YEATMAN

ISSN 0705-4858

SEED ORCHARDS AND STRATEGIES FOR TREE IMPROVEMENT

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

PROCEEDINGS OF THE EIGHTEENTH MEETING OF THE CANADIAN TREE IMPROVEMENT ASSOCIATION

PART 2

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

PARTIE 2

DUNCAN
BRITISH COLUMBIA
AUGUST 17-20, 1981

DUNCAN
COLOMBIE-BRITANNIQUE
DU 17 AU 20 AOÛT 1981

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

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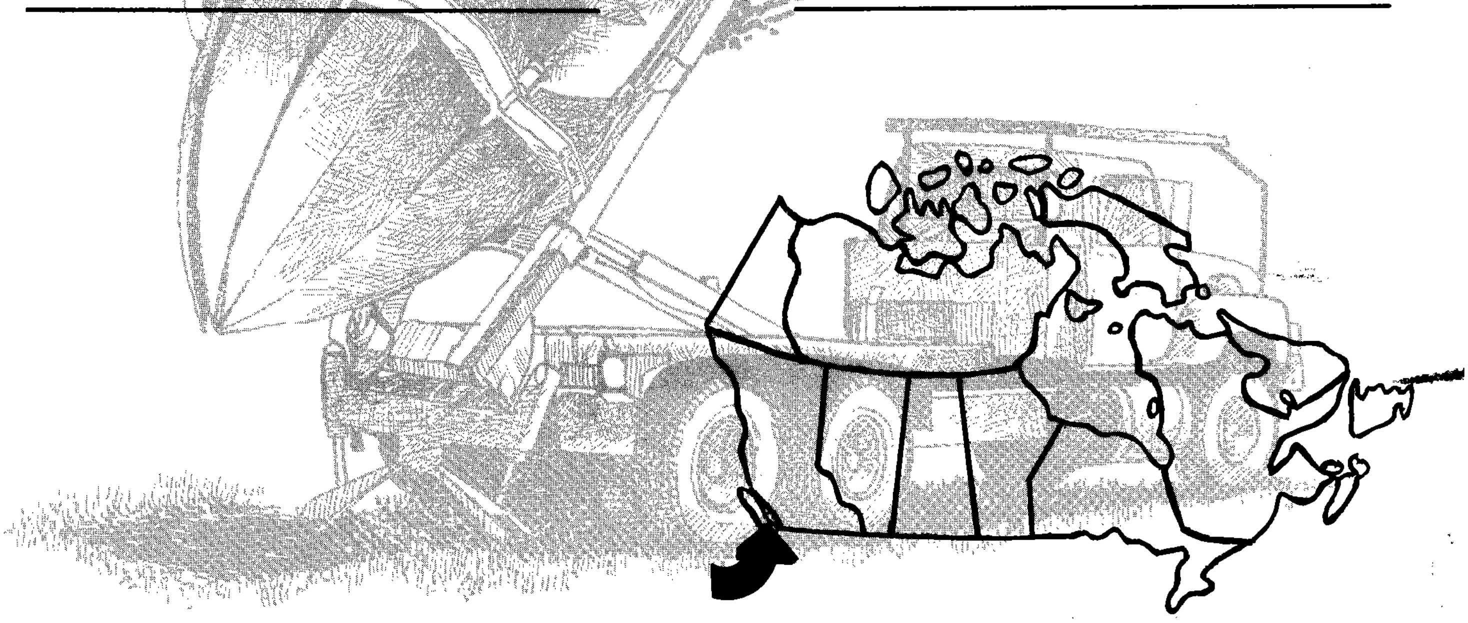

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ASSOCIATION

PART 2:

SYMPOSIUM ON

SEED ORCHARDS AND STRATEGIES

FOR TREE IMPROVEMENT

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Part 1. Minutes and Members' Reports

Distributed to Association members and to others on request to the Editor, C.T.I.A./A.C.A.A., Chalk River, Ontario. Canada, KOJ 1J0

Part 2. Symposium: Seed Orchards and Strategies for Tree Improvement.

Distributed worldwide to persons and organizations actively engaged or interested in forest genetics and tree improvement.

