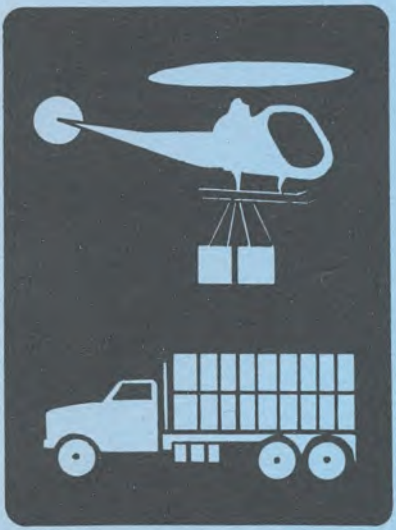
Tom D. Landis

Environment Canada
Canadian Forestry Service

Environnement Canada
Service canadien des forêts

Ministry of Natural Resources
Ontario



Proceedings of the

Canadian Containerized Tree Seedling Symposium

1982

460p.

September 14-16, 1981
Toronto, Ontario

COJFRC Symposium
Proceedings O-P-10

Edited by J. B. Scarratt, C. Glerum and C. A. Plexman

This Symposium was sponsored by the Ontario Ministry of Natural Resources and the Great Lakes Forest Research Centre of the Canadian Forestry Service under the auspices of the Canada-Ontario Joint Forestry Research Committee.

SYMPOSIUM CO-CHAIRMEN

K.H. Reese   J.B. Scarratt

STEERING COMMITTEE

L.W. Carlson   C. Glerum
R.D. Hallett   J.M. Kinghorn
K.H. Reese   J.T. Rudolph
J.B. Scarratt

PROGRAM

J.B. Scarratt   K.H. Reese

ARRANGEMENTS AND REGISTRATION

K.H. Reese   C. Fallowfield
R. Crawford

POSTER SESSION

C. Glerum   B.J. Sutherland

TRADE EXHIBIT

B.J. Sutherland

FIELD TOURS

W.R. Bunting   C. Glerum
R.D. Hallett   T.S. Murray
W.H. Patterson   B. Thompson

Cover design by P. Jakibchuk, Great Lakes Forest Research Centre, Sault Ste. Marie, Ontario.

Proceedings of the

CANADIAN
CONTAINERIZED TREE SEEDLING
SYMPOSIUM

September 14 - 16, 1981
Toronto, Ontario

1982

Edited by :
J. B. Scarratt
C. Glerum
C.A. Plexman

COJFRC SYMPOSIUM PROCEEDINGS 0-P-10

Published by:

Department of the Environment

Canadian Forestry Service

Great Lakes Forest Research Centre

Sault Ste. Marie, Ontario

1982

PREFACE

Throughout North America, the past decade has witnessed a dramatic increase in the use of containerized tree seedlings in reforestation practice. This is especially true of many parts of Canada where, concurrently with the growing impetus for substantially expanded forest renewal programs, increasing reliance is being placed upon container planting as a means of achieving reforestation goals. Today, container planting plays an important role in the reforestation programs of all 10 provinces, either as a complement to bare-root planting or as the sole method of planting in some provinces. From a total production of less than 20 million seedlings in 1972, production of containerized planting stock has now risen to 135 million seedlings, and is likely to exceed 200 million by 1983. Resources permitting, this figure will undoubtedly continue to increase in the short-term in response to the demands of expanding reforestation programs.

In view of the potentially large investments involved in these rapidly developing container programs, it was considered an opportune time to review our progress over the eight years which have elapsed since the North American Containerized Forest Tree Seedling Symposium. Despite significant advances in the areas of seedling culture and planting technique, technology transfer has frequently been slow, and there was a concern that developing programs might, by default, be deprived of the benefits of such technical advances. Further, aggravated by the paucity of field performance data, many forest managers continued to express lingering doubts about the effectiveness of container planting. The time was ripe for a major progress review to address these concerns.

The objectives of this Symposium were to review the current state of the art of the production and use of containerized planting stock for northern tree species, and to examine the overall effectiveness of container planting as a reforestation method. While the program deliberately emphasized Canadian experience and practice in order to provide a focus for the meeting, we were anxious that it should also reflect experience under comparable 'northern conditions' in the United States and Scandinavia. Thus, we are especially grateful to the speakers from the United States, Britain, Finland and Sweden for sharing with participants the benefits of their knowledge and experience.

It is a measure of the considerable interest in container planting, and perhaps of the timeliness of the Symposium, that the meeting attracted well over 300 delegates from eight countries. In addition to the expected government and forest industry participation, it was encouraging to note the relatively large number of private growers in attendance. However, the number of participants from the United States was unfortunately far lower than had been hoped for because of travel restrictions within the U.S. Forest Service.

The Symposium lasted three days, and comprised five sessions during which a total of 60 papers were presented. The program covered all facets of container planting from seedling production to plantation establishment. It will be noted that the program lacked contributions dealing with specific cost studies or economic analyses of container planting. Surprisingly, we were unable to bring to light any recent economic studies of this nature, a deficiency which must surely be rectified before we can evalute the overall effectiveness of container planting for reforestation. Another topic which may appear to have received less .than adequate attention is the contentious issue of rooting habit in containerized planting stock. However, many readers will recall that the subject was discussed exhaustively at the 1978 Root Form of Planted Trees Symposium held in Victoria, British Columbia. Under the circumstances, it was decided that a brief review of that meeting would be an appropriate way to cover the topic.

The main program was supplemented by a poster session, brief abstracts of which are included in these Proceedings, and a very successful trade exhibition. The latter attracted 13 exhibitors, representing 19 firms, and provided a valuable focal point for informal technical discussions during breaks in the program.

At the conclusion of the Symposium, four optional field tours were offered. Two two-day field tours, one to New Brunswick and one to Kirkland Lake, Ontario, included visits to various production and planting operations with containerized spruce and pine. The third tour concentrated on the vegetative propagation program for black spruce being conducted at the Orono nursery, east of Toronto. The fourth tour, under the guidance of Dr. Theo Blom, was to the Ontario Ministry of Agriculture and Food Horticultural Research Institute at Vineland and four nearby commercial greenhouse operations, and was concerned primarily with energy conservation measures in greenhouses. Approximately 120 delegates participated in these field tours.

We wish to express our sincere appreciation to the many people who contributed to the success of this Symposium. Our greatest debt, of course, is to the speakers for their stimulating, fact-filled presentations; their collective efforts have effectively redefined the state of the art for some time to come. We are grateful also to those individuals who so ably acted as session chairmen and panel moderators, keeping the program on schedule and leading the discussion periods. The poster session was a successful supplement to the main program, and we wish both to thank contributors for their efforts and to congratulate them on the excellent standard of their displays. A word of thanks also to the commercial exhibitors, whose participation not only provided a rare opportunity for dialogue between supplier and customer, but also helped to bring the whole meeting together.

We are deeply indebted to members of the steering committee and others, listed on the inside cover, whose organizational efforts ensured the success of the Symposium and field tours. To the many unnamed individuals whose contributions of time and effort ensured that everything ran smoothly, our sincere thanks. We also gratefully acknowledge the part played by a number of individuals, both from Canada and the United States, who travelled to Toronto to participate in the early planning stages of this Symposium: A.A. Alm, A. Dancause, E. Van Eerden, J.F. McLeod, J. Tetreault. By their participation they made a significant contribution to the program that was subsequently developed.

The editing and retyping of manuscripts was carried out mostly at the Great Lakes Forest Research Centre in Sault Ste. Marie. We would like to express our sincere gratitude to Miss Donna Weeks of that Centre who, with great fortitude and cheerfulness, typed these entire Proceedings.

The Symposium showed that we have made significant advances in container planting technology over the past few years, and that containerized seedlings can now be considered a viable reforestation vehicle provided that the technology is not misapplied. The information and experience distilled in these published Proceedings will undoubtedly serve as a valuable state of the art reference for many years to come. Our thanks once more for everyone's efforts.

K.H. Reese and J.B. Scarratt
Symposium Co-chairmen

TABLE OF CONTENTS

Page

WELCOMING REMARKS BY SYMPOSIUM SPONSORS

KEYNOTE ADDRESSES

THE STATUS OF CONTAINER PLANTING PROGRAMS IN CANADA AND THE NORTHERN UNITED STATES

CONTAINER SEEDLING PRODUCTION PRACTICES AND RELATED PROBLEMS

Page

HANDLING, TRANSPORTATION AND PLANTING OF CONTAINER-GROWN SEEDLINGS

FIELD PERFORMANCE: IS CONTAINER PLANTING AN EFFECTIVE REFORESTATION METHOD?

FINAL REMARKS ON CONTAINERIZED REFORESTATION

Page

WELCOMING REMARKS BY SYMPOSIUM SPONSORS

A.H. Peacock
Executive Coordinator, Forest Resources Group
Ontario Ministry of Natural Resources
Toronto, Ontario

This symposium is being co-sponsored by the Ontario Ministry of Natural Resources and the Great Lakes Forest Research Centre of the Canadian Forestry Service. I am pleased to welcome you on behalf of the province of Ontario and the Ministry of Natural Resources.

The mechanism for the joint sponsorship of this symposium is through the Canada-Ontario Joint Forestry Research Committee (COJFRC). This committee is composed of administrators and research staff from the Great Lakes Forest Research Centre at Sault Ste. Marie, the Petawawa National Forestry Institute at Chalk River, and the Ministry of Natural Resources. Their mandate is to discuss new research proposals and to review the progress of continuing work in order to resolve areas of responsibility and cooperation, and to avoid duplication of effort.

One of the undertakings of COJFRC is to hold annual technical symposia as a means of upgrading the working knowledge of field foresters in Ontario and bringing them into direct contact with researchers working in different areas of interest. These meetings usually involve only Ontario foresters, representing government, industry and universities, although a few delegates from other provinces are usually in attendance as well. Previous symposia dealing with such topics as direct seeding, artificial regeneration, tree improvement, mechanization of silviculture and the management of particular silvicultural working groups have been held in various parts of Ontario.

As the concept for the present symposium evolved, it was decided to include it within the COJFRC series, but to give the program a national, rather than a purely provincial outlook. This meeting therefore has a special meaning for us. Container planting in Ontario has very recently received a new stimulus through the development of Forest Management Agreements with the forest industry. These agreements are generating a lot of interest in container planting as a means of rapidly expanding planting stock production to meet the demand from the private, forest industry and government sectors.

Containers are also finding a permanent role in forest regeneration in other parts of Canada. We are certainly interested in developments in other regions of Canada, particularly if they are applicable to Ontario. From a more general viewpoint, information is accumulating at a very fast rate and it seemed timely to update the information which came out of the North American Containerized Forest Tree Seedling Symposium held in Denver, Colorado in 1974 by reviewing the role of containers in various regions and discussing their technical problems. Ontario is pleased to host this meeting but we quickly acknowledge the support received from other federal, provincial and university agencies in Canada and the northern United States. By allowing their staff to travel to Toronto during the early planning stages of this meeting they contributed greatly to the symposium program that was subsequently developed. It was my pleasure to review the registration and to discover the broad representation from all Canadian provinces, our neighbors from the United States and numerous visitors from abroad. This will surely contribute to the value of this symposium.

I wish you success in your deliberations, and have pleasure in introducing the cosponsor of this symposium, the Great Lakes Forest Research Centre and its Acting Director Bob Haig.

WELCOMING REMARKS BY SYMPOSIUM SPONSORS

R.A. Haig
Acting Director, Great Lakes Forest Research Centre
Canadian Forestry Service
Sault Ste. Marie, Ontario

It is a privilege and a pleasure for me, on behalf of the Great Lakes Forest Research Centre and the Canadian Forestry Service, to join Mr. Peacock in welcoming you to the Canadian Containerized Tree Seedling Symposium. We particularly appreciate the participation of delegates from the United States and from abroad, including representatives from Alaska, Finland, Italy, Scotland, South Korea, Sweden and Yugoslavia. We welcome the opportunity to share your expertise in the dynamic field of containerized reforestation and hope that you will find the experience mutually beneficial.

On the basis of the large attendance at this meeting, it would appear that the subject of container stock production and planting is of considerable interest to a wide range of forestry agencies. Thus the topic of the symposium is a timely choice.

I think it would be safe to say that, in Canada, all sectors of the forestry community have reached a virtual consensus on the critical issue of long—term wood supply and the related issues of forest renewal and intensive forest management. The standard response of most agencies is that reforestation programs must be expanded rapidly, but at the same time tight constraints on both manpower and dollars mean that the new reforestation targets must be achieved with minimal increases in resources. The big question is the extent to which containerized seedling systems can meet these two conflicting criteria. In theory, containerized systems offer certain advantages over conventional bare—root systems in terms of reductions in time, cost and manpower per unit planted. Containerized stock systems also offer other theoretical advantages in terms of shorter and more flexible production schedules, a longer planting season, and greater potential for mechanization.

These theoretical advantages of containerized systems have been recognized for many years, and we will presumably learn during the next three days the extent to which these advantages have been realized.

In Ontario, experimentation with container-grown stock began about 25 years ago and the first operational plantings took place in 1966. Similar developments occurred at about the same time in a number of other provinces, and the first Canadian workshop on container planting was held in 1972 at Kananaskis in Alberta. By this time the Canadian Forestry Service had programs under way in most regions, in support of provincial efforts to evaluate and develop the potential of containerization. Two years later the North American Containerized Forest Tree Seedling Symposium was held in Denver, Colorado, where Canada was well represented. The proceedings of that symposium essentially described the state of the art as it was in 1974. Although progress has been rapid, I am not so naive as to suggest that the development of containerization has been a smooth unbroken curve, or that all problems have been solved.

