periods of calm weather and the seed falls onto tarpaulins laid out on the ground.

The Georgia Forestry Commission has further mechanized this concept for application in loblolly pine (Pinus taeda L.) seed orchards (Wynens and Brooks 1979). Prior to cone opening, polypropylene netting is laid on the ground, using a tractor to pull the netting off large rolls. The netting is fixed to the ground and at the appropriate time a tree shaker is used to hasten seed dispersal from open cones. Fallen seeds and other debris which lands on the nets is windrowed and then mechanically collected. A modified peanut combine is used to separate the seeds from needles and other debris. Further refinements and mechanization of the system are under development, including an "Orchard Netting Machine" which gathers the netting and its collected material, at the same time separating the needles from the seeds (R.G. Hallman 1981, pers. comm.).

A variety of vacuum seed harvesters have been developed for the collection of fallen seeds without the aid of tarpaulins or netting. The advantages of the Bowie Vac-U-Seed Harvester, developed for use in the Southern Region of the U.S.A., have been enunciated by Hallman (1981) and could be extended to all forms of mechanical seed collection after dispersal:

"1. Extends the harvesting season from about 2 weeks to 2 months.

- 2. Eliminates the need for ladders and lift trucks, permitting orchard managers to let their trees grow taller because no climbing is involved, therefore extending the useful life of the trees.
- 3. Reduces collection costs compared to hand collection."

Calculations resulting in the last conclusion included costs of turf management necessary for the successful operation of the machine. The disadvantages of the harvester have also been enunciated:

- "1. The orchard floor requires extensive preparation for the machine to operate well.
- 2. The harvester is noisy and produces large quantities of dust.
- 3. It does not operate well when the ground is wet.
- 4. The harvester has had a number of mechanical problems that have been largely corrected, but minor design changes still need to be made."

Two other considerations, which apply equally to the Orchard Netting Machine and other sophisticated machinery, are limitations imposed by terrain and portability from one seed orchard to another.

A report from France (Bastide and Gama 1980) describes two types of vacuum seed harvesters which are much smaller than the selfpropelled Bowie Vac-U-Seed Harvester. The first, designed for beechnuts, weighs only 14 kg empty and can be carried on a man's back. The second, larger machine was designed for acorns and at present it is wheeled around on a small trailer. Again, the authors report that neither machine works well under wet conditions.

#### New concepts

Several years ago the idea occurred to me of enclosing trees in a mesh envelop butIdismissed it as impractical. Apparently the idea has occurred to others and it has been published in "An Analysis of Seed and Cone Collection" (Hallman and Casavan 1979). Seeds would be caught in the envelope as they are released, and a spout or trough at the bottom of the envelope would convey them to a container on or near the ground from which they could be collected. Seedlot identity could be maintained. Rodent and bird depredation would be eliminated if the mesh material was tough enough to resist chewing.

The technology of injecting trees is developing rapidly, and it may soon be possible to inject a compound which would promote the timely formation of abscission layers so that cones would fall out of the trees.

### HANDLING

Stein <u>et al</u> (1974) described handling and storage of cones to avoid losses and degradation of quality. Seed orchard material, in my view, need not be handled in any special way. Unfortunately, in many cases, cone handling is treated in a casual fashion. This is certainly not acceptable with seed orchard seeds. Improved technology is not as important in cone handling as is attention to logistics and administrative procedures. One must never forget the fact, as expressed by Wang and Fogal (1979), that "seeds reach their highest quality at physiological maturity, and they degenerate from then until planting, with the rate depending upon the degree of deviation from optimum conditions in the subsequent phases from harvesting to seeding".

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### SEED PROCESSING

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#### ABSTRACT

Seed extraction is identified as a critical phase in providing seeds for artificial regeneration. All extraction methods are potentially harmful and only the most efficient, least damaging systems should be used for seed orchard seeds. Extraction without the use of artificial heat is recommended. Rotating Drum extractors should be used when artificial drying is required.

# RESUME

On y établit que l'extraction des graines est une étape critique de la production de graines destinées à la régénération artificielle. Toutes les méthodes d'extraction sont potentiellement dommageables, et, dans le cas des semences de vergers à graines, on ne devrait employer que les plus efficaces et les moins dommageables. On recommande de ne pas utiliser de méthodes qui font appel à une source artificielle de chaleur, mais si c'est nécessaire, on devrait utiliser des extracteurs à tambour rotatif.

### INTRODUCTION

The increased demand for abundant and improved forest tree seeds brought into existance the seed orchard concept, which was first emphasized by Bursdorf (1787), and later Sylven (1918), Fabricius (1922), Oppermann (1923), Bates (1928) and Feilberg and Soegard (1975).

The first seed orchard was established in Scotland in 1931 with the intention to produce back-cross larch seeds. Presently approximately 20,000 ha of seed orchards have been established in the world. The largest total seed orchard area is reported from U.S.S.R. (10,670 ha), China (4,264 ha), U.S.A. (2,550 ha) and Japan (1,530 ha). On the Pacific Coast (Wheat and Bordelon 1980), Oregon had established by 1980, 359.2 ha, Washington 167.8 ha and B.C. 120.5 ha of seed orchards. Since many of the early orchards are already in the production phase, more and more emphasis is placed in obtaining:

- a) high quality viable seeds through improved seed processing,
- b) genetic parameters ease of extraction, seed weight, germination energy, and germination capacity: to enhance roguing and increase gains in cone and seed yeilds from the

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next generation orchards.

### SEED PROCESSING

Seed processing commences with collection, proceeds through the pre-curing followed by extraction, dewinging, cleaning, testing and then the seeds are placed in storage till sowing in the nursery (Fig. 1).



Fig. 1 Simplified scheme of seed processing

Among these steps - due to time constraints - the seed extraction phase will be discussed to suit the small lot size so important for the future success of the seed orchard.

Bulk, commercial or run-of-the-mill seed extraction is characterized by large quantities of cones, frequently over in 500 hl. Seed extractors were designed for these large quantities of cones, partially or fully fulfilling the three important requirements of seed extraction:

1. to provide optimum temperature

2. to remove moisture, and

3. to release seeds.