Additional Copies of this publication are available from:

Editor C.T.I.A./A.C.A.A.
Canadian Forestry Service
Petawawa National Forestry Institute
Chalk River, Ontario KOJ 1J0

Produced by
Canadian Forestry Service,
Environment Canada,
for the
Canadian Tree Improvement Association,
Ottawa, 1982

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

1re partie. Procès-verbaux et rapports des membres.

Distribués aux membres de l'Association et aux autres sur demande au rédacteur, C.T.I.A./A.C.A.A., Chalk River, Ontario, Canada, K0J 1J0

2e partie. Symposium: Colloque sur les vergers a graines et les strategies d'amelioration des arbres.

Distribué à l'échelle mondiale aux personnes et organisations activement engagées ou intéressées à la génétique forestière et à l'amélioration des arbres.

Des exemplaires de cette publication peuvent être obtenus à l'adresse suivante:

Rédacteur C.T.I.A./A.C.A.A.
Environnement Canada
Service canadien des forêts
Institut forestier national de Petawawa
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Publié par
le Service canadien des forêts
Environnement Canada,
pour
l'Association canadienne pour l'amélioration des arbres,
Ottawa, 1982

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.*
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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.*
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ACKNOWLEDGEMENTS

On behalf of the Canadian Tree Improvement Association, the Editors wish to express thanks to the following agencies for assisting invited speakers to attend the Symposium on Seed Orchards and Strategies for Tree Improvement:

B.C. Forest Products
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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)

Remerciements

Au nom de l'Association canadienne pour l'amélioration des arbres, les rédacteurs désirent remercier les organismes qui ont permis aux conférenciers invités de participer au Colloque sur les vergers à graines et les stratégies d'amélioration des arbres:

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L'Association désire également remercier Mike Crown, vice-président (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)

CONTENTS

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".

KEYNOTE ADDRESS

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

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 *A. lowiana* 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 artificial-pollinations 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 *et al.* (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 *et al.* 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^3/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^3/ha/ann and lies within a range of 6-24 m^3/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 <u>tested</u> 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 <u>providing</u> 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 *P. radiata* have already been noted by Shelbourne *et al.* (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 *et al.* (1976), Bonga (1977) and Reinhart *et al.* (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 *et al.* 1980). A technique for loblolly pine has been recently published by Mott *et al.* (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 et al. 1980). Since conifers are generally devoid of viruses there seem to be little hope for the first method but the Ti plasmid of A. tumefaciens 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 Pisolithus tinctorius when compared with other mycorrhiza-forming species was reported to enhance the growth of loblolly pine seedlings (Marx et al. 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 macro- and 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 could walk. In the formative years of a tree improvement programme there 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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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.

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)[1] 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)[1] 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

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

Table 1.

CTIC SEED ORCHARDS

TARGET AREA

No.	AGENT	SPECIES	ZONE	ELEVATION (m)	SEED TARGET (kg)
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/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 - 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	21.7
35	MB	Ba	EVI/SCM	900 +	31.7
36	Tahsis	Hw	WVI	0 - 600	1.3
37	MB	Cy	SCM/CIT	700 - 1200	3.2
38	CZ	Cy	WVI/EVI/JS	600 - 1200	3.2
39	MB	Cr	WVI	0 - 600	1.6
40	CZ	Cr	EVI/SCM	0 - 600	0.5
41	MoF	Ba	SCM/EVI/JS	450 - 900	27.5
42	WFP	Ss	QCI	0 - 450	3.5
43	MoF	Hw	JS/SCM	450 - 900	3.0
R-1*		Sx	T	450 - 900	4.9
R-2*		Ss	NC	450 - 900	2.7
R-3*		Ss	MC	0 - 450	2.2
R-4*		Ss	QCI	450 - 900	2.2
R-5*		Ss	NC	0 - 450	2.0
R-6*		Pl	T	450 - 900	3.1
R-7*		F	MC	0 - 450	4.8
R-8*		Hw	NC	450 - 900	2.0
R-9*		Hw	MC	450 - 900	2.0

* Proposed New Orchards.