Even the symposium held in Denver left many critical questions unanswered, particularly regarding the long-term survival and growth of containerized seedlings, their performance relative to bare-root stock, and the success of operational production and planting programs. Presumably the Southern Containerized Forest Tree Seedling Symposium, held recently in Savannah, Georgia, provided some of the necessary answers with respect to southern tree species and conditions. We will hear something about this today. What we are hoping for at this symposium is a similar review of the state of the art with emphasis on northern species and conditions. My hope is that our timing is such that it is not too soon to expect reliable long-term results from some of the earlier work, and not too late to permit substantial change, if necessary, in both the scale and the technical aspects of developing operational programs. I am looking forward eagerly to the proceedings of the next three days, as I expect this symposium will represent a significant milestone in the history of container stock production and planting, and in Canada's forest renewal program as a whole.

CONTAINERIZED SEEDLINGS AND CANADA'S FOREST RENEWAL

K.A. Armson[1]

Abstract.--The role of containerized seedlings in Canada's regeneration efforts is reviewed. The changing emphasis in forest management has given rise to demands for containerized planting stock. Because of these demands there is an increased need for critical analysis of present production techniques and for cooperation between stock producers and forest managers.

Résumé.--Cette communication passe en revue le rôle des plants en mottes emballées dans le reboisement au Canada. Les nouvelles priorités de l'aménagement forestier ont décuplé la demande de plants en mottes emballées et, par ainsi accentué la nécessité d'une analyse critique des méthodes actuelles de production ainsi que d'une collaboration entre les producteurs de plants et les aménagistes.

Seven years ago, Bingham (1974) in his keynote address to the North American Containerized Forest Tree Seedling Symposium suggested that, in forestry as in agriculture, North Americans had "graduated from being guardians of a nature-provided, unmanaged forest to becoming managers of a forest from seed to harvest". In Canada I think our role is more that of exploiter and sometimes protector, rather than guardian, of the natural forest.

There is nothing unnatural or reprehensible in our treatment of such a vast forest resource. It is human nature to exploit and convert our capital into forms deemed most appropriate to society at the time. Roads, schools, the infrastructure necessary for agricultural and urban development all have flowed from the converted capital of Canada's forests. Foresters and others in their professional and technical capacities have rendered the exploitation of our natural forests increasingly more efficient and extensive. In the settlement and development of this country late in the 19th century, agriculture was considered more important than forestry, yet it was also late in the 19th century that the first major concerns about the results of forest renewal and destruction were voiced -- by agriculturists. These people had experienced the loss of productivity in farmland associated with the absence of trees. Erosion and lack of shelter together with a growing scarcity of local fuel-wood were the main objects of such concern. By the turn of the century lumbermen were also expressing concern about the lack of regeneration, and about the destruction, particularly by fire, of the white pine *(Pinus strobus* L.) and red pine *(P. resinosa* Ait.) forests in eastern Canada.

Nevertheless, it seems that each time we have been about to embark on a program of forest management, either a new forest has been opened to exploitation, or a national crisis or economic catastrophe has intervened. As an example of exploitation, I would offer the establishment and development, in the early 1900s, of the pulp and paper industry in the boreal forest of eastern Canada as red pine and white pine lumbering diminished. It was during this same period that the west coast sawmill industry gathered steam, and the logging of Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) forests began in earnest.

In eastern Canada, particularly in Ontario, there were a few foresters who, as a result of their professional background,

---

[1] Chief Forester, Forest Resources Group, Ontario Ministry of Natural Resources, Toronto, Ontario.

could see that the regeneration and management of forests was the key to a sustained forest economy. They, and a number of politicians and industrialists of the time, were able by the 1920s to embark on a limited program of forest renewal and management. The plantations of Grand'Mere and various parts of Ontario are living evidence of their efforts. The economic depression of the 1930s and World War II put an end to this work and little more was done until the 1950s.

Following World War II, renewed concern about the state of forest regeneration was expressed in several Canadian provinces and a number of Royal Commissions were appointed. There was much debate about the adequacy and standards of regeneration; in fact, the debates among foresters on this subject were almost interminable. In the meantime, the forest industry was mechanizing its logging to such an extent that it became the world leader in the 1960s. Paradoxically, it was the scale and extent of exploitation made possible by mechanized logging and the expansion of these hitherto seasonal operations to a year-round activity that provided the major opportunity for foresters to convince society, and governments in particular, that management of our forests is essential if a forest industry is to be maintained or increased in future decades. This is a major challenge and a continuing one. In meeting the challenge, I believe we have yet to establish the full credibility of our profession. We can do this only by demonstrating our unique ability to provide the professional and technical knowledge and expertise necessary to make efficient management of our forests a reality. Nowhere is our expertise more needed than in the field of forest regeneration.

The productive forest lands of Canada comprise some 3 million km^2; approximately 90% are Crown or public lands. As recently as last year some 12% of this land was considered inadequately stocked (Roberts 1980). The regeneration of even a significant portion of this presents an immense challenge to governments, industry, and the forestry profession.

In rationalizing the renewal of Canada's forests we have to take several factors into account. To most of you these are self-evident, but often we lose sight of them because we become too engrossed in our specific interests or projects. I suggest that we start by considering the basic components of the natural forest which we are putting under management for timber. These are:

1. forest lands which are converted to other uses after commercial logging. Their extent, as a proportion of the original productive forest land base, will vary with terrain, logging system, etc.

2. forest lands which, because of species, size of timber, or overall area, are deemed inoperable for commercial logging by current criteria. These criteria usually change with time and with the needs of the entrepreneur and marketplace. Nevertheless, at any time there is a quantifiable area in this category.

3. forest lands which are logged commercially but, because of their location, site class or extent, or for some other reason, are not considered suitable for forest renewal. This does not mean that they do not regenerate. In fact, the silvicultural prescriptions for harvesting these areas should be aimed at this objective, but only by virtue of the harvesting process itself.

4. forest lands which are logged commercially and require a deliberate cost-effective input to ensure regeneration of desired species to specified standards. These lands require the most attention silviculturally and economically because, if they are to be cost-effective, the input:output ratio has to be known or estimated. Essentially, these lands can be placed in one of two categories, although the boundary between them is not necessarily fixed or sharp, viz.:

    i) lands supporting species which can be regenerated naturally by specific harvesting techniques with or without relatively inexpensive site preparation or seeding. For example, sugar maple *(Ater saccharum* Marsh.), poplars *(Populus* spp.), jack pine *(Pines banksiana* Lamb.), lodgepole pine (*P. contorta* Dougl.), white pine and black spruce *(Picea mariana [Mill.]* B.S.P.) can be handled in this way. Site productivity and condition, seed availability, location and extent of the area, together with the objectives of management, including rotation and anticipated tending requirements, all enter into the decision-making process.

ii) lands which, because of their productive nature, extent and location, must he artificially regenerated by planting. The key concerns are species control (including genetic control), density control (i.e., spacing), and a rotation age that will maximize productivity in keeping with the objectives of management. It is with these lands and associated species that we should be concerned in the application of containerized planting to forest renewal.

I stress the need for applying different techniques and treatments to different types of land because, in the past, not enough of this was done. Inappropriate use of containerized seedlings in relation to type of land or objectives of management was often a cause of failure or poor growth.

There are two aspects of container planting that are very important hut are not strictly part of forest renewal. These are the regeneration and amelioration of wastelands such as mine spoils, and the planting of stock for amenity, wildlife, or other nonconsumptive purposes. Container production for these two broad-use areas has not been well developed, but will, I believe, assume greater importance in the future.

My first direct involvement in containerized seedling production was in 1966 when Professor R.J. Day and I planted and assessed jack pine seedlings which were grown in the 1.4 x 7.5 cm plastic "Ontario tube". In the 15 years since then, I have had continuing contact with container production and have made observations and assessments of plantations developed from container seedlings in six Canadian provinces. The following remarks are based on this background.

The use of containerized seedlings has caught the attention of many foresters in recent years, and both government and industry now see this type of planting stock as potentially one of the most effective for artificial regeneration. The large tubed seedling program begun by Ontario in 1966 was in many ways in advance of its time. The expertise and knowledge required to grow seedlings and to provide adequate site preparation before outplanting were not well developed at that time and undoubtedly this was a factor in the slow expansion of container planting programs in Ontario. While there is much more knowledge to draw upon today, an important new factor in regeneration planning is the degree to which the forest industry is becoming involved in forest management, especially in planning and integrating harvesting and regeneration activities.

As I mentioned earlier, containerized stock plays a significant role in the regeneration of certain forest lands. If this stock is to be used effectively it must be planned for and integrated into the overall forest management process. Too frequently this has not been the case. The production of containerized seedlings requires seed of high quality and very high viability. It must be germinated uniformly and rapidly, and grown in containers of appropriate dimensions so that it will meet the requirements for outplanting. All this, as most of you know, is easier said than done. Yet it is necessary to make this our objective if we are to do the job properly and establish our professional credibility.

Containers offer the most effective use of limited amounts of quality seed, especially if that seed is from genetically improved sources. Uniformity in germination and growth are key items in the production of such material as has already been mentioned. In Ontario we have begun production of vegetative cuttings on a large scale and for this type of rooted stock, container production is virtually mandatory. For certain genera such as *Picea* and *Larix* I believe that vegetative propagation in containers of genetically improved stock will become the main method of production.

It is not my intention to dwell at length on a comparison between bare-root and container stock, although there are certain basic advantages to containers. These advantages may be cancelled out, however, if the planting stock, rooting medium, type of container, cultural practices and related management practices are not matched to time of outplanting, outplanting conditions, and purpose for which the stock is being produced. inevitably, man and nature in their perversity will force compromises. Changes in plans and even catastrophes will occur, but the fact that they do should only serve to emphasize the necessity for clearheaded professional planning to ensure built-in safeguards to prevent or minimize the effects of such adversity. Keep in mind that, operationally, one of the most important advantages of containerized seedlings is that their performance is, or should be, superior to that of bare-root stock.

The prime biological advantage of container stock over bare-root stock is that the root system of the former is packaged and protected. The type and size of container, therefore, have to be chosen with regard for this fact. There is no point in growing seedlings in a plug-type container and then shipping them out to the field before the root systems have developed to the point at which the plug can be handled by the planter without disintegration. Conversely, holding over containerized stock so that the roots grow from one container into another not only leads to root damage but can also mean unnecessary expense and time spent in separating them before they are shipped or planted.

The nature of the rooting medium itself has received considerable attention from the standpoint of seedling growth but very little, to my knowledge, in terms of the physics of soil water movement between the container, its contents, and the soil in which it is placed. For a majority of forested soils this is probably not a critical feature, but I suspect that, in the reforestation of certain types of mineral materials such as mine spoils or tailings, the cause of failure can be traced in several instances to a mismatching of pores between those of the container and those of the surrounding soil, with a consequent loss of hydraulic conductivity.

One topic which continually arises with respect to container stock and its outplanting success is that of root development in relation to the type of container. I would like to bury once and for all the myth of "root strangling". Roots do not have suicidal or murderous tendencies. They grow in a simple biological manner. The anthropomorphic view of roots which has developed is totally without foundation. Vigor of root development and root symmetry are important, but let us judge them in light of the full development of trees and stands, not in terms of whether straight, uniform lines in a container appeal to us. The soil in which the tree has to grow is usually heterogeneous and anyone who has observed the roots of trees in natural stands will soon be disabused of the notion that they grow uniformly or in straight lines.

The cultural practices associated with container planting are, I believe, the most important area in which we have not advanced significantly. There is no substitute for the proper application of knowledge and expertise or the keen observation and judgment of properly trained and motivated people. Too often we assume that sophisticated controls will compensate for inexperienced, untrained people who obey a fixed set of instructions. This just isn't so. I am not opposed to the intelligent use of equipment, which in certain instances may be quite sophisticated, but let us use it wisely and sparingly.

This leads me to a final observation. Historically, in Canada, we have looked to the various provincial forest services for the provision of seed and planting stock. This is still the case, but I believe that, with all due respect to those government employees who have been involved in provincial nurseries, motivation, incentive and exchange of information have too often been lacking. These are more likely to be fostered if more than one organization is in the business of growing stock. In provinces with several nurseries, exchange of information and the stimuli to innovate are possible, but where there is only one nursery they are less Likely.

In recent years, production of containerized seedlings by the private sector -- both individual growers and forest companies -- has increased. In many instances these private growers are producing seedlings under contract for a provincial forest service. I view this development as a healthy one. It means that the production base is growing and also is being diversified. The challenge for forest renewal is here. If the owners of the land and those responsible for maintaining its productivity are to meet that challenge, you who produce and use containerized stock -- whether at the scientific, professional, technical or operational level -- have a formidable task ahead.

LITERATURE CITED

Bingham, C.W. 1974.
1974. Achieving forestation goals. p. 3-7 in R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Roberts, J.
1980. The federal commitment to forestry in Canada. p. 96-100 in Proceedings of the Canadian Forest Congress: The Forest Imperative. Can. Pulp. Pap. Assoc., Montreal, Quebec.

CONTAINERIZED FOREST TREE SEEDLING PRODUCTION AND DEVELOPMENT PROSPECTS IN FINLAND AND SCANDINAVIA

Pentti K. Rasanen[1]

Abstract.--Sweden, Finland and Norway produced 250, 65 and 40 million containerized seedlings, respectively, in 1980. Paperpot seedlings accounted for 210 million of the total figure. Although climate—controlled greenhouses are frequently used for crop production, maximum biological benefits have yet to be achieved. Development work aims at the integration of seedling production and planting systems, including the development of advanced planting machines. Norway is changing to containerized seedlings most rapidly, with 60% of total planting stock being containerized in 1980.

Résumé.--En 1980, la Suède, la Finlande et la Norvège ont produit respectivement 250, 65 et 40 millions de plants en mottes emballées. De ce nombre, 210 millions ont été produits dans des pots de papier. Bien qu'on emploie fréquemment des serres à climat contrôlé pour la production des cultures, on n'a pas encore réussi à obtenir le maximum d'avantages biologiques. Les travaux de développement visent à intégrer la production de semis aux systèmes de plantation et à mettre au point des machines à planter perfectionnées. La Norvège est le pays qui se convertit le plus rapidement au système des plants en mottes emballées; en 1980, 60% de son matériel de reproduction était composé de ces plants.