Extraction without artificial heat

According to Turnbull (1975), the extraction could be carried out without artificial heat, which is an important means of extracting seeds in the temperate, subtropical and tropical regions.

a) Drying in the open, when fruits are spaced on canvas, polyethylene sheets, fine meshed screens or sometimes on clean and level ground. <u>Pinus ponderosa</u> in Utah, <u>Pinus kesiya</u> in the Philippines, <u>Pinus</u> <u>pinaster</u>, and <u>Pinus halepensis</u> in Italy, <u>Quercus petrea</u> and <u>Fagus</u> <u>sylvatica</u> in Hungary are the most frequently used examples of this method.

b) Drying under cover has a main requirement to provide ample air circulation around the thinly spread layer of fruit. Controlling temperature and air humidity is important to avoid a "case-hardening" of cones. Ables spp. are especially suitable for this method, but any other species could be processed under cover as has been done with <u>Pinus</u> radiata in Australia.

The availability of controlled greenhouse space during the early fall in many of our developing nursery facilities could provide a cheap and efficient means for extracting seeds of Douglas-fir, Sitka spruce and western hemlock produced in our coastal seed orchards.

Extraction with artificial heat

In cool and humid regions, artificial heating is required during extraction. Furthermore, the temperature requirements of serotinous cones are usually higher than can be obtained during fall in the open or even under cover; e.g. fresh lodgepole pine cones require  $52.5 \pm 5.7^{\circ}$ C while old cones need  $54.6 \pm 5.8^{\circ}$ C to melt the resin sealing on the cone scales (MacCauley, 1975).

a) Stationary tray kilns are the simplest means of seed extraction (Fig. 2).

Cabinets with trays of drawers in stove-heated rooms with portable trays are the most frequently used models. Due to uneven heat distribution, extraction time is longer - 3-4 days - than in a fully controlled plant. Seed quality varies and depends on the individual operator.

b) Progressive kilns are characterized by controlled heated air flow, which increases in temperature - usually from  $30^{\circ}$ C to  $60^{\circ}$ C - and decreases in moisture content progressively during the drying period.

The two main types area:

- 1. Kapper Gogolicin or vertical,
- 2. Pentz or horizontal flow kilns.



Fig. 2. Cross and longitudinal sections of a modern, automatically controlled, forced-draft, internal-fan steam-heated kiln for drying cones.



Different versions using these principles are: WOLFGANG SEED EXTRACTION PLANT (Fig. 3) (Baldwin 1942).



Fig. 3. Side and front of Wolfgang seed extraction plant. MECHANICAL SEED KILN (Fig. 4) (Toumey and Korstian 1960)



Fig. 4. Vertical section of mechanical seed kiln.



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Fig. 5. Horizontal continuous dryer.



Fig. 6. Benno Schilde fully automated rotating drum kiln.

c) Rotating drum kilns are usually metal constructions with fully (Fig. 6 and 7), or partially (Fig. 8) automated processes. Pre-treatment of the cones is an important phase of this process. Usually two shelves are available for pre-drying, while the final drying is carried out in a rotating drum, which usually takes 4-6 hours. The seeds, after release, fall into a separate container which is located outside the warm air chamber. This sequence reduces heat damage to seeds and guarantees complete extraction, during the shortest period of time.



- 1. Loading Hatch
- 2-3 Pretreatment Space
- 4. Operating Hatch
- 5. Extraction Drum
- 6. Unloading Hatch

- 7. Perforated Metal Plate
- 8. Seed Container
- 9. Dust Filter
- 10. Heating Source
- 11. Ventillator
- 12. Rotary Drive for Drum

Fig. 7. Werner-Pfleiderer fully automated rotating drum kiln.



Fig. 8. End view of rotating drum type kiln at Angus, Ontario.

Their capacity is usually low (2 to 100 liters) and two or four sets of drums are generally operating, depending on the extractory. The smaller electrical types are portable, self-contained and especially suitable for small cone lot extraction (Lowman 1974).

d) Portable kilns. McConnell (1973) described a small portable kiln (Fig. 9) as a response to the seed orchard survey sponsored by the Southern Forest Tree Improvement Committee to fulfill the following requirements.

1. Economy - The initial cost had to be relatively low. A figure of \$3,000 to \$5,000 was judged to be in keeping with its function. Operating cost must be in line with the number of cone lots being dried.

2. Saftey - The kiln must be easy and safe to operate by relatively inexperienced people. Automatic safety controls are highly desirable.

3. Portability - Space to locate the kiln was not available at the Eastern Tree Seed Laboratory. Borrowed space would have to be used; therefore, it is very likely the kiln will have to be moved before the life of the survey is over.

4. Versatility - For the reason stated above, it was desirable that the



Fig. 9. Digaram of the portable kiln.

firing unit for the kiln operate on either natural or bottled gas.

5. Quantity - The minimum load size would be the 10 cone lots for the Seed Orchard Survey. A maximum load size of approximately 50 bushels (15.2 hectoliters) was chosen. The kiln must be able to handle any combination of cone lots within this range.

### CONCLUSIONS

Extraction is a critical phase in obtaining viable seeds for artificial regeneration. The duration of exposure close to the temperature causing denaturation of proteins, could create instant or latent seed damage. Mutagenic effects expressed in chromosome aberrations have been detected in stored seed samples (Simak 1973). For this reason the most efficient system should be applied when we are dealing with material intended to be used in our intensive forest mangement programs. The methods of extraction without artificial heat appear to be the least damaging. When artificial heat is used the rotating drum type models expose seeds for the shortest period of time to 54°-60°C temperature. On the other hand, with stationary type systems extraction time is the longest. Since seed yield, seed quality including germinative energy and capacity, plant percent and seedling growth will influence roguing in seed orchards, the least damaging extraction method should be applied specifically for samples originating from seed orchards. The seed orchard program in addition to seed processing comprises many facets of different problems, from flowering to progeny testing. These problems should be approached from not only the technical but embryological, cytological, biochemical, physiological and genetical aspects.

We are dealing with complex, and unexplored phenomena, which need to be solved soon, since seed orchards are becoming essential to our future forestry practice.

Since the evolution of seed processing equipment is continuous, evolution of commercially available seed processing equipment for small seed lots should include the following objectives:

- 1. a) high seed quality.
  - b) suitability for western conifers,
  - c) economy,
  - d) safety,
  - e) portability,
  - f) versatility,
  - g) capacity,
- 2. Seed research on families and clones should be enlarged to obtain genetic parameters for future improvement in the next generation seed orchards.