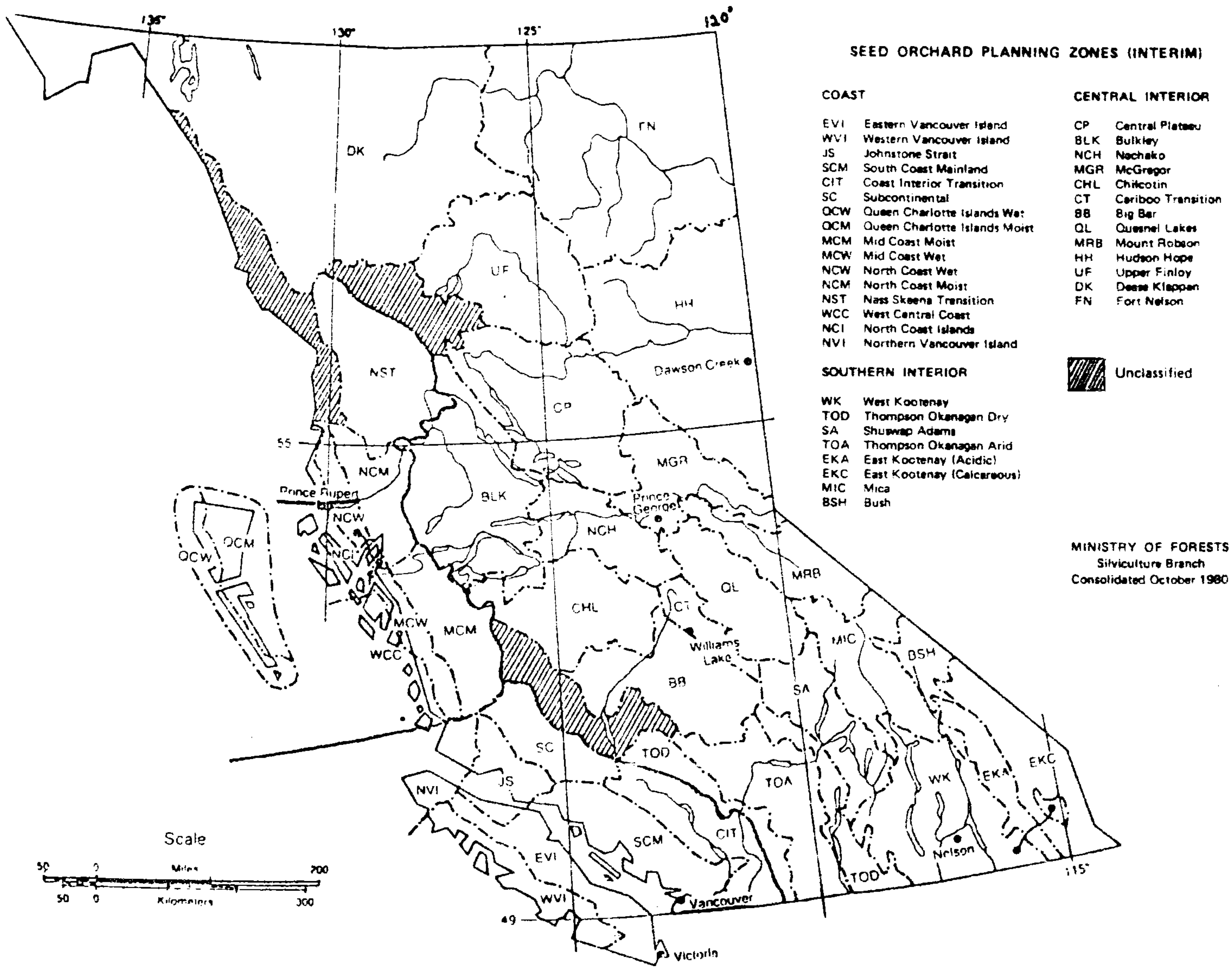

Fig. 1. Seed orchard planning zones.

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 communication[1]) 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 et al. (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.