INTRODUCTION

Finland, Denmark, Sweden and Norway have similar forestry problems. They all have relatively important and similarly developed forest industries, and there is a great deal of mutual cooperation among the four countries. Several joint working groups have been set up in the reforestation sector, such as the Nordic Committee for Forest Seed and Seedlings (NSFP), established in 1970.

There are, however, rather considerable geographical differences both within and among these countries. Denmark, southern Sweden and Norway resemble oceanic regions of central Europe. The annual precipitation of Norway sometimes exceeds 5,000 mm, whereas that of the other Scandinavian countries ranges from 500 to 800 mm. The length of growing season ranges from 210 days in Denmark to 130 days in more northerly areas. In northern Finland, Sweden and Norway, forestry activities are carried out right up to the treeline, where conditions are extreme.

The area covered by forests in Sweden is 24 million ha, in Finland 20 million ha, in Norway 6 million ha, and in Denmark 0.5 million ha. However, forest ownership differs slightly from country to country (Table 1). Companies own a higher percentage of forest land in Sweden than elsewhere in Scandinavia. In Finland particularly, but also in Norway, the tendency for privately owned forests to be small has important consequences for those involved in reforestation planning. Besides developing different types of high-quality container-grown planting stock, the planners have to be able to promote the use of such stock by the hundreds of thousands of small landowners who, in effect, make the decisions on reforestation.

---

[1] Superintendent of Nurseries, National Board of Forestry, Helsinki, Finland.

Table 1. Forest ownership as a percentage of total forest area.

	Sweden	Finland	Norway
State	25	28	18
Company	25	7	7
Private	50	65	75

CURRENT PRODUCTION OF CONTAINER-GROWN STOCK

The combined production of forest tree seedlings in Sweden, Finland and Norway is 750 million. Seedling production in Sweden has risen steadily since the early 1970s, but in Finland and Norway it decreased for a while because of the economic recession, and has not yet returned to the level of the 1970s.

In Sweden the main increase has been in the production of container-grown stock--from 150 million in 1974 to 250 million in 1980. Relatively speaking, the most rapid change to container-grown seedlings has been in Norway --from only a small percentage in 1974 to 62% of all stock in 1980. In Finland container-grown seedling production totalled 75 million in 1974, or 34% of all stock. However, the figure later dropped to about 20%, and only recently has risen to 30% (65 million) (Table 2). The production of container-grown planting stock in Denmark is only in the experimental stage.

In Sweden and Finland the Japanese paperpot accounts for nearly 70% of all container stock production. The only other system used to any significant extent in Sweden is the Kopparfors multipot. In Finland, however, 5-8 million seedlings are produced annually in Finnpots (peat pots), Enso multipots and styroblocks. In Norway, 33 million seedlings were grown in the Kopparfors multipot in 1980, 5 million in the Kombiform (KF) container, and a further 4 million by the modified Nisula method. (This last will be replaced by the other two in 1982.)

Different cultural methods are used in each country to accommodate the various tree species. In Finland, Scots pine *(Pinus sylvestris* L.) accounts for 80% of all trees planted, and Norway spruce *(Picea abies* Karst.) for 15%. The respective figures for Sweden are 50% and 40%, while for Norway they are 11% and 80%. Two thirds of all container-grown Scots pine seedlings are planted after one growing season, and the remaining third after two seasons. Spruce seedlings are usually grown for two or more years before outplanting.

CONTAINER NURSERIES

A typical Finnish forest tree seedling nursery produces 5-10 million containerized and bare-root seedlings annually. A few large nurseries produce 20 million seedlings annually, some of these specializing in the production of container-grown stock. Greenhouses are usually used for growing containerized stock, and for the early (seedbed) stages in bare-root stock production. Irrigation and fertilization are often controlled automatically. Supplementary heating, though seldom used, and ventilation are usually controlled manually. In general, the capital outlay for buildings and extra equipment has been minimal.

In Sweden, most nurseries (bare-root or bare-root plus container) have a production capacity of 4-8 million seedlings. There are, however, more than 10 nurseries specializing in the production of container-grown tree seedlings. The largest is the Svenska Cellulosa AB (SCA) in Bogrundet, Timra, which grows about 50 million seedlings annually in Kopparfors multipots (Fahlroth and Persson 1978). This operation represents a considerable capital outlay: it has large, well-equipped greenhouses, a high level of auto-

Table 2. Planting stock production in 1980.

	Sweden	Finland	Norway	Total
		(000,000)		
Bare-root	200	160	27	387
Container-grown	250	65	42	357
Total	450	225	69	744
Percent container-grown	56	29	61	48

mation, supplementary heating and lighting, and mechanized handling and packing. The whole operation is run by a small hut highly productive labor force.

A few large nurseries in Norway specialize in containerized seedling production, although they are not nearly as well equipped as those in Sweden.

FIELD SURVIVAL AND EARLY GROWTH

The 1980 figures for survival and growth of container-grown forest tree seedlings show that, amongst the large landowners, forestry boards and companies in Sweden and Finland, results were as good as with bare-root planting stock. Survival rates 2-3 years after outplanting have averaged 85-90% although, particularly in Finland, they have been rather variable and have sometimes dropped below 80%. Nevertheless, such results show that it is possible to achieve good plantation establishment with container-grown seedlings without the necessity for infilling. However, careful attention must be given to all components of the establishment process: site preparation, seedling condition, outplanting factors, etc.

COSTS

No detailed cost/benefit statement for the various methods of container stock production is possible, since this requires information on both expenditures and income. It is difficult to place a value on stands, and only gradually are input-output data for young stands established by different container systems being gleaned from the records of the various companies and organizations involved.

Production costs (and selling prices) of one-year-old container-grown stock have generally been about double those for bare-root stock of the same size, and about the same as for transplants. Cost data for two-year-old container-grown stock are less precise, because of the smaller quantities involved, but will probably rise to double those of bare-root seedlings of the same age.

Seedling prices in Sweden are generally higher than those in Finland. Some forestry board nurseries in Finland, which have used Japanese paperpots for 10 years, produced seedlings in FH 408 paperpots at US $30-36/1000 in 1980, when the price in Finland was US $43/1000 and in Sweden US $59-79/1000.

Production costs for container-grown stock vary according to wage levels, the amount of capital tied up in production, and the interest rate. However, in considering planting stock costs it should be realized that they usually constitute a relatively minor item of the total expenditures involved in reforestation. In Table 3 reforestation costs using different types of planting stock have been calculated on the basis of information gathered by the Finnish Board of Forestry. In Sweden, SCA claims a saving in labor costs of US $100/ha by using container-grown planting stock.

The main reason that container-grown stock is cheaper to use than bare-root in Sweden, Finland and Norway is that outplanting with container stock is relatively easy. Mechanical site preparation, which has become more common in Sweden and Finland since the beginning of the 1960s, has made for easier planting of both containerized and bare-root planting stock. In addition, planter productivity with containerized seedlings has been improved by the introduction of the 'Pottiputki' planting tube, which reduces planter fatigue. However, the greater weight and volume of container-grown stock have increased the costs and logistic problems associated with the handling and transportation of planting stock. Large investments in planning and labor have been necessary to ensure that transportation distances to the planting site are kept as short as possible. Nevertheless, on the whole it has been possible to keep costs at a reasonable level.

BRIEF HISTORY OF CONTAINER PLANTING

There is nothing new in the idea of using container-grown stock for planting forests. For hundreds of years pine and spruce were planted in central Europe with their roots protected by a clump of earth. The use of bare-root seedlings, however, dates from the beginning of the 19th century, when G.L. Hartig published the results of his experiments. Interest in the use of container-grown stock arose again in the 1950s. The lessons of a hundred years of research in other biological and technical fields were applied to add new dimensions and significance to this work.

In the early 1960s several new types of container were developed for forestry use in Finland--Finnpots, Nisula rolls, Enso multipots, paperpots, etc. The main stimuli to this development were the rapidly increasing need for forest regeneration and the varied results obtained to that time with direct

Table 3. Calculation of reforestation costs for the northern part of Central Finland using different types of Scots pine planting stock (1981 costs).

Cost component	Reforestation function								
			Planting				Totals		
	Land clearance[a]	Site preparation[b]	Container[c]	2-0[d]	1-1[d]	Cleaning/ thinning[a]	Container	2-0	1-1
1. Labor									
day/ha	0.7		1.9	3.2	3.4	1.0	3.6	4.9	5.1
Fmk/day[e]	250		200	200	200	250			
Fmk/ha	175		380	640	680	250	805	1065	1105
2. Machinery									
hr/ha		1.8					1.8	1.8	1.8
Fmk/hr		165					165	165	165
Fmk/ha		297					297	297	297
3. Planting stock									
no./ha			2000	2000	2000		2000	2000	2000
Fmk/1000			190	110	250				
Fmk/ha			380	220	500		380	220	500

4. Transportation

		Seedling transport					
		Long-haul[f]			Short-haul[g]		
	Equipment	Container	2-0	1-1	Container	2-0	1-1
Mean distance(km)	200	200	200	200	2	2	2
Fmk/unit	7.33	.025	.005	.010	.04	.04	.02
Fmk/ha[h]	15	50	10	20	80	20	40

	Container	2-0	1-1
Transportation	145	45	75
Overheads and supervision - 50% of wages	403	533	553
Total cost/ha (Fmk)	2030	2160	2530

[a] Brushsaw
[b] D6 Caterpillar and Marttiini plow
[c] FH 408 paperpot, planted with Pottiputki
[d] Planted with mattock
[e] 1 Fmk = US $0.21
[f] By truck
[g] By forest tractor
[h] These costs assume a total regeneration area of 100 ha.

sowing and bare-root planting. It was argued that, if production were rationalized, container-grown stock would become cheaper and more reliable than bare-root. Only later were other arguments added, such as the possibility of a longer planting season and the need for a smaller labor force with container-grown stock. Gradually, the need to create an integrated container system was recognized. Most successful was that developed by Lannen Tehtaat Dy, based on the Japanese paperpot; it eventually became the most widely used container system in Finland.

Container-grown seedlings gave good biological results in small-scale tests (e.g., Huuri 1965). However, many problems were encountered when it was first introduced on a large scale, both at the production stage and after outplanting (Kaila and Rasanen 1974, Metsämuuronen et al. 1978). Not all nurseries knew how to grow and handle containerized stock. Watering and hardening-off before outplanting were often neglected, and insufficient attention was paid to site selection. On private lands, there was hardly any mechanical site preparation. Because of the difficulties encountered and the poor results --the average failure rate was as high as 25-30%--interest in container-grown stock declined among private forest owners. Nevertheless, in state and company reforestation programs about 70% of all planting stock used is container-grown.

Inventories were conducted in Finland in 1973 and 1979 to determine the condition of stock at time of planting and the manner in which it had been grown (Kaila and Rasanen 1974, Rasanen and Kokkonen 1980). The 1973 inventory revealed that the quality of seedlings varied, growing methods were not properly established, and overall regeneration planning was often inadequate. The 1979 inventory noted a great deal of improvement, particularly in relation to use of the FH 408 paperpot. There was less variation in seedling height growth, while the number of seedlings per container and the number of empty containers had both decreased. On the other hand, it was surprising how small seedlings were when outplanted in northern Finland. The average height of 92 batches--14.8 million seedlings in all--was only 5.2 cm. The inventory revealed that container production is still being refined in Finland, 15 years after it started. Only in the production of container-grown pine has a routine methodology been established.

In Sweden there was a rapid and large-scale change to container-grown stock in the early 1970s. The changeover was evidently due to economic considerations and the labor savings realized when containerized stock was used. Wage levels in Sweden are higher than in Finland, and there is also a shortage of skilled labor. Swedish forest managers had the courage and the capital to establish large industrial-scale nurseries, even though they had little experience in growing containerized stock. Therefore, the results varied at first in Sweden just as much as in Finland (Hulten and Jansson 1974). However, intensive research and development work has brought about the automated production of container stock on an industrial scale and the introduction of fully integrated systems for handling, packing, storage and transportation.

In Norway, spruce planting predominates, and therefore the Norwegians have been less interested in the paperpot system, which is especially suitable for growing pine seedlings. Since the beginning of the 1970s they have concentrated on developing methods for growing spruce planting stock in the Kopparfors multipot and the modified Nisula roll, and conducting planting experiments. The results have been promising from both a biological and a technical viewpoint, with the result that Norway, too, has changed over to container-grown planting stock very rapidly in the last few years.

The scale of tree seedling production in Denmark is small in comparison with that of other Scandinavian countries. Moreover, many different tree species are used, while the areas involved are small. Norway spruce is the most important species planted, and successful results have been achieved with container-grown seedlings. However, it is felt that extensive economic and biological research are needed before any large-scale change to containerized stock can be made. The most important contributions made by the Danes in the field of containerized stock production are their research into seedling culture, fertilization and watering regimes in greenhouses, and in the building of advanced automated greenhouses.

In Finland, the development of containerized seedling production methods has been strongly influenced by commercial interests. This commercial orientation has had its drawbacks. Some incomplete production systems and methods have been sold without any guarantee of success. Little consideration has been given to biological factors in particular. In what have turned out to be trial-and-error methods, the trial has often been made by the producer, and the error by the customer.

On the whole, though, industrialization and commercialism have definitely proven more beneficial than detrimental to the development of container planting. Commercial projects have had specific goals in view, and the companies involved have been able to benefit from both their own and their customers' experiences, as well as from the work of other research and development agencies. A good example of the need for an interdisciplinary approach has been the development of a planting machine. The development of such a machine has proven to be very difficult, requiring the input of expertise from many fields other than forestry, and more money than is usually spent in forest regeneration research.

DEVELOPMENT PROSPECTS

The use of container-grown stock in Sweden, Norway and Finland is already quite common, and may eventually increase to become the major method of stock production. In Norway it is estimated that 80% of stock produced in 1982 will be containerized. Container-grown stock is in a favorable position in Sweden, since it is well established, and if the need for further capital investment decreases, production costs may even drop below those of bare-root stock. Finland may also need to increase container stock production, although at the moment this is hampered by a lack of capital.