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### SEED TESTING

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#### ABSTRACT

The advantages and disadvantages of bulking seed orchard seeds are discussed in relation to the observed variation in seed characteristics from individual seed orchard trees. It is stressed that cone and seed maturity, which affect seedling vigour and establishment potential, should be optimized in seed orchard production, and various ripeness criteria are compared. Since the use of standard sampling and seed testing techniques may be precluded by the small size of seed orchard lots, alternative methods, including so-called quick tests for seed viability, are described. Several guidelines for monitoring seed orchard production, and their incorporation into existing systems of seed orchard management, are also outlined.

### RÉSUMÉ

On discute des avantages et des inconvénients de la mise en vrac des graines de vergers en relation avec les variations de leurs caractéristiques, observées d'un arbre à l'autre dans les vergers. On souligne qu'il convient d'optimiser, dans les vergers, la maturité des cônes et des graines car elle influe sur la vigueur des plants et leur capacité d'implantation. Divers critères de maturité sont comparés à cette fin. Puisque l'utilisation des techniques ordinaires d'échantillonnage et d'essai des graines puet être exclue en raison du volume réduit des lots de graines produites en vergers, on décrit d'autres techniques, y compris celles qu'on appelle tests rapides de viabilité. En outre, on donne plusieurs indications pour contrôler la production des vergers à graines et on discute de leur intégration aux systèmes actuels de gestion.

#### INTRODUCTION

The development of seed orchards has progressed to a point where we can evaluate past and present practices, and start planning management strategies for the future. Thus, it is appropriate at this time that we are having a workshop on seed technology for seed orchards in order that we may critically evaluate the handling of a valuable resource--seed orchard seeds.

There are a number of topics that could be discussed in the area of seed testing, but for the purposes of this workshop I have arbitrarily chosen to examine four main areas:

1. Identification of seed source--how are lots defined?

- 2. Determining cone and seed maturity--when to pick?
- 3. Testing seed quality--are special techniques required?
- 4. Monitoring seed orchard production--a few guidelines.

My intention with this talk is to present ideas for your consideration using past experiences or posing questions to illustrate my points. I am not setting myself up as an expert on seed orchards. My primary objective is to stimulate thinking on these and the other topics that hopefully will be explored during this afternoon's workshop session.

### IDENTIFICATION OF SEED SOURCE-HOW ARE LOTS DEFINED?

According to criteria set by the British Columbia Ministry of Forests (BCMF), the definition of seed lot varies depending upon whether the seeds were obtained from a seed orchard or from a wild stand. The identification of a source for a wild stand is broadly based upon a classification scheme which divides the province of British Columbia into 8 biogeoclimatic regions (Krajina 1969). These regions are sub-divided into a number of seed zones which for convenience and coordination closely follow forest management boundaries. Seeds collected from a wild stand within a localized area of the same seed zone are designated as an individual seed lot. Specifically, a seed lot is defined as:

> "All the seeds of a single species collected in the same year within the same provenance and obtained from trees of the same quality".

Practically speaking, seeds of the same provenance would include all the collections made within a diameter of 80 km and an elevation band of  $\pm$  150 m. The "same quality" refers to seeds obtained from trees of the same parental phenotype. A seed orchard lot is defined as:

"All the seeds of a single species obtained from the same seed orchard in the same year".

Most BCMF seed orchards ordinarily produce only one seed lot each year although production may be divided into more than one lot if the seed orchard contains parent trees from distinctly different provenances. One high and one low elevation seed lot per year are produced at the BCMF Koksilah Seed Orchard because the orchard is comprised of trees obtained from different elevation bands within the coastal tree breeding region.

Knowing the variability of most tree species even within a small geographic area, the question arises whether our definition of a seed orchard lot is specific enough to provide a meaningful description of a seed source. Most of the trees in B.C. seed orchards are individuals derived from many different families within a broad geographic planning zone. Operationally, it may be convenient to physically consolidate all seed orchard production into a single lot, but is this practice good tree improvement management when the seeds are from genetically distinct origins or are of very dissimilar quality? For instance, assume that cones from one tree in the seed orchard yield seeds which germinate vigourously at 95%, but suppose that cones from another tree yield seeds which germinate poorly and erratically at 55%. Should we be mixing the cones of both trees and calling the result a single lot? It is doubtful that seed orchards will realize any gains if we continue to combine good with poor quality seeds. Currently it costs ten times as much to produce a seedling from orchard seeds as it does to produce a seedling from wild seeds. It may be difficult to justify the cost of orchard seed if the quality of our "improved" seeds is the same or even poorer than seeds from wild stands.

The basic assumption behind bulking all seed orchard cones is that trees within a broad elevational band will be suitably adapted to most outplanting sites within a similar elevational band. However, we may not be justified in assuming that seed characteristics and early seedling survival are homogenous even for seeds obtained within a limited area. In a study of the genecology of Douglas-fir in an Oregon watershed, Campbell (1979) found that genetic differentiation was much larger than expected when seeds were transferred from one part of the watershed to another. He estimated that in a 3.5 km transfer between north- and south-facing slopes at the same elevation, almost 80% of the seedlings would be poorly adapted. In British Columbia, we may also be overlooking the strong intra-provenance differences that have been observed within a small geographic area (Meagher 1981) $\frac{1}{2}$ . Naturally regenerated western hemlock seedlings growing at Mt. Seymour and Haney, B.C. were separated by only 32 km, yet the young trees demonstrated diverse bud set phenologies and degrees of frost hardiness. Elevation and aspect of both sites were similar, but the physiological response of the two populations was very different.

Collecting seeds from the same tree does not assure that seed characteristics will also be uniform, for even seeds obtained from a single tree can vary from one year to another. Wang (1976) found that white spruce seeds collected from individual trees over several seasons exhibited varying degrees of dormancy in different years (Table 1). Using the criterion that seeds were not dormant if germination of stratified seeds was not significantly different (p = 0.01) from that of unstratified seeds, Wang found seed dormancy in 25% of the trees in 1965, 33% in 1966, and 100% in 1967. Dormancy in seeds from the same parent has also been shown by others to vary in <u>Picea glauca</u> and <u>Pinus</u> densiflora (Asakawa and Funita 1966).