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1 Gordon Miller, Entomologist, Canadian Forest Service, PFRC, Victoria

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RECENT DEVELOPMENTS IN ENHANCEMENT OF SEED PRODUCTION IN CONIFERS

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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[1] 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[2] 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

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[1] L.F. Ebell, B.C. Ministry of Forests, Victoria, B.C.

[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_3). Unfortunately, Pinaceae species were virtually unaffected by GA_3. However, in 1973, following leads from bioassay investigation, we (Ross and Pharis 1976) found that certain other GAs, notably the mono-hydroxylated $GA_{4/7}$ mixture (e.g. GA_4 and GA_7 exist in a less oxidized form than GA_3 which has two hydroxyl groups), would promote flowering in Douglas-fir. The efficacy of $GA_{4/7}$ 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 $GA_{4/7}$ 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 $A_{4/7}$ 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 $GA_{4/7}$ 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 et al. 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 cost-effective 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 $GA_{4/7}$ 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 $GA_{4/7}$ 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 et al. 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 $GA_{4/7}$ 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.

1. 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).

Hedged, Full-Sibling Orchards

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 et al. 1979), and we (Haeussler and Ross 1981) and others (Luukkanen 1980, Rottink[1] 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 $GA_{4/7}$ and other induction treatments is also greatly enhanced (Ross 1978, Greenwood et al. 1979, 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

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[1] 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 increaase 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 Pseudotsuga 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