It appears that in the near future production of container-grown stock will increase to some extent, strengthening its position as a regeneration option in the various Scandinavian countries. The most important reason for this likely increase is that labor costs are still rising faster than the cost of machinery and materials (Fig. 1). In addition, it appears that there will be a shortage of labor for forestry purposes, despite unemployment in industry as a whole.

Another key factor likely to influence the continued expansion of container stock production is the development of a suitable planting machine. Intensive work in this area has been carried out in both Sweden and Finland over the past 10 years. Four projects are still under way, three in Sweden and one in Finland. At present all are at the prototype stage and are undergoing large-scale testing. The Finnish prototype, designed by G.A. Serlachius Oy, is fully automatic and designed for operation by one man. This and the Swedish Dorotea prototype appear to be the most promising. Despite difficult site conditions, particularly on the stony moraine soils so common in Finland, it appears that these machines will be able to provide a viable alternative to manual planting over much of the forest area. The main concern at the moment is to improve their mechanical reliability.

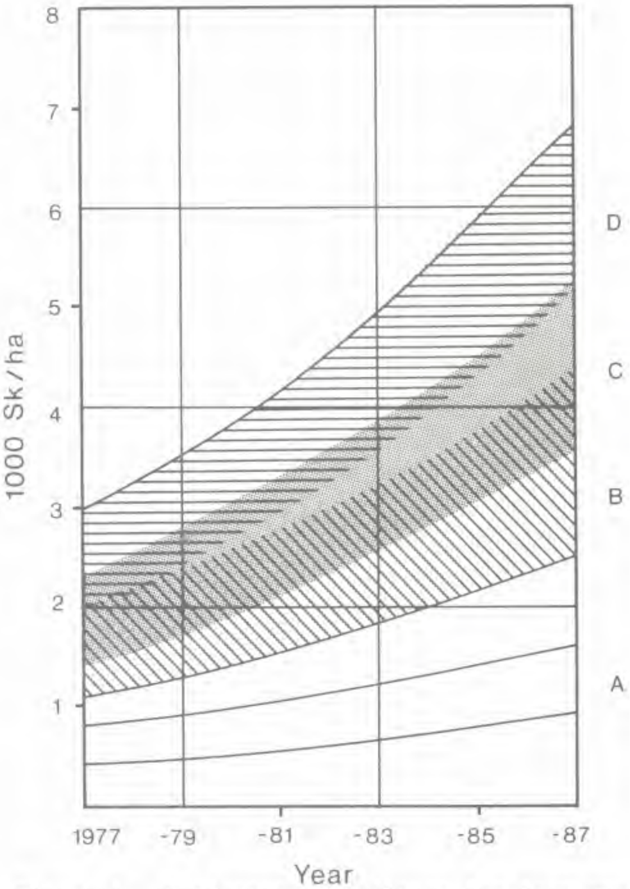


Figure 1. Estimated expenditure for four reforestation methods: (A) mechanical sowing, (B) mechanical planting of container-grown stock, (C) hand planting of container-grown stock, (D) hand planting of bare-root stock. The upper limit shows total expenditure, the lower limit expenditures less cost of seed or seedlings[a].

[a]Source - Bäckström 1977
Basis for calculation:
- area to be regenerated 16 ha
- survival rate: 2500 seedlings/ha one year after planting
- annual inflation rate
  - labor 10%
  - machinery 8%
  - planting stock 6%
- seedling cost 300 Skr/1000
- seed cost 800 Skr/kg

[b]1 Skr = US $0.20

A third problem has to do with improving the overall system of growing, transporting and planting seedlings. There are several container systems that guarantee the production of good seedlings. Nevertheless, it may take decades to weigh the thousands of factors involved in creating an effective, economically viable and integrated container planting system. New containers appear every year--a good sign in itself--but only a few are suited to forming the basis of a competitive system that produces seedlings and grows them through to healthy, free-to-grow stands. The creation of an integrated production, transportation and planting system is made easier when the whole chain is controlled by a single agency. This, of course, places the forestry boards and the large forest-owning trusts in a much better position than the small private owner.

CONTAINER SYSTEMS

In recent years Lannen Tehtaat Oy, in cooperation with its customers, has developed a new filling line on which four or five people can fill 300,000 FH 408 paperpots daily. Twenty of these new filling lines have been sold to date. New container sizes and paper qualities have also been introduced, while the basic handling unit has changed to a European-standard 40 x 60 cm plastic tray with a capacity of 192 FH 408 paperpots. Other new developments include the ribbon cell, and the so-called duracell, which has been laminated with a thin sheet of plastic. The paper and plastic are removed before outplanting. In 1982, the new 'super' filling line will be introduced, with which two or three people will be able to fill and sow 500,000 containers per day.

The Kopparfors multipot and the styroblock containers have also been further improved. A variety of sizes are now in use, and new designs and molds have been developed in an attempt to reduce root spiralling. Just as with the paperpot, these containers have formed the basis for complete systems. These systems are all similar with respect to filling and sowing equipment, the use of air-pruning pallets, and transportation trays.

New container systems already in widespread use are the Enso multipot in Finland (produced, by Enso-Gutzeit Oy, the largest forest owner after the state) and the Norwegian Kombiform (KF) version. Since 1965, Enso-Gutzeit Oy has been developing a system aimed at producing tall, hardened-off Scots pine seedlings without spiralled roots, in which the seedlings are outplanted without the container. They have produced a thin plastic multipot with 40 cavities, 250 cavities/m^2, each cavity having a teardrop cross-section. These are filled on a Lannen filling line, and the 'plug' seedlings are planted with a specially designed Pottiputki. The system has already been exported and further development is under way.

The KF system is based on a styrofoam growing and handling unit which, viewed in cross-section, has partition walls resembling a comb with some of the teeth missing. One unit contains 150 compartments, and a total of 1000 seedlings can be grown per square metre. A larger version is also used in Finland. The KF system can be used for sowing or transplanting, and special equipment has been developed for transporting and planting the containerized seedlings. The system is designed for one-way use.

Many other approaches to 'container' planting are currently under development in Finland and Sweden.

RESEARCH AND DEVELOPMENT

A great deal of biological research related to the production of container-grown stock has been carried out in all four countries. This research has been concerned mainly with improving the survival and growth performance of outplanted container-grown stock through planting experiments or assessments of operational plantings. There have also been numerous studies relating to cultural regimes--seedling nutrition, irrigation and growing schedules. In addition, the advent of containerization has raised a number of specific questions, the most important undoubtedly relating to root development in container-grown seedlings, both in the nursery and after outplanting. At present it appears that there is less root deformation in container-grown than in bare-root stock. However, such deformations may still be considerable, and may occur in 10-15% of all seedlings planted. There is joint Nordic research into this problem.

Considerable resources have already been directed toward improving the quality of container-grown stock. The work forms part of the research concerned with the basic biology of growth. Research into short-day treatments has resulted in the development of techniques, already in use in Sweden and Norway, to improve the overwinter survival of seedlings. However, there is a school of thought that considers container-grown stock to be more variable, in terms of size and physiological quality, than bare-root stock. This is one of the reasons that many countries--Finland in particular--are undertaking research to develop classifications and minimum standards for container-grown stock.

A serious economic disadvantage of many container systems is that empty cavities remain in the growing tray. At first, blank cavities were avoided by sowing several seeds per cavity, but it was often difficult to decide whether to thin or leave multiple seedlings. Nowadays the most common solution is to sow two seeds per cavity, and to thin multiples or fill blanks accordingly. More precise sowing machines are under development, as well as machines for sowing pregerminated seed and one for transplanting small containerized seedlings into blank cavities.

Correct fertilization practices, designed to provide seedling crops with the correct amount of nutrients according to their size and stage of development, can be assured by following the guidelines drawn up by Ingestad. (1974). Most nurseries adopt nutrient regimes based on his work.

The use of containers in the production of planting stock can allow us to exploit the results of tree breeding, and make the most effective use of expensive, high-quality seed. On the other hand, success in the use of container methods depends on use of the best quality seed available. Although Norway spruce has been propagated by rooting cuttings directly into containers, the results have been unsatisfactory. Attempts to grow containerized seedlings propagated by tissue culture are now under way in Norway.

For understandable reasons, container planting research has tended to concentrate upon rather narrow biological questions. The extent of multi-disciplinary research, where biological, technical and economic questions have been considered simultaneously, has been rather meagre. There is a great need for more broadly based studies, which will require further cooperation between the practising nurseryman or forester and the scientist.

CONCLUDING REMARKS

Conditions have been favorable for the development of containerized seedling production methods in Finland, Sweden and Norway. Forestry is important to the economy in each country, there are few tree species to be grown, there are evident benefits to be derived if the efficiency of planting stock production is improved in such a harsh climate, and each country is troubled by high labor costs. All three countries have played a role in the development of seedling production techniques.

Most arguments for the use of container-grown stock are accepted, although the advantages have not turned out to be as great as predicted, either in the nursery or in the field. The use of container-grown seedlings appears to require more careful planning and greater precision than is customary in reforestation. There is still a great deal of room for improvement in the implementation of available technology.

There is also a great deal to be done in developing integrated systems for container stock production. Continuous research is needed to monitor planting stock quality, field performance and the economics of containerization--factors which must always be kept in view in the course of technical development.

The aim in developing container-grown planting stock is to produce cheaper, healthier, faster-growing seedlings, in a more rational yet labor-intensive manner. In these respects, container planting can compete successfully with other methods of reforestation, such as bare-root planting, sowing and natural regeneration.

LITERATURE CITED

Backstrom, P.O.
1977. Rapport fran Skogsbrukets Plantgrupp. [Forest Stock Research Group report on forest work.] Skogsarbeten, 21 p. + appendices.

Fahlroth, S. and Persson, P.
1978. SCAS system for plant produktion och plantering. [The SCA system for nursery stock production and planting.] Arsskrift for Nordiske Skogplanteskoler. 1978:45-73.

Hultén, H. and Jansson, K.-A.
1974. Biologisk uppfoljning av rotade plantor vid praktisk skogsodling

av inventeringar hosten 1973. [Biological follow-up of rooted plants at practical artifical regeneration. Planting year 1972 - Compilations of results from inventories in the autumn of 1973.] Skogshögskolan, Inst. for Skogsforyngring,Res. Notes 56, 42 p.

Huuri, O.
1965. Eraita männyn turveruukkuistutusta koskevia Suomalaisia havaintoja. [Finnish observations on planting pine in peat pots.] [Summary in English] Suo 16(5-6):1-10.

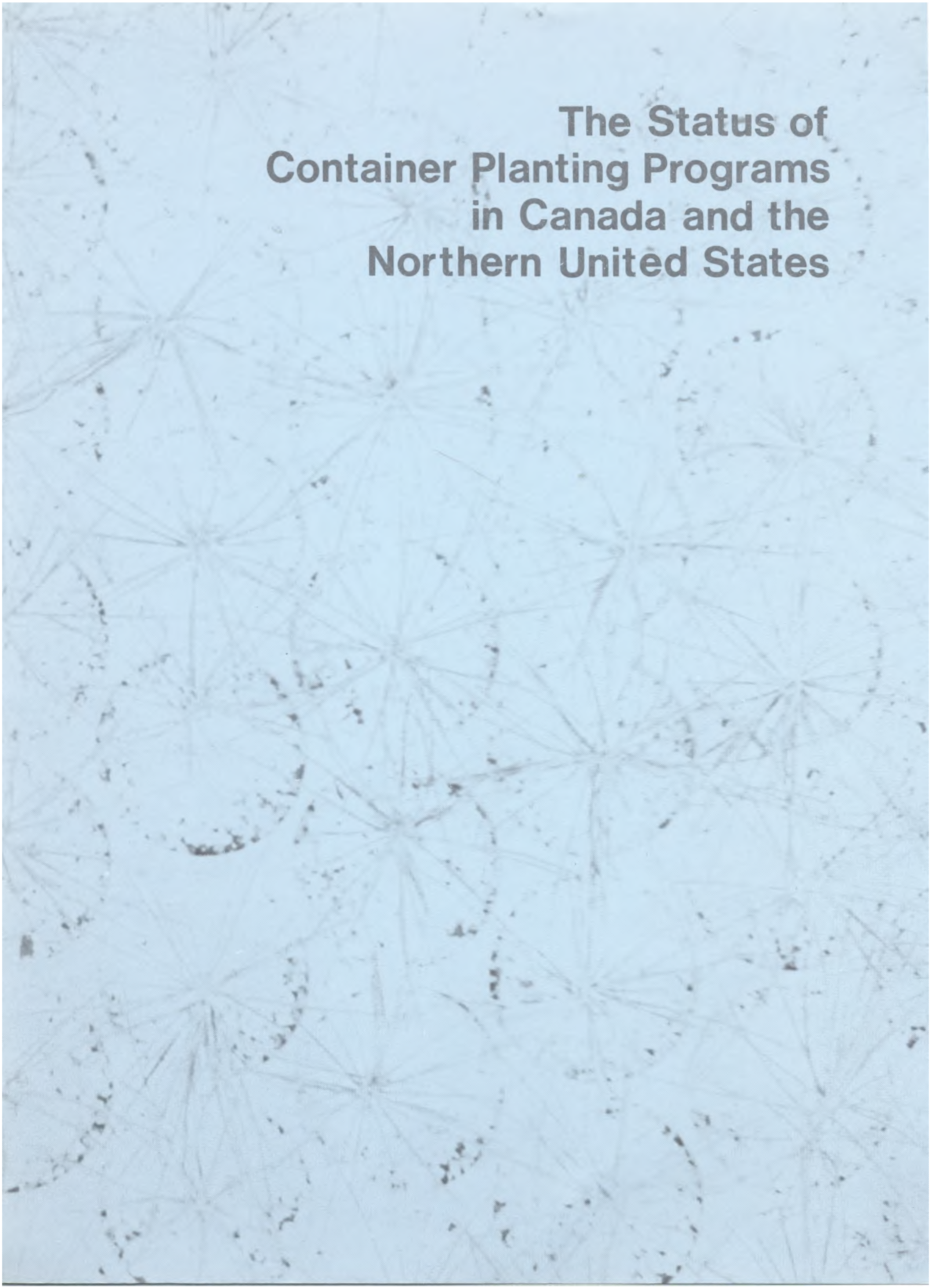
Ingestad, T.
1974. Towards optimum fertilization. Ambio 3:49-54.