Bulking seed orchard seeds may present other problems. We may be inadvertently restricting our genetic base and reducing the ability of orchard seedlings to survive under changing environmental conditions. In a case reported from Oregon, the orchard manager observed that come and seed production varied considerably between orchard trees, with some

<u>1</u> Meagher, M.D. 1981. Research Branch, British Columbia Ministry of Forests. Unpublished data.
trees producing much more than others. Upon closer examination he discovered that the majority of the orchard seeds were being produced by a limited number of clones. Thus, the genetic material of the heavy producing clones was disproportionately represented relative to the less prolific clones. The net result is that the trees produced from these seeds could be lacking the genetic adaptability usually found in natural forest populations. Because of our present system of bulking collections, it is not possible to determine the proportion of seeds that an individual clone may contribute to total seed orchard production.

Table 1. Dormancy and Laboratory Germination Criteria of White Spruce Seed.2

		Germinati	on (%)	Seed
Tree	Coll.	Strat'd	Un-	Dormancy
No.	Year	3 wk	Strat'd	Rating
1853	1965	92.7	70.9	ND
	1966	82.3	70.5	ND
	1967	95.9	80.0	D
1857	1965	65.9	31.2	D
	1966	53.0	<b>28</b> - 5	D
	1967	63.7	36.0	D
1861	1965	60.3	69.9	ND
	1966	48.4	54.4	ND
	1967	83.4	47.9	D
1624	1965	51.4	52.2	ND
	1967	76.6	47.4	D
1756	1965	37.5	40.9	ND
	1967	97.2	89.6	D
1855	1965	86.7	80.9	ND
	1967	94.4	75.4	D
1860	1965	17.9	58.9	ND
	1967	93.4	51.7	D
1865	1965	92.0	71.5	D
	1967	94.5	64.7	D

<u>2</u> Wang 1976.

Thus, it is strongly recommended that if seed collections are to be bulked there should at least be procedures for routinely monitoring the distribution of genetic material within all seed orchard lots.

Genetic bias can be introduced in other ways. In a study on seed sizing, Silen and Osterhaus (1979) collected seeds from 210 Douglas-fir trees belonging to 18 different families. They examined the effect of eliminating the lightest fraction by plotting seed weight distribution curves. Removal of the lightest one third of the seeds would affect 16 of the 18 families to varying degrees. Six families would lose more than 50% of their seeds, and of those six, three families would lose more than 90% of their seeds. A surprising implication of the study was the long-term effect of sizing seeds: two of the above six families were among the top families for 10-year progeny height. By sizing collections and eliminating the lightest fraction, seeds of some of the best performing phenotypes would have been discarded.

Even if convinced that seeds should not be bulked, some may argue it is not operationally feasible to collect a number of different lots in each seed orchard. However, it is apparently feasible, and presumably economic, to handle orchard seeds in very small units. In the southeastern United States, Weyerhaeuser and other commerical forest companies are collecting and planting by clones in their loblolly and slash pine seed orchards. Since they are dealing with known genotypes that have already been progeny tested, the situation is not exactly comparable to British Columbia. However, the southern pine orchards demonstrate that small lot collections can be realistically managed on an operational basis. Seed orchard production is separated into five lots primarily on the basis of elevation bands (Fashler 1981)<sup>3</sup>. However, it has also been suggested that other variables such as moisture, edaphic factors, and biogeoclimatic zones may be equally important.

The decision as to whether or not we bulk seed orchard seeds may ultimately come down to one of biology vs. economics. In this regard, long-term objectives should not be forgotten. We are planning now for our future forests and the question is whether we are going to opt for cheaper short-term management at the possible expense of long-term adaptability. Will progeny from bulked seeds produce vigourous, fast-growing seedlings which are suitably adapted to the climatic and edaphic conditions of our future plantations?

#### DETERMINING CONE AND SEED MATURITY

In the area of maturity, seed orchards offer advantages over collecting from wild stands since picking crews and equipment are already at the harvesting site, and the developing crop can be monitored and picked at exactly the right time. However, whether obtained from wild

J Fashler, A. 1981. Pacific Forest Products, Victoria, B.C. Pers. comm.

stands or seed orchards, the more mature the seeds are when harvested, the greater their vigour and establishment potential. Immature or light seeds are usually slow to germinate, more susceptible to disease, produce more abnormal germinants, and decline in germination when prechilled. The effects of collecting seeds prematurely was illustrated in a study of Douglas-fir by Olson and Silen (1975). Seed orchard lots collected early (before the third week of August) required several-fold efforts in seed extraction and germination, produced very light seeds, contained nearly all lots germinating less than 10%, suffered heavy losses after germination, required inordinate efforts to produce enough seedlings for the progeny test, and were the major cause of poor seedbed densities. By contrast, cones collected within 10 days of natural seedfall developed less mold prior to extraction, required minimal efforts in seed extraction and processing, germinated well in the nursery, and produced excellent seedlings. Olson and Silen estimated that at least 10 times the effort was required to produce seedlings with immature seeds than with seeds collected within 10 days prior to seed fall. Although exact comparisons cannot be made, the results of their study place a better perspective on the true costs of immature seeds. To quote our friend and colleague Alan Orr-Ewing, "Good seed doesn't cost--it pays".

Maturity is dependent upon a number of factors and can be very difficult to determine. Maturation is not necessarily complete when maximum dry weight is achieved. In some species, embryos may be immature and continue to develop after removal from the parent plant even though morphological maturity has been reached (Bonner 1973; Edwards 1980; Rediske and Nicholson 1965; Thomas et al. 1973). Morphological maturity is determined mostly by size, whereas physiological maturity is based primarily upon the ability of the seed to germinate when placed under favourable conditions. Rediske and Nicholson (1965) thought of maturity as a developmental process which could be separated into two stages. Maturation is the first stage and is characterized by organic accumulation, seed weight gain, and greater radiographic density of the megagametophytic tissues. The second stage is artificial storage, during which seed moisture is reduced and germinability develops.

Operational definitions of maturity may be slightly different. The criteria used by BCMF to determine cone and seed maturity are embryo length, condition of the endosperm, and cone and seed colour (Table 2). In the BCMF Koksilah Seed Orchard the criteria used to judge maturity are even more well defined (Table 3). However, maturity cannot be determined on the basis of a single criterion. The entire developmental picture must be viewed before assuming a crop is ready to harvest. Even with well defined guidelines there can be problems in assessing the maturity of a crop. In British Columbia, Douglas-fir seed orchards developed good cone crops during the very warm summers of 1978 and 1979. Under favourable climatic conditions embryos quickly reached 75% of the embryo cavity length. According to the guidelines (Table 2) they were ready to pick. However, if embryo length had been used as the sole criterion the crop would have been picked too soon. The megagametophytic tissue was soft and milky. Therefore, the crop was allowed to remain on the trees until all the tissues were mature.