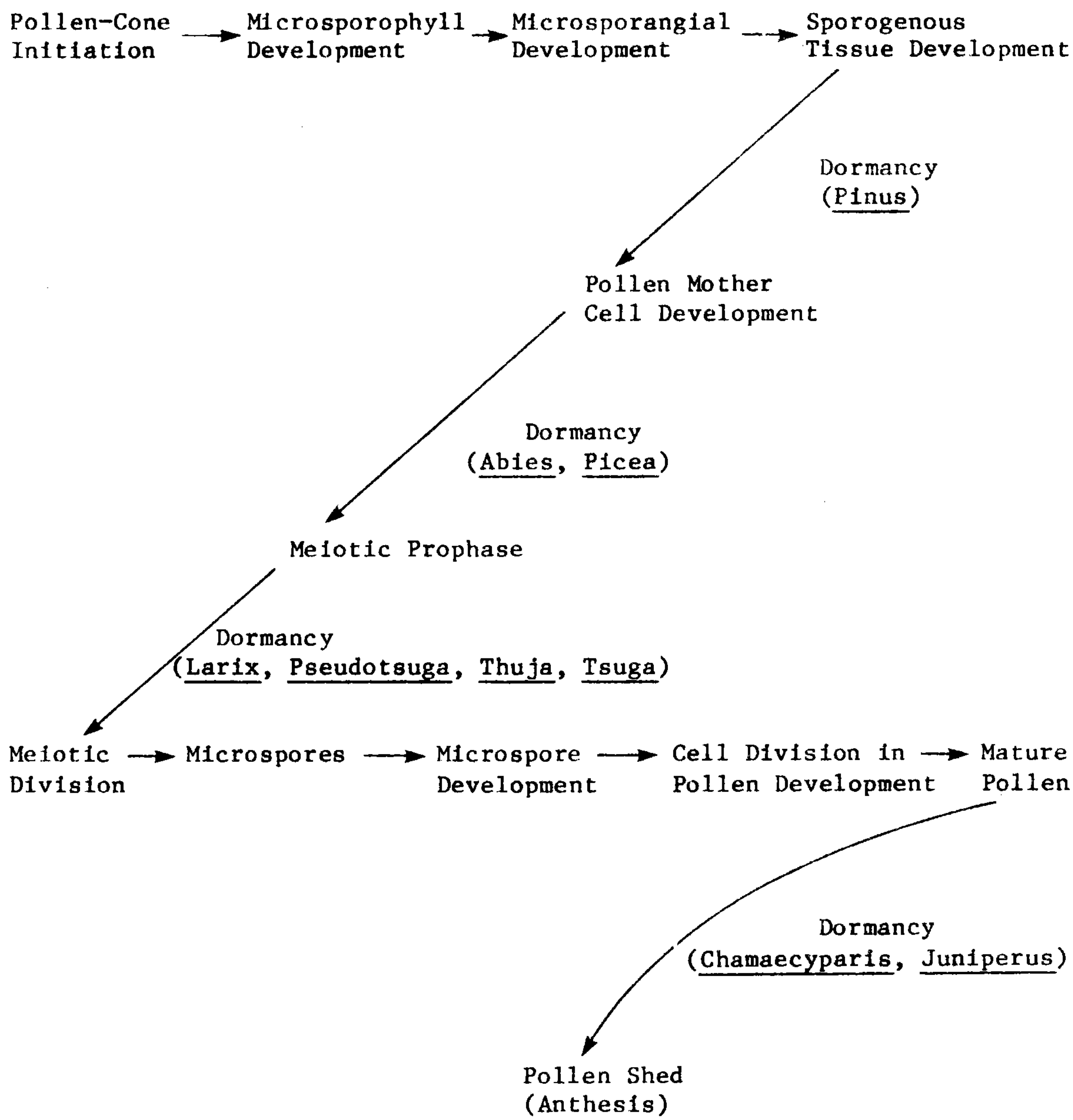

Fig. 1 Stages of pollen cone and pollen development and the times when dormancy may occur in different species.

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 Chamaecyparis and Juniperus 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 Thuja (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 Chamaecyparis, Juniperus, Taxus and Thuja, 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 intine 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,

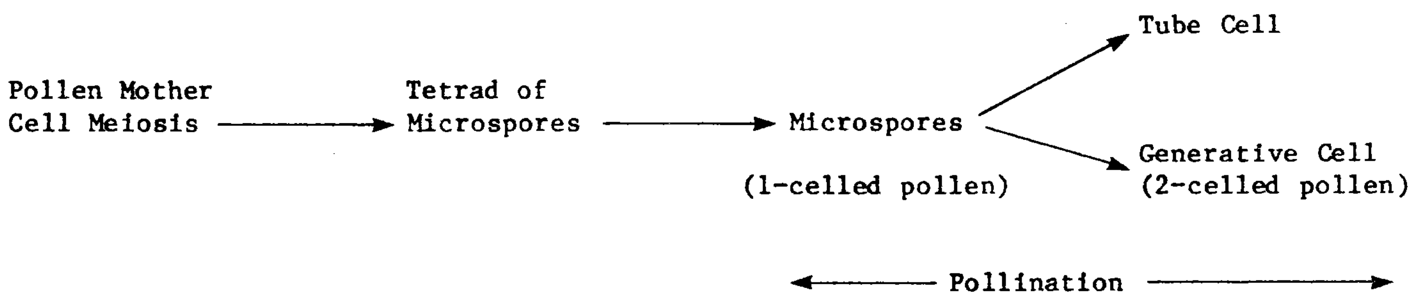

Fig. 2 Pollen development in <u>Chamaecyparis</u>, <u>Juniperus</u>, <u>Taxus</u> and <u>Thuja</u>. Pollen is shed at the 1- or 2-celled stage.