Kaila, S. and Rasasne, P.K.
1974. Paakkutaimet ja niiden käyttbluokituksen perusteet. [Container-grown nursery stock and its quality.] Internal report, Natl. Bd. For. 53 p.

Metsämuuronen, M., Kaila, S. and Räsänen, P.K.
1978. Männyn paakkutaimien alkukehitys vuoden 1973 istutuksissa. [First-year planting results with containerized Scots pine seedlings in 1973.] Folia For. 349:2-36.

Räsänen, P.K. and Kokkonen, M.
1980. Männyn paakkutaimet ja niiden luokitus. [Container-grown Scots pine nursery stock and its grading.] Univ. Helsinki, Dep. Silvic. Res. Notes 27:2-102.

The Status of Container Planting Programs in Canada and the Northern United States



THE STATUS OF CONTAINER PLANTING PROGRAMS IN CANADA

1. BRITISH COLUMBIA

C.M. JOHNSON[1]

Abstract.--In British Columbia, the Ministry of Forests operates under a Five-Year Forest and Range Resource Program. This program calls for the production of 97 million plantable seedlings in 1981-1982 and 150 million seedlings by 1985-1986. About 60% of current production (58 million seedlings) is container stock; by 1985-1986 container stock will account for 63% of production (95 million seedlings). Currently, in British Columbia, the major container type used is the BC/CFS styroblock.

Résumé.--En Colombie-Britannique, le Ministère des Forêts a établi un Programme Quinquennal des Ressources Forestières et des Prairies, selon lequel 97 millions de semis plantables seront produits en 1981-1982 et 150 millions d'ici 1985-1986. À l'heure actuelle, a peu pres 60% (58 millions) des semis sont réservés à la culture en mottes emballées et, d'ici 1985-1986, ce chiffre sera porté à 63% (95 millions). En ce moment, le type de récipient le plus utilisé en Colombie-Britannique est le BC/CFS styroblock.

In British Columbia, the Ministry of Forests operates nine nurseries, eight of which have container growing facilities. The total productive capacity is 100 million trees a year, with individual nursery capacity varying from 1 million to 35 million seedlings.

Reforestation in British Columbia began on an operational basis in 1939; 4,000 ha were planted in 1941 and planting was maintained at this level until 1965. Since 1972, the increase in container planting has been quite rapid: 19,651 ha were planted with container-grown stock in 1980 and this figure will increase to 80,000 ha by 1985. At present, 58 million seedlings are container stock, 97% of which are styroplugs; by 1985, the container seedling program will increase to 95 million seedlings.

The first trial of containerized planting, with seedlings grown in milk cartons, was established in British Columbia in 1957. However, it was Jack Walters (1961) who provided a significant impetus to the container seedling program when he published *The planting gun and bullet: a new tree—planting technique.* Between 1961 and 1967, a number of experimental trials were conducted with Walters bullets, bullet plugs, Ontario tubelings, and standard 2-0 bare—root by the Pacific Forest Research Centre (PFRC) of the Canadian Forestry Service and the Research and Silviculture Branches of the British Columbia Ministry of Forests. PFRC also began growing interior Douglas—fir *(Pseudotsuga menziesii* var. *glauca* [Beissm.] Franco), lodgepole pine *(Pinus contorta* Dougl.) and white spruce *(Picea glauca* [Moench] Voss) for field testing in the central interior of British Columbia (Kinghorn 1972). This work is well documented by Bamford (1974). Out of this trial work there emerged an acceptance of the 'plug' concept and a commitment by the Ministry of Forests to the testing of the container planting concept.

In 1967, a liaison 'container committee' was set up with members from PFRC's Liaison and Development Section and the Ministry of Forests' Silviculture Branch. The Silviculture Branch established a cooperative pilot container facility at Koksilah nursery in

---

[1] Director, Silviculture Branch, Ministry of Forests, Victoria, British Columbia.

Duncan, which in 1968 produced 100,000 seedlings grown in 4 1/2 inch (11.25 cm) Walters bullets. The racks of bullets stood in plastic-lined plywood tanks and were watered and fertilized by subirrigation.

In 1969 the capacity of the pilot facility at Koksilah Nursery was doubled to 200,000 bullets and the irrigation system for water and fertilizers was changed to an overhead system of square-pattern sprinklers. The bullets were grown on an asphalt pad under shadecloth (Matthews 1971). Seedlings produced were comparable to those grown in subirrigation tanks.

In 1969-1970, the Liaison and Development Section of PFRC, in cooperation with the Silviculture Branch, designed and started production of the BC/CFS styroblock plugmould-2, and a joint production model styroblock nursery was prepared at Duncan. In 1970, production of container stock at Duncan increased to one million styroblock cavities, plus 200,000 bullets in subirrigation tanks.

By the fall of 1970, growth and survival rates of styroplug-2 seedlings encouraged the Silviculture Branch to begin production of this stock on an operational basis. A new container production facility was started at the Surrey Nursery in the Lower Fraser Valley where 980,000 seedlings were grown in Walters bullets and 6,420,000 in styroblock-2s.

During the 1970s, a number of significant changes have taken place in forestry in British Columbia. The Pearse Royal Commission on Forest Resources (1976) recommended that the private sector be allowed to engage in forest nursery activities. Subsequently, the Forest Policy and Advisory Committee was appointed to study the Royal Commission recommendations and draft a new Forest Act. This new Forest Act was proclaimed in 1978, and provided for the entry of the private sector into the growing of forest seedlings under Sections 88 and 146. In February, 1979, a white paper on the growing of tree seedlings was issued for discussion purposes, and from submissions made in response to the white paper, a 'Policy Statement Regarding Tree Seedlings' and a 'Private Nurseries Financial Policy' were issued in January, 1980.

The Ministry of Forests Act was also proclaimed in 1978. Section 9 of this Act requires that the Ministry of Forests provide the Lieutenant Governor-in-Council with an annually updated five-year program for restocking forest land. This program sets out projected five-year expenditures and goals, and includes nursery operations.

The 1981 to 1986 Five-Year Program calls for 150 million seedlings to be planted by 1985-1986 (Anon. 1981). The Ministry of Forests nursery program will be maintained at 100 million seedlings, of which 50% will be container stock (Anon. 1979, 1980a). To meet this objective, we shall bring on line three new regional container nursery units of 5 million capacity each in the Nelson, Cariboo and Prince Rupert regions. between 1981 and 1986, the challenge is to increase production

Table 1. Present and projected greenhouse area and container seedling production in the province of British Columbia

	Greenhouse Area (m^2)						Container Production	
	1981			1985			1981	1985
	Heated	Unheated	Shadeframe or open compound	Heated	Unheated	Shadeframe or open compound	(000,000)	
Private nurseries[a]	23,435	3,255	7,085	73,230	0.0	5,970	20[b]	45[b]
Ministry nurseries	27,645	3,660	19,815	55,404	3,660	19,815	38	50
Total	51,080	6,915	26,900	128,634	3,660	25,785	58	95

[a] Includes greenhouse area for private land production

[b] Production for Crown land only

of plantable seedlings from private nurseries to 50 million. The private sector will be developing new nursery capacity in all six regions (Anon. 1980b), and at present, 45 million of the total has been scheduled for styroblock production. Projected production and types of production unit for the container program in British Columbia up to 1985 are summarized in Tables 1 and 2.

Table 2. Container production by species and stock type, spring 1981[a]

Species	No. of seedlings sown (000)	Percent of total
Spruce[b]	23,093.3	35.0
Lodgepole pine *(Pinus contorta* Dougl.)	12,984.6	19.7
Douglas-fir	11,746.7	17.8
Western hemlock *(Tsuga heterophylla* [Raf.] Sarg.)	8,237.5	12.5
Sitka spruce *(Picea sitchensis* [Bong.] Carr.)	3,559.0	5.3
Western red cedar *(Thuja plicata* Donn.)	2,826.0	4.3
True fir *(Abies* spp.)	1,871.0	2.8
Larch *(Larix* spp.)	958.4	1.4
Yellow cyprus *(Chamaecyparis nootkatensis* [D. Don.])	269.4	.4
Pine - Misc.	253.1	.4
Mountain hemlock *(Tsuga mertensiana* [Bong.] Carr)	241.0	.4
Total	66,040.0	100.0

[a] Includes about 8 million trees for private land

[b] Includes white and Engelmann spruce *(Picea engelmannii* Parry) and the hybrid of these two species

It is evident from Table 1 that the container program in British Columbia is expanding rapidly. A great many challenges remain to be faced in the implementation of container planting programs. However, there has been wide acceptance of the styroblock system by practising foresters in British Columbia. High survival rates, ease of planting, and good growth performance of seedlings grown with the styroblock system have provided justification for this support. White spruce and lodgepole pine are currently the major components of the production program (Table 2). However, in the period 1975-1979 the Ministry of Forests lost 22 million interior spruce 1-0 bare-root seedlings as a result of frost heaving. Consequently, one of the solutions to this loss is an expansion of the container program for interior spruce.

LITERATURE CITED

Anon.
1979. The growing of tree seedlings. Section 146 of the Forestry Act: A white paper for discussion purposes. B.C. Min. For.

Anon.
1980a. Policy statement regarding the growing of tree seedlings. B.C. Min. For.

Anon.
1980b. Private nurseries financial policy. Ministry Policy Manual, Vo. III. B.C. Min. For.

Anon.
1981. Five-year forest and range resource program. B.C. Min. For.

Bamford, A.H.
1974. Development of the B.C. container program. p. 53-48 in R.W. Tinus, W.I. Stein, and W.E. Balmer *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Kinghorn, J.M.
1972. Container planting program at the Pacific Forest Research Centre. p. 7-9 in Waldron, R.M., *Ed.* Proceedings of a workshop on container planting in Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. DPC-X-2.

Matthews, R.G.
1971. Container seedling production: a provisional manual. Dep. Environ., Can. For. Serv., Victoria, B.C. Inf. Rep. BC-X-58. 57 p.

Pearse, H.P.
1976. Timber rights and forest policy in British Columbia. p. 278-279 in Report of the Royal Commission on Forest Resources, Victoria. Volume I.

Walters, J.
1961. The planting gun and bullet: a new tree-planting technique. For. Chron. 37 (2): 94-95, 107.

THE STATUS OF CONTAINER PLANTING PROGRAMS IN CANADA

2. ALBERTA

S.A. LUCHKOW[1]

Abstract.--Reforestation programs in Alberta have relied heavily upon containerized seedlings in recent years. Current annual production is about 15 million Spencer-Lemaire seedlings. While this reliance on containerized seedlings will continue, the development of a large bare-root nursery capacity is expected to stabilize the demand for containerized seedlings at approximately 22 million per year by 1986. However, increases in harvesting and concomitant reforestation activities may dictate increases in the production of all types of planting stock.

Résumé.--Au cours des dernières années, la production de plants en mottes emballées a constitué une partie très importante des programmes de restauration forestière en Alberta. On produit annuellement environ 15 millions de plants en utilisant le système Spencer-Lemaire. La production de ce type de plants se poursuivra, mais on s'attend à ce qu'elle se stabilise à environ 22 millions d'unités par année d'ici 1986 à cause de la construction d'une grande pépinière pour les plants à racines nues. Cependant, il est possible qu'il faille augmenter la production de matériel de reproduction de toute sorte si une plus grande récolte de bois nécessite une restauration forestière accrue.

INTRODUCTION

The forest region of Alberta encompasses 39 million ha or approximately 60% of the provincial land area. Timber harvesting in Alberta is modest in comparison with that of other parts of Canada. The current annual harvest covers approximately 25,000 ha. At present, only 60% of the annual allowable coniferous cut is allocated. Most of the timber is cut under the authority of Forest Management Agreements (FMAs) and Timber Quotas. The province is committed to sustained yield forest management and reforestation legislation requires that all cutover areas be satisfactorily reforested by the tenth year after harvest. Responsibility for reforestation is shared by government and industry. Long—term holders of FMAs must reforest at their own expense. Quota holders may elect to undertake reforestation or transfer the responsibility to the Crown by paying a levy indexed to the cost of reforestation. Reforestation of all lands harvested prior to 1966, with the exception of FMAs, is the responsibility of the province.

NURSERY FACILITIES

Three forest tree nurseries have been established in the province in an effort to satisfy reforestation policy objectives. One is owned and operated by the provincial government and two by private industry (Table 1).

CONTAINER SELECTION

All three nurseries use the Spencer-Lemaire (Ferdinand) 41 cm^3 container. Selection of this container came about after years of experimentation with various other sys-

---

[1] Forester, Reforestation and Reclamation Branch, Department of Energy and Natural Resources, Edmonton, Alberta.

Table 1. Containerized forest tree seedling nurseries in Alberta, 1981

Nursery	Source of funding	Year seedling production began	Heated greenhouse area (m^2)	Production capacity one crop (000,000)	Annual production capacity (000,000)
Pine Ridge	Government	1977	13,780	10.0	10.0[c]
Simpson Timber	Simpson	1977	613	0.5	1.1
St. Regis	Government[a]	1980[b]	4,858	1.0	4.0

[a] Funded through reimbursement of production costs calculated on the basis of Alberta Forest Service cost experience.
[b] This is a replacement facility. The original facility started production in 1965.
[c] Will be doubled in the near future.

terns. Economics and a decision by the Alberta Forest Service to use container seedlings only on the better sites reinforced this decision. By utilizing containers only on the better sites, a survival rate of 80% after three years is anticipated. Furthermore, growth rates of container seedlings are expected to equal or surpass those of natural seedlings of the same age and species. Bare-root seedlings are still used on sites with difficult conditions for seedling establishment.

The following characteristics of the Spencer-Lemaire (Ferdinand) container system appealed to Alberta nurseries:

1) The container system comprises separate, reusable components.

2) The container protects the seedling from mechanical damage while permitting easy extraction at the planting site.