Table 2. Cone and seed maturity of B.C. Conifers4

SPECIES	CRITERIA		COLLECTION PERIOD
ABIES	Embryo75% of cavity Endospermfirm	Aa Ag	Late Augmid Sept.
		A1	Mid-Septmid Oct.
CHAMAECYPARIS NOOTKATENSIS	Conesyellow to golden-brown Seeds-brown, dry, hard		AugOct
PICEA	Seed coats & wings-golden-brown Embryoyellow-green,75% of	Sw Se	Mid AugSept.
	Endospermfirm	Ss	Sept.
PINUS	Cones Coastal, shiny golden-brown Interior, brown, tightly close	ed	Late SeptOct OctMar.
PSEUDOTSUGA MENZIESII	Cones-green to yellow brown Seed coats & wings-golden brown Seeds detach readily from scales Embroy75% of cavity Endospermfirm	1 3	Mid Augearly Sept
TSUGA	Conesyellow brown	Hw	
		Hm	SeptOct.

<u>4</u> Dobbs, <u>et al.</u>, 1976.

Table 3. Cone ripeness criteria

- 1. Bracts should be brown.
- 2. Cones should be turning brown.
- Endosperm should be opaque white, not milky or liquid (leave cut seed over-night. If much shrinkage, then not ripe).
- Embryo should be 90% or more developed, i.e., be about as long as seed itself.

In some cases, proper storage of immature seeds can offset potential losses from collecting crops too early. Douglas-fir cones have been successfully artificially ripened in storage when picked as early as 5-6 weeks prior to natural seed fall (Rediske 1969; Silen 1958). But after ripening treatments are effective only if seed development has reached a critical minimum level. Even under optimum conditions, seeds picked prior to this critical stage are unable to continue the maturation process in storage.

Because this critical stage can be so difficult to determine, a number of maturity indexes have been proposed to aid in the collection of cone crops. One index which may prove to be very useful to seed orchard managers is the degree-day summation. This index relates the summer temperature experienced by a developing crop to the degree of seed maturation. To obtain a good ripeness indicator, measurements should account for the variation due to latitude, elevation, and slope aspect and should be made during the months of June to August. In an Alaskan study of white spruce, Zasada (1973) calculated the heat sum from the time of pollination, then related that value to cone and seed development. He found that a minimum of 625 degree-days above 5°C was necessary before seeds were morphologically complete. In the year of the study the required heat sum was not reached until August 5. The degree-days summmation has good potential as a reliable maturity index, but the technique needs to be refined. Improving the reliability of the index by correlating degree days with other meteorological variables such as solar radiation and precipitation could result in the development of a significant management tool.

#### TESTING SEED QUALITY--ARE SPECIAL TECHNIQUES REQUIRED?

Traditionally, forest geneticists have concentrated on improving phenotypic characteristics such as tree volume and form, but phenotypic selection based on mature form does not guarantee either good cone production or seed quality. In reality, the "improved" seeds of breeding programs refer to improved tree qualities. Tree breeders have not been interested in improving the physical and biological qualities of seeds. However, breeding for improved seed characteristics is not unknown. Agricultural breeding programs have already been established to improve seed qualities such as vigour, seed coat permeability, seed colour, seed size, chemical constituents, and the ability to germinate at low temperatures (Dickson 1980). Since generation times in vegetable crop plants are so much shorter, perhaps forestry and agricultural breeding programs should not be compared. But the concept of breeding for seed qualities does deserve some consideration. There are a number of tree seed traits that might be genetically improved--increased seed vigour, greater disease resistance, and improved germinability at low temperatures are just a few possibilities. Any or all of these improvements would be of immense benefit to our reforestation program.

Realistically, it will be some time before we are able to breed for improved tree seed quality. For now the relevance of seed quality for orchard managers is using quality testing to gauge the progress of the tree improvement program. Sampling and testing procedures have been explicitly defined for tree seeds (Association of Offical Seed Analysts 1978; International Seed Testing Association 1976), but there are several reasons why standard testing procedures may not be suitable for testing and monitoring orchard seeds. In the near future at least, seed orchard lots will not be very large relative to lots collected from wild stands. Thus, scarcity of orchard seeds will be a major factor restricting the amount of seeds available for testing. The intensive management associated with seed orchards means that orchard seeds will also cost more than seeds from natural production areas. Both these factors have an impact on the way seed quality is tested.

The size of seed orchard lots will likely preclude the use of the usual sampling techniques. Samplers such as seed triers cannot be used for lots less tha approximately 7 kg, therefore alternative sampling techniques will be necessary. Many sampling methods have already been devised by the International Seed Testing Association (1976) for sampling small lots. There are several which are suitable for seed orchard use;

The Boerner conical divider consists of a hopper, a cone, and a series of baffles which subdivide the stream of seeds into many small streams. The separate streams are recombined and the mixed seeds are directed through two spouts into separate collection pans.

The <u>soil divider</u> is built on the same principle as the conical divider, but with the channels arranged in a straight row instead of a circle.

In the <u>random cups method</u>, 6-8 small cups are placed at random on a tray. After preliminary mixing the seeds are poured uniformly over the tray. Seeds that fall into the cups are taken as the working sample.

The modified halving apparatus is a grid of equal-sized cubical cells. All the cells are open at the top, but every alternate cell has no bottom. Seeds are poured evenly over the grid so when the grid is lifted approximately half the sample remains on the tray. The sample is successively halved until a working sample is obtained.

Sample sizes will probably also need to be modified for seed orchard testing. The usual technique for determining sample size depends on prior knowledge of the variation of the sample. Data variability is measured by the Coefficient of Variation, easily calculated as follows:

$$CV = \frac{SD}{\overline{X}} \times 100$$

where X is the arithmetic mean of the sample data and SD is the standard deviation of the mean. Essentially, the Coefficient of Variation measures the amount of variation relative to the mean and expresses that relationship as a percentage. Once the Coefficient of Variation is known, tabulated values such as those in Table 4 can be consulted. The appropriate number of samples can be chosen so that one is reasonably assured that the qualities being measured in the sample reflect those of the entire population. But prior to taking measurements, the variation of the data is usually unknown. However, the expected variation can be approximated by examining the variation of comparable data which has already been collected. An example may help to illustrate.