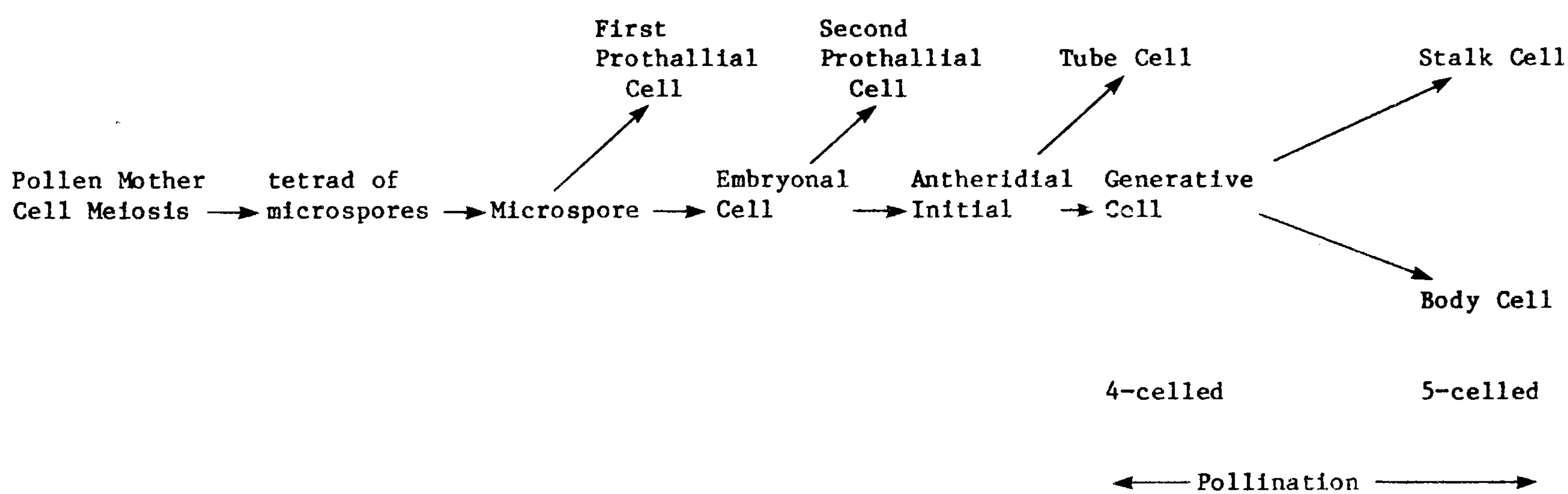

Fig. 3 Pollen development in <u>Abies</u>, <u>Larix</u>, <u>Picea</u>, <u>Pinus</u>, <u>Pseudotsuga</u> and <u>Tsuga</u>. Pollen is shed at the 4- or 5-celled stage.

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 Tsuga mertensiana (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 post-dormancy 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 Pseudotsuga and Larix (Owens and Molder 1971a, 1979b) to 4 weeks in Pinus monticola (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 Pinus monticola and Thuja plicata (Owens and Molder 1977a, 1980b) to 6 weeks in Tsuga mertensiana (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.