3) The containers used in the system allow constant monitoring of seedling root development without the possibility of damage.

4) The uniformity and strength of this container makes possible the mechanization of seedling production, transportation, and distribution in the field.

5) The sides of the containers are grooved to prevent the roots from spiralling; a slip-lap seal between cavities prevents root growth into adjacent cavities.

6) The container maximizes the utilization of greenhouse space while providing sufficient growing medium for the size of stock required for Alberta planting projects.

7) The system offers all the advantages of container rearing while allowing easy removal and planting as plugs without the container.

PRODUCTION

The use of containerized seedlings in Alberta has increased steadily during the last 6 years because of a lack of bare-root production over the same period (Table 2).

The decrease in bare-root production was due to the inability of Alberta tree nurseries to produce stock of adequate quality in the quantities required for forestry use. At present the new Pine Ridge Forest Nursery is able to produce 10 million bare-root seedlings per year. By 1984 the production capacity will be increased to 18 million--sufficient to meet demands for bare-root stock for the forseeable future. The planned bare-root production capacity will therefore limit the demand for containerized stock to a probable maximum of 22 million seedlings per year (Table 3). Long-range predictions indicate that production levels for both containerized and bare-root stock are likely to remain relatively stable after 1986. Further increases would be needed only if additional FMA areas were established, thereby dictating the construction of new forest nurseries.

Table 2. Number of tree seedlings planted in Alberta, 1976-1980

Planting activity	Year				
	1976	1977	1978	1979	1980
Containers planted (000,000)	5.58	6.63	8.25	11.26	14.18
Bare-root stock planted (000,000)	0.93	0.22	0.14	——	0.80
Total planted (000,000)	6.51	6.85	8.39	11.26	14.98
Containers as % of total	86	97	98	100	95

Table 3. Projection of number of tree seedlings to be produced in Alberta, 1981-1986

Planting activity	Year					
	1981	1982	1983	1984	1985	1986
Container production (000,000)	15.40	18.00	20.50	21.00	21.00	22.00
Bare-root production (000,000)	7.33	8.17	12.63	13.00	15.00	18.00
Total production (000,000)	22.73	26.17	33.13	34.00	36.00	40.00
Containers as % of total (000,000)	68	69	62	62	58	55

THE STATUS OF CONTAINER PLANTING PROGRAMS IN CANADA

3. SASKATCHEWAN

H.S. PRICE[1]

Abstract.--Containerized seedlings accounted for 11% (2.6 million seedlings) of all planting stock produced for reforestation in Saskatchewan in 1980. It is expected that container stock will eventually increase to about 30% (approximately 8 million seedlings) of total planting stock production. Although the container program is currently based on use of the FH 408 paperpot, future program development will be determined by planting considerations rather than nursery factors.

Résumé--En Saskatchewan, 11% du reboisement s'effectue actuellement au moyen de plants en pots en papier FH 408; on projette de porter cette proportion à 30%. À l'avenir, le système de contenants utilisé tiendra compte des facteurs associés à la plantation plutôt qu'à la culture en pépinière.

INTRODUCTION

Containerized seedlings have been tested in Saskatchewan since the mid-1960s. The benefits of container-grown reforestation stock were recognized in the early 1970s, but it was not until 1977 that adequate container-growing facilities were constructed. Since then, nursery and reforestation personnel have developed a greater appreciation for the container-grown seedling and the flexibility that it offers.

CURRENT PRODUCTION

All reforestation stock used by both government and industry in Saskatchewan is grown by the Department of Tourism and Renewable Resources at one of the four provincial tree nurseries.

The largest nursery in Saskatchewan is in Prince Albert, and was established in the early 1960s to produce stock for highway and park plantings in the southern part of the province. With the opening of the pulp mill in Prince Albert the emphasis at the Prince Albert nursery was shifted to the production of reforestation stock.

Current production capacities at the four Saskatchewan nurseries are summarized in Table 1. The container facilities at the Prince Albert Nursery were constructed in 1977 and consist of two Lord and Burnham glass greenhouses with a total growing area of 1,115 m^2. These have propane unit heaters and evaporative coolers. There is one double-poly greenhouse at the Big River Nursery which has a growing area of 268 m^2 and is heated by two oil furnaces.

Container planting in Saskatchewan is confined mainly to white spruce, which is produced in the FH 408 Japanese paperpot. The FH 308 paperpot has been used with suc-

---

[1] Acting Supervisor, Silviculture Section, Forestry Branch, Department of Tourism and Renewable Resources, Prince Albert, Saskatchewan.

Table 1. Production capacity of Saskatchewan nurseries, 1981

Nursery	Species	Bare-root stock[a] (000,000)	Containerized stock (000,000)
Prince Albert	Jack pine *(Pinus banksiana* Lamb.)	4.0	-
	White spruce *(Picea glauca* [Moench] Voss)	5.3	1.3
Big River	White spruce	4.9	0.3
Other nurseries (2)	Jack pine	2.2	-
		16.4	1.6

[a] Jack pine as 2-0; white spruce as 3-0.

cess at the Prince Albert Nursery, but the FH 408 is preferred. The Big River Nursery is currently growing seedlings in Spencer-Lemaire "Rootrainer" 5s to gain nursery and operational planting experience with this type of container stock.

Under current growing schedules both the Prince Albert and Big River nurseries would normally be able to produce two crops annually. However, only the Prince Albert Nursery was in operation in 1980, when it produced 2.6 million white spruce seedlings in three crops. The third crop was grown in a shade area rather than in the greenhouse; success was limited because of seed losses to birds. In 1981 budget restrictions reduced production to one crop at each nursery, for a total of 1.6 million seedlings.

FUTURE PRODUCTION

It is not anticipated at this time that container production in 1983 will exceed the 1981 level of 1.6 million white spruce seedlings. This situation reflects uncertainty in a number of areas, including the outcome of negotiations with forest management licence holders. The provincial government currently plants 9.3 million of the 12 million seedlings planted annually in Saskatchewan. The proposed level of planting for 1983 is 20 million seedlings, of which it appears that 17 million will be planted by the province and 3 million by industry. Recommendations have been made that the province maintain a production level of 20 million seedlings per annum until such time as negotiations with forest management licence holders have been completed. It is anticipated that one of the results of these negotiations will be the transfer of reforestation responsibilities to industry.

Recent investigations show that Saskatchewan has amassed a backlog of 122,000 ha of unregenerated forest land since 1965. At present, over 15,000 ha of provincial forest are burned over and harvested each year. Thus, an estimated 42 million seedlings per annum would be required to reforest 100% of the current annual cutover and burnover and to reforest the existing backlog within 10 years.

Considerable capital investment would be required to enable Saskatchewan nurseries to produce 42 million seedlings per annum. An estimated 3,500 m^2 of additional greenhouse space would be required at the Big River Nursery and an additional 5,900 m^2 at the Prince Albert Nursery. In addition, one of the smaller nurseries should double its bare-root capacity, and a new nursery consisting of bare-root facilities plus 7,000 m^2 of greenhouse space would have to be established in the eastern part of the province.

It is idealistic, however, to think that Saskatchewan will increase seedling production to the 42 million level. In all probability, reforestation plantings will eventually increase to a maximum of 25-30 million seedlings per annum, of which container stock will likely comprise 30% (in comparison with the present 11%).

As indicated earlier, Saskatchewan nurseries are using the paperpot system. The decision to use paperpots was made early in the 1970s after testing of numerous container systems. Disposability was a major selling point. However, over the years we have investigated other containers as they became available. We will continue to evaluate new systems and re-evaluate old systems to satisfy the demands of both government and industry reforestation programs. The paperpot system has presented a minimum of problems. However, our industrial clients have indicated a preference for the Spencer-Lemaire system. One industrial client is currently testing a number of container types in its research greenhouse and its findings will no doubt have an impact on the future of containerized seedlings in Saskatchewan.

At present, over 90% of the seedlings planted each year by the provincial government are planted under contract. Recent experience has shown that Saskatchewan contractors demand more to plant containerized seedlings than to plant bare-root seedlings. This can be attributed to the increased handling problems associated with the planting of containerized seedlings on our typically wet, inaccessible sites.

In light of the above, the future of containerized seedlings in Saskatchewan is likely to be determined more by field factors than by cultural considerations. Over the years, we have demonstrated, to our own satisfaction, that a healthy plantable seedling can be grown in any type of container. Therefore, the critical factors in evaluating containers for future production will be those associated with planting.

THE STATUS OF CONTAINER PLANTING PROGRAMS IN CANADA

4. MANITOBA

L.G. Yarn'

Abstract.--The Japanese paperpot was selected as the standard container in 1973. The FH 315 paperpot was the preferred container for pine and spruce until 1980, when the FH 408 paperpot was adopted to produce only spruce. Current greenhouse capacity is 875,000 paperpots, grown in two crops. The planting stock production target for 1983 is 1.7 million paperpot and 6.5 million bare-root seedlings.

Résumé.--Au Manitoba, on a commencé à expérimenter les semis de conifères en tubes Ontario en 1969. En 1973, on a opté pour le tube en papier japonais et on a agrandi et modifié les installations de production. Le tube FH 315 est demeuré le récipient préféré pour les semis de pin et d'épinette jusqu'en 1980 lorsque le Manitoba a adopté le tube 408 pour ne produire que des semis d'épinette.

INTRODUCTION

Interest in and development of a containerized seedling program as an important part of Manitoba's reforestation program began in 1969 with the construction of a small corrugated plastic greenhouse at the Pineland Provincial Forest Nursery. That same year field trials were conducted with white spruce *(Picea glauca* [Moench] Voss), Scots pine *(Pinus sylvestris* L.), jack pine *(P. banksiana* Lamb.), and red pine *(P. resinosa* Ait.) grown in the 13 x 75 mm plastic Ontario tube.

A second small greenhouse was built in 1971 and trials were begun with the Japanese paperpot. On the basis of the field performance of paperpot seedlings and ease of handling, it was decided in 1973 to adopt the Japanese paperpot as the standard container for use in Manitoba. Initially, jack pine seedlings were grown in BH 313 paperpots. However, the container was found to disintegrate too fast in the greenhouse, and this led to excessive inter-rooting between cavities and difficulties in separation. Consequently, in 1976, the more durable FH 315 paperpot was adopted for jack pine production.

NURSERY CAPACITY

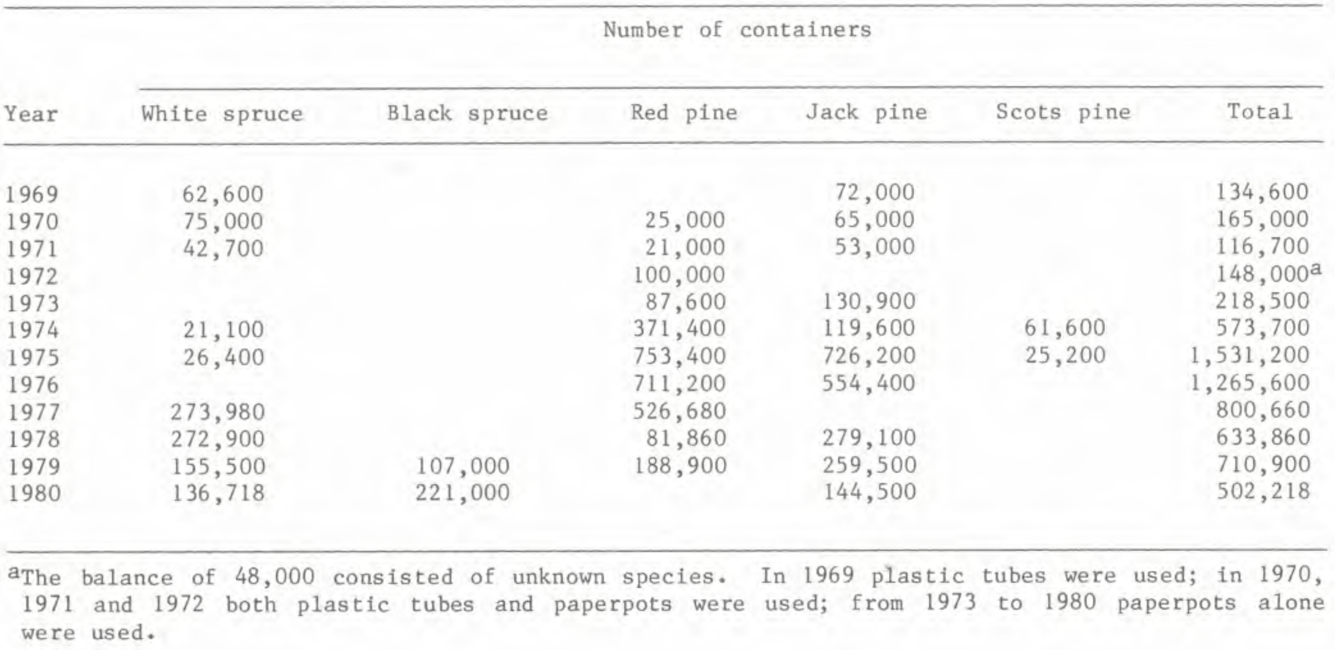
Manitoba has only one nursery, the Pineland Provincial Forest Nursery, located beside the Whitemouth River about 100 km east of Winnipeg on the south side of the Trans-Canada highway. The nursery has a total area of 126.62 ha, of which 29.0 ha, with a total capacity of 23 million seedlings, are used for the production of bare-root planting stock.

The container-growing facilities were expanded in 1973 with the addition of a third greenhouse, 29.3 x 8.3 m, covered with 4.0 oz. (113 g) fibreglass. This greenhouse was constructed to be moveable on rails over a total of four foundation sections. Seeded trays were placed on the ground where germination and early growth took place. The greenhouse was then moved to cover another section where the process was repeated. This was done to avoid the rehandling of trays. However, because of numerous operating problems, this greenhouse was finally made stationary.

---

[1] Silvicultural Forester, Manitoba Department of Natural Resources, Winnipeg, Manitoba.

Table 1. Container production in Manitoba, 1969-1980.