A question commonly asked is how many samples should be taken to provide a reliable estimate of seedlot germination. One must first find comparable data on which to calculate Coefficients of Variation. An examination of many germination tests conducted in the BCMF Tree Seed Laboratory shows that CV for germination data have generally ranged from 1% to 6%. Next, the sample size table (Table 4) should be consulted to find the sample size corresponding to the CV of the test data. The table indicates that at a 95% confidence level and a potential error of  $\pm$ 10%, the germination test should contain at least four replicates if the CV equals 6% or less. Using the CV for similar data, this simple procedure can be repeated for determining sample sizes for any untested material. However, CV should be recalculated at the completion of the germination tests to ensure that sample sizes are appropriate for the seeds actually being tested.

	Sample	sample	sample	sample	sample	sample	sample	sample
CV	size:	size:	size:	size:	\$1ze:	\$12e:	S1Ze:	S1ZE:
****	P比≕1る ★★★★★★	ピ≡3% ★★★★★★	ビビニンペ ******	PE=10%	PL≕13% ******	PE=20%	PL=236 *****	*****
19	7	2	2	2	2	2	2	2
16 79	19	5	2	2	2	2	2	2
2% 29	10	7	5	3	3	2	2	2
3% 1.4	50	10	4	2	3	2	3	2
4%	04	10	ך ד	5	2	2	2	2
5% (*	99	14	/	4	2	י ג	2	2
0%	141	18	9	4	5	2	2	נ ז
1%	191	24	11	2	4	2	3	2
8%	249	30	13	5	4	3	3	3
9%	314	38	15	6	4	4	3	3
10%	387	46	18	7	5	4	3	3
11%	468	55	22	8	5	4	4	3
12%	556	64	25	9	5	4	4	3
13%	652	75	29	9	6	5	4	3
14%	756	87	33	11	6	5	4	3
15%	867	99	38	12	7	5	4	3
16%	986	112	42	13	7	5	5	3
17%	1113	126	47	14	8	6	5	3
18%	1248	141	53	15	9	6	5	3
19%	1390	157	58	17	9	6	5	3
20%	1539	174	64	18	10	7	5	3

Table 4. Sample size table (95% confidence): sample sizes for a range of coefficients of variation (CV) and percentage errors (PE).

Modified from Stauffer, 1981. (Used with permission).

#### TESTING SEED QUALITY

#### Quick Tests

The germination test is the most familiar method by which tree seed quality is assessed. The test is conducted in controlled environment chambers and generally takes 6 to 8 weeks to complete (Association of Official Seed Analysts 1978; International Seed Testing Association 1976). The germination test is the standard by which most other seed assessment methods are evaluated because it is an actual measure of growth, and because the results can be related to field performance. However, the test has several drawbacks—it takes almost 2 months to complete and requires at least four replicates of 100 seeds each. In the small lots likely to be encountered in seed orchards, we may not be able to spare 400 or more seeds, or we may question using so many scarce and valuable seeds just for testing. There are alternative methods called quick tests which may be as suitable as the standard test. These tests use less seeds, may even be non-destructive, and take little time to perform.

The most commonly used quick tests for tree seeds are the tetrazolium chloride test (TZ), the hydrogen peroxide test ( $H_2O_2$ ), and the X-ray contrast test (X-C) (Leadem 1981). All three tests are based upon some special biochemical of physiological feature of the seeds.

The TZ test is a viability staining method in which cut seeds are incubated in a 1% tetrazolium chloride solution for 24 hours. Hydrogen ions from respiring tissues react with the colourless TZ solution to form a red product in the tissues, formazan. Examination of the location and pattern of staining enables the seed analyst to evaluate seed quality. While classification of completely stained or totally unstained seeds is relatively easy, intermediate staining patterns may require a very experienced analyst. However, as a general rule seeds will not germinate properly if meristematic regions such as the radicle tip or the shoot apex do not stain well.

Hydrogen peroxide  $(H_2O_2)$  is a growth test in which cut seeds are incubated in a 1% H\_2O\_2 solution. Oxygen is released by the breakdown of H\_2O\_2 into O\_2 and H\_2O, Respiration is stimulated by the increased availability of oxygen and germination occurs without the need for stratification. Using the H\_2O\_2 method, seed lot viability can be assessed within one week.

The X-ray contrast method uses X-radiography in combination with a vaporous contrast agent (such as chloroform) to stain dead and damaged tissue (Simak 1974). Differential staining of the embryo and endosperm aids the analyst in evaluating seed quality. The use of vapourous contrast agents is not always essential, for X-rays can reveal a great deal about seed development and quality without staining the seeds. Empty seeds, insect-filled seeds, aborted embryos, and seed immaturity can all be monitored with X-rays. The versatility of X-radiography makes it one of the more important tools in the field of Each test method has its own advantages and disadvantages, therefore individual circumstances will dictate which quick test is most suitable (Leadem 1981). The TZ test requires much skill and experience, and the procedures are time-consuming and tedious. However, proponents of the method claim that in the hands of a skilled analyst the TZ test divulges more about inherent seed characters than any other quick test (Moore 1969). The  $H_{2}O_{2}$  test is technically simple and easy to learn. In addition, since evaluation is based upon physical measurement of the radicle, the  $H_{2}O_{2}$  is the most objective of the three methods. The X-C method is also easy to perform. Although it is the quickest of the test methods and can be completed in 2 hours, the X-C method requires an X-ray unit which may not be readily available.

The three methods suffer from one disadvantage in common with all correlation methods. By their nature, correlation methods do not directly measure performance, but some quality or characteristic believed to be related to performance. Therefore, correlation tests cannot be regarded on their own merit until results have been compared with an accepted standard. In the case of quick tests, results should be checked against incubator germination tests before being used as the sole criterion of lot quality. This presents few problems for seed orchard managers wishing to take advantage of quick test technology; orchard seeds are not required to make the comparisons, so seeds collected from wild stands can be used for the initial tests. The tests are not difficult to perform, and regressions relating quick methods to germination tests are easily derived (Leadem 1981).