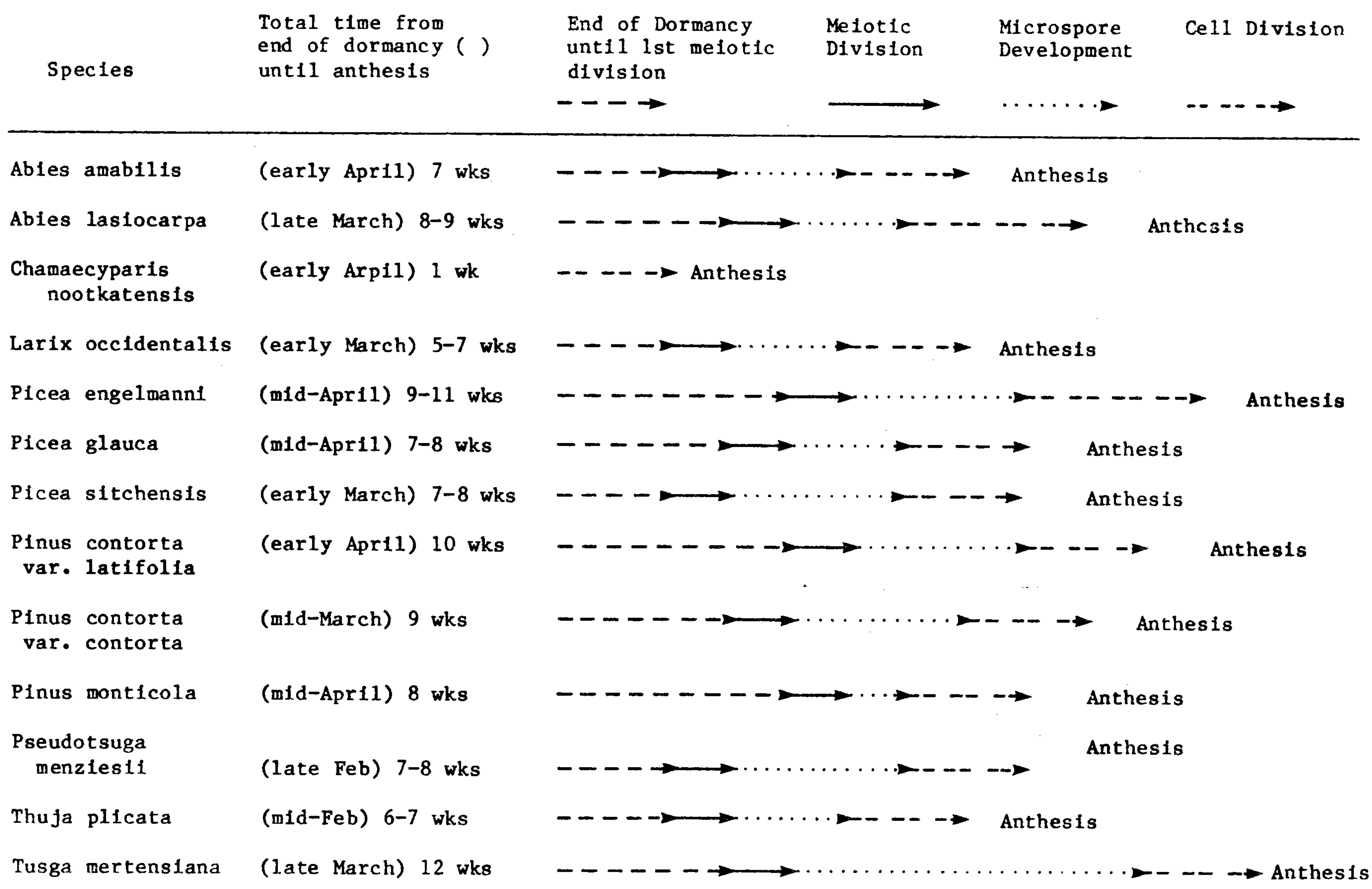

Fig. 4 Phenology of post-dormancy pollen cone development in 13 native conifers.

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.

ACKNOWLEDGMENTS

I wish to thank my colleagues Marje Molder, Dr. Hardev Singh and Sheila Simpson who have co-authored some of the original publications. Appreciation also is extended to the many research assistants who helped with collections and to the National Engineering and Research Council of B.C. Forest Service for financial support.

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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	Sitka spruce	hemlock
interior spruces	western white pine	larch
true firs	western red cedar	lodgepole pine
ponderosa 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 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. Insect-resistant 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.

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®) 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 et al. 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 coût 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[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.

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1 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.

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[1].

	Coos Bay Block (CB)		Springfield Block (SP)		Percent Increase	
Trait	Fertilized (N=494)	Control (N=495)	Fertilized (N=650)	Control (N=650)	CB	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

[1] 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).

Table 2. The effect of girdling on cone production at Turner Oregon and Rochester, Washington[1].

	Turner (CB)			Rochester (LV)		
Trait	Girdling (N=256)	Control (N=255)	% Inc.	Girdling (N=276)	Control (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	294±39[2]	225±50	31	291±53	232±52	25
Cones/Tree	134±19	76±18	76	97±20	46±12	111
Cone Effic. (%)	66±6	70±10	—	88±3	80±4	—

1 1980 data: Turner age 12; Rochester, 11.
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.

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

Treatment	Percent Clones producing		Female Cones/ producing ramet		Female Cones per ramet		Male Buds per ramet	
	Females	Males	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$
Early root pruning	74	54	22	120a[2]	41	68a	41	520a
Late root pruning	43	37	8	4b	41	1b	41	5b
Control	22	20	15	23b	196	2b	196	60b

[1] 1975 data; graft age 8
[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 $GA_{4/7}$, 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 ± 45 (S.E.) flowers and yielded a total of 2352 harvested cones. For the spray treatment, the mean was 246 ± 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[1].

Trait[2]	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	88	---

1 1979 data; graft age 8.
2 Treatments were significantly different at the 0.01 level.

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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.

RÉSUMÉ

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 considèrent 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.