Year	Number of containers					
	White spruce	Black spruce	Red pine	Jack pine	Scots pine	Total
1969	62,600			72,000		134,600
1970	75,000		25,000	65,000		165,000
1971	42,700		21,000	53,000		116,700
1972			100,000			148,000[a]
1973			87,600	130,900		218,500
1974	21,100		371,400	119,600	61,600	573,700
1975	26,400		753,400	726,200	25,200	1,531,200
1976			711,200	554,400		1,265,600
1977	273,980		526,680			800,660
1978	272,900		81,860	279,100		633,860
1979	155,500	107,000	188,900	259,500		710,900
1980	136,718	221,000		144,500		502,218

[a] The balance of 48,000 consisted of unknown species. In 1969 plastic tubes were used; in 1970, 1971 and 1972 both plastic tubes and paperpots were used; from 1973 to 1980 paperpots alone were used.

A fourth greenhouse, 29.3 x 8.3 m, was added in 1975, bringing the total area of heated growing space to 642.1 m^2. With these four greenhouses, the current container production capacity, with two crops annually, is 1.38 million FH 315 or 875,000 FH 408 paperpot seedlings.

CURRENT PROGRAM AND FORECAST

Container production in Manitoba for the period 1969 to 1980 is summarized in Table 1. It will be seen that production has declined in recent years, concurrently with a drop in the level of bare-root production.

In 1973 total nursery stock production at the Pineland Forest Nursery was 4.35 million, of which 4.13 million (95%) were bare-root and 218,500 (5%) were containerized seedlings. Container production reached a peak two years later at 1.53 million seedlings. However, total nursery stock production had declined to 1.22 million trees by 1979, and containerized seedling production, while accounting for 58.4% of the total, amounted to only 710,900 seedlings. This drop in planting stock production has been attributed to a variety of problems as well as to the emphasis placed on scarification for natural regeneration.

Until 1979 all container stock had been produced for government planting. In 1979, under a new Forest Management Licence Agreement with Abitibi-Price Inc., responsibility for forest renewal on its licence area was assigned to the company, with the province providing the seedlings. The company requested FH 408 black spruce paperpot seedlings for planting on its licence area, which was a change from our usual production of FH 315 paperpots.

Planting stock production in 1980 consisted of 1.52 million (75%) bare-root seedlings and 502,218 (25%) paperpot seedlings. These low figures are due to severe drought in the province, which resulted in large quantities of bare-root and containerized stock being carried over until 1981. Of the total paperpot production, 177,400 black spruce seedlings were grown in FH 408 paperpots for the use of Abitibi-Price Inc.

In 1980 approximately 700 ha of bare-root and 400 ha of containerized stock were planted.

Abitibi-Price Inc. has requested 1.1 million paperpot seedlings for the 1981 season and 1.7 million for each year thereafter until 1983, when its new regeneration plan will be submitted to the province. This increased demand has created some immediate problems as the Pineland Forest Nursery has the capacity to produce only 875,000 FH 408 paperpot seedlings. Consequently, because the total production will be going to Abitibi-Price Inc., the remainder of the province must rely on bare-root seedlings.

Current (1981) container stock production therefore amounts to 875,000 FH 408 paperpot black spruce seedlings exclusively for the Abitibi-Price Inc. licence area. It is hoped that with the construction of two more greenhouses an additional 700,000 paperpot seedlings can be produced to meet Abitibi's requirements.

With the increase in greenhouse capacity, planting stock production targets for 1983 are 1.7 million FH 408 paperpot seedlings and 6.5 million bare-root seedlings. This should be sufficient to replant approximately 4,000 to 4,500 ha. The containerized stock will be grown in two crops annually, one of which will be overwintered at the nursery.

It is impossible to predict the extent of our future production as it will depend entirely on the financial support we receive. At present we are dependent on federal/provincial cost-sharing agreements, but no funds are available for Manitoba in 1981.

Our plans are to increase planting activity in northern Manitoba, and our first step will be to establish clonal seed orchards. It is hoped that a nursery will eventually be established in the north as the planting season is approximately three to four weeks behind that of the southern area.

MANAGEMENT CONSIDERATIONS

The container program in Manitoba was originally established to supplement the bare-root program during periods of shortfall. This was soon changed when it was realized that the planting season could be extended with the addition of the container program.

With the development of forest activity away from the traditional southern areas of the province, later springs, weather conditions, and inaccessibility posed problems for the normal bare-root planting program. It was soon recognized that container planting solved many of these problems.

The other major concern was the change in soil type from a light sandy soil to the heavier clays with thin duff or humus layer. When these clay soils are exposed by site preparation, excessive drying and hardening of the clay can lead both to difficulties in the planting of bare-root stock and to increased mortality due to opening of the planting slit.

However, experience shows that we can successfully plant the FH 408 in the duff layer without site preparation, provided that the bottom of the container comes into contact with the clay. This is a very promising technique, although it must be followed with some type of post-planting site treatment to reduce the surrounding competition.

In conclusion, we are satisfied with the paperpot container and the results that it has provided to date. We have used the FH 408 paperpot planted into the duff layer for only one season, and the data are limited; however, the results are promising. White and black spruce seedlings grown in FH 315 paperpots have experienced some frost heaving and poor initial growth when planted on site-prepared clay soils.

Jack pine and red pine, the first species used in FH 315 paperpots, had limited success when planted on dry sandy sites that had been site prepared. There were numerous insect and disease problems, and consequently we now restrict these species almost entirely to bare-root planting.

THE STATUS OF CONTAINER PLANTING PROGRAMS IN CANADA

5. ONTARIO

C .J . Heeney[1]

Abstract.--Containerized planting stock has been used operationally in Ontario for 17 years with varying degrees of success. The program has expanded slowly and now produces 15 million seedlings annually or 18% of all stock planted on Crown lands in the province. Several types of greenhouse and container system are used; among the latter, the Japanese paperpot system is the most common. Six production centres are operated by the province, but future expansion is expected to be mainly in the private sector.

Résumé.--En Ontario, on utilise, depuis 17 ans, des plants en mottes emballées pour la plantation en plein champ, avec des taux de réussite variables. Le programme a lentement pris de l'expansion et produit maintenant 15 millions de semis par année soit 18% des semis plantés dans les terres de la Couronne dans cette province. On utilise de nombreux types de serres et de contenants, dont le plus commun est le pot en papier japonais. Actuellement, six stations de production du Ministère des Richesses Naturelles de l'Ontario fonctionnent, mais on prévoit que toute expansion future se fera principalement dans le secteur privé.

INTRODUCTION

In Ontario the planting of containerized tree seedlings was begun experimentally in the early 1960s with a process developed by McLean (1959). In this process, 1.4 x 7.6 cm white plastic tubes, commonly referred to as "Ontario tubes", were used. Seedlings were grown in temporary plastic greenhouses for 6-12 weeks (MacKinnon 1968, 1970) and were quite small when planted (approx. 5 cm tall). In 1965, despite the lack of field performance data, the tubed seedling was deemed suitable for operational use and a production target of •0 million seedlings was set for 1966 (Reese 1974). In that year 17 million seedlings were planted on Crown lands with highly varied results (MacKinnon 1968, 1970). However, plans for the program called for continued production of 20 million tubed seedlings annually to 1971, with improved production techniques. In reality, the production figures for 1970 and 1971 were much lower, and declined to fewer than 4 million seedlings by the mid-1970s. The program met with little success in most districts and was considered successful only in two (Swastika and Fort Frances). Successes were greatest with jack pine *(Pinus* banksiana Lamb.).

In the early 1970s, dissatisfaction with seedlings grown in the "Ontario tube" and the high cost of plastic led to the development and testing of other container systems. The principal systems now in use are the Japanese paperpot and Spencer-Lemaire "Rootrainers". Production and planting by the Ontario Ministry of Natural Resources (OMNR) over the period 1970-1981 are summarized in Table 1.

MANAGEMENT AND BIOLOGICAL CONSIDERATIONS

The increased proportion of containerized stock planted during the late 1970s was due to several factors related to the biological characteristics of containerized seedlings. Container-grown stock, particularly jack pine, is ideal for extending the

---

[1] Supervisor, Program Development and Control Section, Forest Resources Group, Ontario Ministry of Natural Resources, Toronto.

Table 1. Summary of tree production and planting by OMNR in Ontario[a]

Year ending 31 March	Bare-root stock Produced (000)	Bare-root stock Planted (Ha)	Containerized stock Produced (000)	Containerized stock Produced (%)	Containerized stock Planted (Ha)	Containerized stock Planted (%)
1970	62,623	31,484[b]	5,958	8.7	2,259	14.3
1971	68,183	32,446[b]	4,428	6.1	3,273	9.2
1972	76,597	36,293[b]	5,079	6.2	4,025	10.0
1973	68,161	36,067[c]	2,862	4.0	2,442	6.3
1974	65,362	31,598[c]	3,402	4.9	1,962	5.8
1975	59,794	29,910[c]	3,148	5.0	2,166	6.7
1976	50,945	27,285[c]	5,347	9.5	2,767	9.2
1977	45,981	24,165[c]	4,292	8.5	2,005	7.7
1978	48,292	24,101[c]	5,461	10.2	2,406	9.1
1979	52,928	25,189[c]	5,487	9.4	2,360	8.6
1980	61,453	26,693[c]	7,945	11.4	4,137	13.1
1981	65,360	27,147[c]	10,497	13.8	4,934	15.4

[a] Does not include private sector or forest industry production and planting (see Table 2).
[b] Crown, Agreement and Woodlands Improvement Act plantings.
[c] Crown, Agreement, Woodlands Improvement Act, and other patent land plantings.

planting season after bare-root planting is completed, and can be programmed for planting into midsummer. Containerized seedlings also make the best use of valuable seed and, with precision seeding, can reduce seed requirements to 15-20% of what is required to produce the equivalent amount of bare-root stock. Although, in the past, containerization has been claimed to increase flexibility in seedling production (MacKinnon 1970) this is no longer found to be the case. Rather, we find that, with modern growing facilities, high energy costs and the trend to larger, often overwintered seedlings, flexibility in production is no longer a significant factor. Nevertheless, the amenability of containerized stock to mechanized handling throughout the production/planting cycle can be advantageous in reducing labor costs, depending on the type of container and handling system used.

It is in the planting phase that the real advantage of containerized stock becomes apparent. The increased planter productivity with containerized stock in comparison with bare-root stock, the longer planting season and the better utilization of labor over an extended period are tremendous advantages in any large planting program. On shallow and stony sites an auger or Pottiputki has a distinct advantage over the shovel used to plant conventional bare-root stock. The fact that containerized plants are planted with the container and growing medium protecting the roots is another advantage on shallow, droughty sites. With both jack pine and red pine *(Pious resinosa* Ait.), root deformation at the time of planting can be a serious problem with bare-root stock as the root frequently develops in a single plane established by the shovel cut in the soil. There is much less chance of such root deformation with containerized stock planted with a Pottiputki.

Containerized seedlings produced today are no longer cheap, small plants grown in inexpensive plastic greenhouses. As the production system has become more sophisticated, so the demand for larger and sturdier stock has grown. Containerized planting stock produced today ranges from 500 mg to 1000 mg dry weight, several times heavier than that grown in the past. In general, production and planting prescriptions for jack pine are well established, but techniques for black spruce *(Picea mariana* [Mill.] B.S.P.) are still being refined.

CURRENT SITUATION

Containerized seedlings are grown at five OMNR production centres located in Dryden, Thunder Bay, Swastika, Thessalon and Kemptville, respectively. A sixth centre, at Orono, uses containers primarily for the vegetative propagation of special seedlots and planting stock for the provincial tree improvement program. There are also five private growers of containerized tree seedlings.

At present (1981) the total greenhouse area used for container production is 15,332 m^2, of which 11,936 m^2 (78%) is heated. Approximately 85% of the growing space is owned and operated by OMNR.

Four different container systems are currently used in Ontario. The Dryden nursery has pioneered the development and use of a continuous container production system which employs a cigarette machine modified to produce a 19 mm diameter extruded container of adjustable length. A special paper composed of synthetic and natural fibres is used to form the container. The Thunder Bay nursery uses Spencer-Lemaire "Rootrainers" while, in the same region, Abitibi-Price Inc. is contracting out the production of approximately 1 million jack pine and spruce seedlings in FH 408 paperpots for planting on its freehold lands. OMNR is currently negotiating additional contracts with private growers in the Thunder Bay area to produce paperpot stock for use on Abitibi-Price Inc.'s Forest Management Agreement (FMA) area.

At the Swastika nursery the 19 mm diameter "Ontario tube" was phased out two seasons ago, and the entire program was given over to the production of FH 308 and FH 408 paperpots. Two small contract growers in the Swastika area also use paperpots. The Thessalon nursery uses FH 408 paperpots exclusively. The Kemptville nursery was using paperpots but has switched to Can-Am multipots both for its own (OMNR) production and for use by contract growers. The Orono nursery uses the Leach container for most of its production, as well as some FH 408 paperpots.

Current (1980) and forecast (1983) containerized seedling production (OMNR, forest industry and private sector) is summarized by species in Table 2 and by region in Table 3. Planting programs are summarized in Table 4.

Table 2. Current (1980) and proposed (1983) container production by species[a].

	Seedling production in 1980 (000)							
	Pj[b]	Pw	Sb	Sw	La	C	H	Total
Heated houses	6,162	485	3,117	57	100	591	75	10,587
Unheated houses	3,425	100	440	-	50	-	-	4,015
Total production	9,587	585	3,557	57	150	591	75	14,602
	Proposed production for 1983 (000)							
Heated houses	10,571	1,939	6,048	520	164	851	-	20,093
Unheated houses	4,348	-	400	-	-	-	-	4,748
Total production	14,919	1,939	6,448	520	164	851	-	24,841

[a] Includes OMNR, forest industry and private sector production.