The vigour test is another technique which may be used to assess the quality of orchard seeds. Usually seed performance is evaluated under optimum conditions, but the vigour test differs from other tests in that seeds are assessed according to their ability to perform under stress conditions, such as hot or cold temperatures. Stress conditions tend to eliminate all but the most vigourous individuals, thus results are generally lower than standard test figures. However, since results are more likely to corresponds to actual nursery performance, vigour tests are considered to provide a more meaningful measure of lot quality.

#### MONITORING SEED ORCHARD PRODUCTION

In any business, the presence or absence of good quality control can mean the difference between success or failure of the enterprise. An essential element of good quality control is the care with which both production and performance are monitored. Seed orchards, like other enterprises, are also responsible for achieving and maintaining the highest possible quality of their product. Likewise, success or failure of a seed orchard depends upon continual and systematic surveyance of the developing crop. However, monitoring is an activity which is too important to be left to chance. To ensure adequate supervision during all phases of seed production, monitoring must become an integral part of seed orchard management. The previously mentioned case of the Oregon seed orchard manager illustrates the utility of continuous surveyance. Because of an established monitoring system, the seed orchard manager was aware of the situation in time to take remedial steps before a serious problem developed. After he discovered that certain clones produced a greater portion of the bulk lot, the manager endeavored to broaden the genetic base by combining the current crop with seeds produced the following year. Thus, he avoided biasing total orchard production in favour of a few heavy producing parent trees.

Cone analysis is another monitoring technique which has been developed in the southeastern United States (Bramlett et al. 1977). Orchard managers use cone analysis to check for embryo abortion, seed immaturity, insect infestation, and a number of other aspects of cone and seed development. In its present form, cone analysis may be too detailed to be of practical use in British Columbia. Cone analysis is probably better suited to southern pines which take 2 years to reach maturity, but it is the philosophy underlying the practice that is of broader significance than the actual procedure. Cone analysis is used in an interactive manner to assist the orchard manager in making management decisions. As cones mature, samples are taken at regular intervals and systematically analyzed. If the analysis reveals potential problems, the manager can prescribe remedial treatment before major difficulties arise. By means of this regular monitoring program, the manager keeps abreast of crop development throughout the production period.

Monitoring procedures could be easily incorporated into existing systems of seed orchard management. Several seed orchards already have procedures which could be modified to provide additional information regarding seed orchard production. One example is the bud survey taken in October and February of each year. The number of buds on each tree are classified into low, medium, and heavy production classes so that the relative cone production of each ramet can be determined. Bud surveys could also be used to assess whether seed orchard production is being biased towards a particular clone. In most years, cone production should be fairly uniform among clones. However, routine monitoring will ensure that the genetic base of seed orchard crops is not inadvertently being restricted. The insect survey is another monitoring technique which has already been established in seed orchards. Because of early detection, technical staff have had enough time to take protection measures and prevent major seed orchard losses from insect infestation.

The seed orchard manager should also share responsibility for monitoring the seeds after they leave the orchard. Generally, nursery performance of orchard seeds is a facet of seed orchard production that has received little attention. But again we should consider our ultimate objective, which is to produce vigourous trees of superior quality. This will not be possible unless proper attention is given to the performance of seed orchard seeds.

As a final point, it should be mentioned that all possible

factors should be examined when rating the performance of orchard seeds. A recent report documents an example of how seemingly unrelated conditions may alter the interpretation of results (Mueller et al. 1981). The study compared the performance of orchard seeds with lots collected from wild stands, then concluded from survival records that orchard seeds were more subject to frost damage. However, additional analysis showed that the apparent differences in hardiness were actually due to differences in the cultural practices employed for orchard and wild seeds. Because of its cost and scarcity, orchard seed are grown at lower densities in nursery seedbeds. When wild seeds were planted at similar densities, the stock was also more succulent and prone to continue growth late into the fall.

#### CONCLUSION

In relative terms, seed orchards are in their infancy. Optimistic goals have been set for seed orchards in that they are expected to meet a major part of our projected demand for high quality seeds. Yet there are a number of essential questions in the field of seed technology that have not been addressed. While a few of these questions have been touched upon in this paper, how well seed orchards meet our expectations will depend upon the way seed orchard managers deal with and resolve these critical issues.

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## STORAGE AND UTILIZATION OF ORCHARD SEEDS

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#### ABSTRACT

Current methods of storing and utilizing tree seeds are reviewed and judged adequate for handling seed orchard collection. Emphasis is placed on using seed orchard seeds as soon as possible after collection and optimizing the production of vigorous plantable seedlings.

## RÉSUMÉ

On examine les méthodes actuelles de stockage et d'utilisation des semences d'arbres et on les déclare satisfaisantes pour la manutention des graines de vergers. On insiste sur l'utilisation la plus hâtive possible de ces semences après leur récolte et sur l'optimisation de la production de plants vigoureux prêts à être plantés.

#### INTRODUCTION

In order to address the question - do seed orchard seeds require new and different technology in seed storage and utilization, I shall begin by describing the characteristics of orchard seeds in comparison to seeds collected from natural stands.

Based on early seed production experience, primarily from coastal Douglas-fir orchards, the following general characteristics can be listed:

- (i) orchard seedlots are smaller than seedlots collected from natural stands,
- (ii) orchard seed yields are lower than those from natural stands,
- (iii) seeds originating from orchards are larger than seeds collected from natural stands,
- (iv) orchard seeds can cost an estimated 4-10x more than seeds from natural stand seed collections,
  - (v) germination quality of orchard seeds is consistently high,

(vi) seed insects are a problem in orchards,

- (vii) seed diseases are not a problem in Douglas-fir orchard seeds but may be a problem in other species such as spruce,
- (viii) orchards produce seeds more frequently than natural stands,
  - (ix) orchard seeds have higher vigour in comparison to seeds from natural stands (e.g. rate of germination is faster),
    - (x) orchard seeds have higher genetic quality in comparison to seeds from average natural stands. This can be attributed to use of phenotypic selection of parent trees, use of best trees from the best provenances for parent trees, and development of clonal orchards and roguing of undesirable phenotypes based on progeny test results.

Some, but not all, of the above characteristics have impacts on seed storage and utilization practices.

Appendix I and II provide data in support of some of the above general characteristics.

In view of the high vigour and genetic quality of orchard seeds, it is important that the seeds be properly stored and handled to prevent deterioration and damage. Utilization of orchard seeds should aim at obtaining the highest possible seedling recovery.

#### STORAGE

In British Columbia, all seeds for Crown land reforestation are stored at the Seed Centre in Duncan. The current inventory is 35,172 kg of which 80 kg are orchard seeds. Cumulative seed production from all orchards up to and including the 1980 crop is 302 kg.

All seeds are dried to 6-9% moisture content and placed in tightly sealed 4-6 ml polyethylene bags and placed in freezer storage at -17.6°C. Using these conditions, we have stored Douglas-fir seeds for over 25 years with no loss in viability.

The period of seed storage for the early production from orchards may be relatively short owing to high demand and low supply. As first generation orchards mature and produce seeds above demand levels, it will be desirable to bank a 10-15 year seed supply. This will then allow for replacement by a second generation orchard without disruption in seed supplies.

Storage of small orchard seedlots will generally cause increased record keeping and packaging tasks. For example, in British Columbia a different type of tag is used to distinguish orchard seedlots from natural stand seedlots. Considering the above points, minimal problems have been experienced and are foreseen in the future in storage of orchard seedlots. It is recommended that the specifications for drying seeds to 6-9% moisture content, packaging in tightly sealed 4-6 ml polyethylene bags, and storage at -17.6°C be continued for orchard seeds.

#### PREPARATION

Operational experience, based primarily in coastal Douglas-fir and Sitka spruce, has indicated that there is no need to develop special stratification techniques for orchard seeds of these species. However, this does not preclude the need to develop special techniques for other species.

#### UTILIZATION

In view of the high quality and cost of orchard seeds, they should be utilized to provide the highest possible plantable seedling recovery. To optimize use-efficiency and achieve the full benefits of orchard seeds, the following recommendations are made:

- (i) orchard seeds should not be used for direct seeding projects.
- (ii) seed should be cleaned to obtain 90%+ germination to enable single-seed sowing per cavity for container nursery operations.
- (111) when sowing orchard seeds in bareroot nurseries, lowering the sowing density (in comparison to sowing rules for natural stand seeds) has resulted in optimizing plantable seedling recovery from the seeds used,
- (iv) good orchard seeds should be utilized for seedling production and plantation establishment as soon as possible in preference to average quality natural stand seeds. The benefits of high quality orchard seeds will not be realized by retaining this valuable germ plasm stored in a dormant condition, and
- (v) efficient seed utlization must be followed up with the production of vigorous planting stock, the correct matching of species to site, and establishment and management of vigorous plantations to realize the full benefits of increased wood production which can be obtained through the use of orchard seeds.

#### SEED RESEARCH

Several general research topics applicable to both orchard seeds and seed collected from natural stands are listed:

- (i) seed storage life should be monitored for each species. This can be done by reserving enough seeds of each seedlot to be monitored to enable periodic seed testing for a 25 yr. + period,
- (11) to optimize seed germination, further research is needed on the determination of optimum seed moisture content levels, duration and temperature during stratification for certain species such as Abies and white pine.
- (iii) develop dewinging and/or pelletize seeds of western red cedar and yellow cedar,
- (iv) develop sterilization and/or heat treatments to control seed bourne pests.
  - (v) develop precision seedling equipment.

ORCHARD MANAGEMENT PRACTICES TO IMPROVE SEED QUANTITY AND QUALITY

Early orchard seed production experience indicates that emphasis should be placed on various orchard management practices and that the orchard program should be an integral part of the tree breeding plan for a species.

- (i) To maximize seed yields and minimize seed production costs:
  - improve cone and seed pest control,
  - improve pollination,
  - improve cone induction.
- (ii) Seed size and vigour:
  - improve nutrition monitoring and develop cultural prescriptions to produce large, vigorous and high germination seeds.
- (iii) Monitor genetic quality to measure seed improvement:
  - measure both vigour and genetic quality of seeds through testing over long-term (10-20 yrs. +) by comparing orchard seeds with naturual stand seeds,
  - initiate roguing of undesirable parents from orchards using progeny test data from tree breeding program.

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#### APPENDIX I

## Comparison of Average size of Douglas-fir cone collections made from Natural Stands and Seed Orchards<u>1</u>

	Average Size of Cone Collection (hl) for Coastal Douglas-fir					
Year	Natural Stands			ands	Seed Orchards	
<del></del>	Avg.	Size	of $S/L^2(h1)$	No. of S/L's	Avg. Size of S/L(hl)	No. of S/L's
1976		35		33	11	7
1978		32		15	18	13
1979		23		4	25	15
1980		22		9	10	16

<u>1</u> Data Source: Ministry of Forests, Seed Centre and Seed Orchard Annual Reports.

 $\frac{2}{2}$  Seedlot = S/L

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#### APPENDIX II

<u></u> , <u></u> , <u>_</u>	A Clas	38			B Class		
Seedlot	Original Germ %	Seed/gm	Seed Yield kg seed/ hl cones	( Seedlot	Original Germ %	Seeds/gm	Seed Yield kg seed/ hl cones
3187	88	83	N/A				
3235	79	77	N/A				
3236	92	79	N/A				
3237	89	77	N/A	<b>289</b> 0	91	127	.577
3252	84	85	N/A	2950	79	117	•459
3284	96	86	.531	2985	90	101	•548
3285	91	89	.080	3048	87	109	.781
3286	83	93	.176	3063	89	98	•282
3295	84	77	•295	3073	84	115	•790
3825	83	82	.190	3292	95	83	.989
38226	81	94	•218	3294	84	108	•160
3822	75	90	.218	3329	89	102	.503
3826	84	88	.162	3426	85	83	.725
3830	87	87	.187	3506	94	76	.374
3837	90	85	.381	3718	82	115	.085
3842	87	85	.411	3925	88	113	.337
Average	85.8	85	0.259	Average	e 87.5	104	0.509

### Comparison of germination percent, seeds/gm and seed yield between A and B class seedlots

Data Source: Mueller, H., H. Hahn, B. McCutchen and C. Bartram. 1981. Review of Practices Relating to the Treatment of Seed Orchard Seed and Seedlings. Report of Technical Audit Comm. appointed by the Director, Silviculture Branch, B.C. Ministry of Forests, 46 p., (unpubl.).

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