[b] Species abbreviations:
Pj - jack pine
Pw - white pine (*Pinus strobus* L.)
Sb - black spruce
Sw - white spruce (*Picea glauca* [Moench] Voss)
La - Larch (*Larix* spp.)
C - other conifers
H - hardwoods

Table 3. Current (1980) and proposed (1983) container production by administrative region[a]

Region	Greenhouse	1980 production (000)	1983 production (000)
North-western	Heated	2,500	2,000
	Unheated	1,900	1,900
	Total	4,400	3,900
North-central[b]	Heated	1,295	4,290
	Unheated	-	350
	Total	1,295	4,640
Northern	Heated	4,009	6,453
	Unheated	537	797
	Total	4,546	7,250
North-eastern	Heated	1,809	4,971
	Unheated	1,378	1,651
	Total	3,187	6,622
Eastern	Heated	595	2,000
	Unheated	150	-
	Total	745	2,000
Central	Heated	379	379
	Unheated	50	50
	Total	429	429
Ontario total	Heated	10,587	20,093
	Unheated	4,015	4,748
	Total	14,602	24,841

[a] Includes OMNR and private sector production.
[b] Includes production by Abitibi-Price Inc. for planting on its freehold lands.

Table 4. Current (1980) and proposed (1983) planting program by principal species[a]

	Area planted in 1980 (ha)							
	Pj	Pw	Sb	Sw	La	C	H	Total
Containerized stock	3,843	192	780	230	75	202	65	5,387
Bare-root stock	5,376	2,837	7,942	6,522	150	3,508	528	26,843
Total	9,219	3,029	8,722	6,752	205	3,710	593	32,230
	Proposed program for 1983 (ha)							
Containerized stock	6,855	1,070	2,990	269	85	456	25	11,750
Bare-root stock	7,583	3,184	10,272	6,471	157	3,915	504	32,086
Total	14,438	4,254	13,262	6,740	242	4,371	529	43,836

[a] Includes OMNR and forest industry planting.

Most greenhouses in northern Ontario produce two crops of containerized stock per year. A first crop of pine is frequently started in March or April for planting in the current season. A second crop of either pine or spruce is then started in June and is overwintered. The pine is planted in spring, while the spruce is frequently grown on and planted in July. Container stock is usually overwintered outdoors under snow cover; refrigerated storage is rarely used. Both principal species, jack pine and black spruce, may be overwintered outdoors. In 1980 approximately 70% of all containerized stock produced in the province was overwintered.

FUTURE FORECAST

The production of containerized seedlings in Ontario, after an initial flush of activity in the mid-to-late 1960s, levelled off through the 1970s (Table 1). From 1979 to 1981 production has more than doubled, reflecting a trend to increased emphasis on regeneration by both government and industry. This trend is expected to continue, as can be seen from Tables 2 to 4.

Under the new FMAs, agreement holders will be directly responsible for forest regeneration. From the first five agreements signed there are indications of a strong preference for containerized seedlings in planting programs. This preference is reflected in the 1983 production and planting forecasts (Tables 2 to 4).

A factor likely to constrain container production for the next few years is the lack of growing facilities and the lead time required to provide such facilities. For this reason the demand is expected to exceed supply for a number of years.

While OMNR will continue to expand its growing facilities, it is our policy to encourage private greenhouse involvement in the production of containerized forest planting stock. Where the existing private greenhouse capacity is inadequate, 50% capital grants are being used in association with multi-year production contracts to encourage the private sector. In 1980, approximately 15% of the provincial demand for containerized seedlings was supplied by private growers. It is our hope that in the next few years the figure can be increased to over 50%.

LITERATURE CITED

MacKinnon, G.E.
1968. Reforestation in Ontario. For. Chron. 44(1):14-17.

MacKinnon, G.E.
1970. Container planting in Ontario. For. Chron. 46(6):470-472.

McLean, M.M.
1959. Experimental planting of tubed seedlings 1958. Ont. Dep. Lands For., Div. Res., Rep. 39. 13 p. + appendices.

Reese, K.H.
1974. The Ontario tube. p. 211-213 in R.W. Tinus, W.I. Stein, and W.E. Balmer *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

THE STATUS OF CONTAINER PLANTING PROGRAMS IN CANADA

6. QUEBEC

Alain Dancausel

Abstract.--In the past few years Quebec has developed an ambitious reforestation program which aims at supplying high-quality forest products to the forest industry within 40-50 years. This program will involve the planting of some 90 million trees annually on private and Crown lands by 1985. Of this figure, 20 million containerized seedlings will be grown at six nurseries, sufficient to replant 8,000 ha annually. As part of this program the Ministere de l'Energie et des Ressources has developed its own container system.

Résumé--Au cours des dernières années, le Québec a mis en marche un ambitieux programme de restauration forestière visant à fournir à l'industrie forestière, d'ici 40 à 50 ans, des produits de haute qualité. D'ici 1985, on plantera annuellement 90 millions d'arbres sur les terres domaniales et les terres privées. Parmi ceux-ci, il y aura 20 millions de plants en mottes emballées provenant de six pépinières, assez pour replanter une superficie de 8,000 ha chaque année. Pour ce programme, le Ministère de l'Énergie et des Ressources a mis au point son propre système d'emballage.

INTRODUCTION

At the present time, the Ministere de l'Energie et des Ressources de Quebec (MERQ) is responsible for almost all reforestation programs carried out in the province. The forest industry may, however, become more involved in the intensive management of our forests in the near future. Agreements are now being negotiated between representatives of the forest industry and the government of Quebec. Reforestation programs initiated by the forest industry to date have been carried out exclusively on company freehold.

CURRENT REFORESTATION POLICY AND THE ROLE OF CONTAINERIZED TREE SEEDLINGS

In 1979, under a federal-provincial agreement, MERQ instituted a development policy for the pulp and paper industry with a view to improving that industry's competitive position, especially on the North American market. One facet of this policy is intensive forest management, which aims, in the long term, at bringing the forest closer to the mills. This intensive management program will involve the planting of some 90 million seedlings annually on private and Crown lands throughout the province by 1985. Of this total, 20 million seedlings, or more than 20% of total production, will be grown in containers. Current and future reforestation by stock type and organization are summarized in Table 1. (An average planting density of 2,500 seedlings per ha is assumed.)

Under MERQ's own reforestation program, 16,000 ha of private land and 20,000 ha of Crown land will be planted annually by 1985. Forest industry planting will account for a further 2,000 ha in 1985. It should be noted that the entire production of containerized seedlings will be planted on Crown lands.

---

[1] Ing. F., Adjoint au Directeur du Service de la Restauration, Ministère de l'Énergie et des Ressources de Québec, Ste-Foy, Québec.

Table 1. Current and forecast planting program by organization and stock type.

Agency	Stock type	1980 (ha)	1983 (ha)	1985 (ha)
Ministère de l'Énergie et des Ressources de Québec (MERQ)	bare-root	13,200	20,000	28,000
	container	--	3,200	8,000
	total	13,200	23,200	36,000
Canadian International Paper Company (CIP)	bare-root	153	240	40
	container	628	1,435	1,800
	total	781	1,675	1,840
Consolidated-Bathurst Inc. (CB)	bare-root	10	--	--
	container	160	160	160
	total	170	160	160
Grand total	bare-root	13,363	20,240	28,040
	container	788	4,795	9,960
	total	14,151	25,035	38,000

PRODUCTION STATISTICS

Large-scale container production of containerized seedlings is a relatively recent development in Quebec. In fact, in both the public and private sectors, the production of this type of seedling is still in its early stages, as can be seen in Table 2. However, MERQ has been operating an experimental nursery since 1970, while the Consolidated-Bathurst Inc. (CB) and Canadian International Paper Company (CIP) have operated nurseries since 1974 and 1979, respectively.

Table 2. Current and forecast production of containerized seedlings by agency.

Agency	Type of greenhouse	1980	1983	1985
		(000,000)		
MERQ	heated	0.2	8.0	8.0
	partially heated	--	--	12.0
CIP	heated	1.4	3.0	3.0[a]
CB	heated	0.3	0.3	0.3
Total	heated	1.9	11.3	11.3
	partially heated	--	--	12.0

[a] Includes 500,000 seedlings to be produced at Dalhousie, N.B. and planted in Quebec.

It is clear that MERQ's production of containerized seedlings will be increased considerably by 1985. Unless other factors intervene, production in that year will account for 90% of all containerized planting stock produced in Quebec. Seedlings will be grown either by MERQ itself or by private nurseries under contract. To reduce production costs MERQ is studying the feasibility of growing more than 50% (12 million) of these seedlings entirely outdoors on a 2-year production cycle.

CIP estimates that it will double its production by 1983 to meet its own needs, while CB will maintain its production at the present level.

At present, four nurseries are producing containerized seedlings in Quebec. Two of these, with a combined growing area of 9,988 m^2, began production of planting stock for MERQ use in January 1981. One, operated by MERQ at East Angus in the Eastern Townships, has an annual production capacity of 3 million seedlings. Both nurseries are scheduled to produce two crops annually.

The other two nurseries are operated by CIP and CB, and have growing areas of 1,060 m^2 and 23 m^2, respectively. CIP grows three crops annually for a total of 1.4 million seedlings, while CB grows only two crops per year (300,000 seedlings).

CONTAINER TYPES AND SPECIES

Four container types are being used in Quebec this year. At East Angus, MERQ is using a paper container produced by a completely automated filling and sowing machine. All operations are carried out by the machine, from mixing of peat to packaging of filled containers. The machine produces approximately 10,000 filled cavities per hour. The container produces a growth environment which compares favorably with that of other containers on the market. The volume of the container is approximately 115 cm^3. This machine was developed by the Centre de Recherche Industrielle de Quebec (CRIQ) at MERQ's request. CRIQ undertook the development work in 1975 and completed it in 1980. The container now used is made of ordinary paper covered by a thin internal layer of polyethylene. This paper must be removed when the seedling is planted. Research is under way at the pulp and paper research centre of the University of Quebec at Trois Rivieres to develop a biodegradable paper. CRIQ also hopes to develop, in the next few months, a system of vertical ribs inside the container to minimize root development problems.

MERQ decided to develop a paper container in 1974, since it was extremely difficult to obtain sufficient Japanese paperpots at that time, and problems were anticipated with breakdown of the paper in the soil. Another problem was the constantly increasing cost of containers made from oil-based products. Moreover, more seedlings can be grown per square metre of greenhouse space when paper containers are used rather than styroblock containers, transportation costs for the seedlings are lower, and it is possible to eliminate some handling upon delivery.

The first crop of 3 million jack pine *(Pinus banksiana* Lamb.) seedlings was planted in June, 1981. Next year we plan to produce black spruce *(Picea mariana* [Mill.] B.S.P.) in the MERQ container. Within the next two or three years, we hope to acquire considerable expertise in operational techniques with this container system.

Since our system is still in its early stages, we have had to use other types of container for the growing contract signed with a private company in 1980. The styroblock was chosen for this contract, mainly because it is available in various sizes. We have used styroblock-8s for black spruce and we plan to use styroblock-4s for jack pine.

A more durable container, such as the Can-Am multipot, would have been preferred had it been available in 1980 in a size equivalent to that of the styroblock-8. The larger multipot may well be used in the future. However, these containers will be used on a temporary basis, since over the long term all our container production will be carried out with our own system.

CIP currently uses the styroblock and Can-Am multipots; the latter is sturdier and more resistant to handling damage. CIP uses styroblock-4s for species produced during winter and styroblock-2As for species produced during summer. Jack pine (85%) and black spruce (10%) are the main species produced by CIP.

CB has used the FH 408 paperpot since 1974 and sees no major reason for changing. Survival rates are said to be greater than 85%; seedling growth is good and the cost is acceptable. Moreover, CB feels that transportation, handling and planting of the seedlings are easier with the paperpot system than with the other systems. The main species produced by CB are black spruce (50%), jack pine (40%) and European larch *(Larix decidua [Mill.])* (10%).

MANAGEMENT OBJECTIVES

There are many reasons for the increased use of containerized tree seedlings in reforestation programs in Quebec, and these vary according to the agency involved.

MERQ intends to use all of its container production, or 20 million seedlings, on Crown land. Seventy percent of its reforestation program on these Crown lands is concentrated in three administrative regions, and containerized seedlings will be used mainly to extend the planting season in these regions, and thereby provide more flexibility in its reforestation operations. Bare-root stock generally must be planted between 15 May and 15 June for the best results. The use of containerized seedlings will permit MERQ to extend this period by about one month, depending on weather conditions during the planting season in the regions concerned.

MERQ's other objectives in using containerized seedlings are as follows:

1) to reduce manpower requirements and planting costs (With containerized seedlings a planter can almost double his productivity over that with bare-root stock.)

2) to improve planter motivation (Since the use of containerized seedlings

makes it possible to extend the planting season, it is much easier to motivate and educate workers so that quality work is obtained in the planting of the two types of seedlings.)

3) to develop automated systems, since the size of the container is standard and the root system is protected.

The objectives of forest products companies are almost identical to those of MERQ. Moreover, it is felt that the use of containerized seedlings will make it possible to extend the production period to nine months and monitor the growth of seedlings better. It will also simplify the task of supervising workers during the planting operation.

GENERAL COMMENTS

Containerized tree seedlings are becoming more and more popular in North America, especially in Canada and the northern United States. It seems clear that this type of seedling will create many opportunities for the development of new production and planting techniques. However, on the basis of our present knowledge, we believe that bare-root stock is still very useful in reforestation programs. Each type of seedling has advantages and disadvantages, and the best system, in our opinion, involves a judicious use of both types. In its policy, MERQ emphasizes reforestation of the best sites. Both seedling types must therefore be used, depending upon land conditions in the areas to be reforested, so that our final objective, to supply the required amount of wood within the time allowed, may be achieved.

As a result of various tests conducted by MERQ over the past several years we feel that a containerized seedling, regardless of container type, must meet minimum quality criteria, including those concerned with morphological characteristics of the seedlings. We are currently specifying a shoot height of at least 15 cm, a root-collar diameter of 2.5 mm for jack pine and 3.0 mm for spruce, with a dry weight shoot:root ratio of less than 3.0. Although production costs for a seedling of this size are high, we believe that the extra investment required (over that for a smaller seedling) will be amply compensated by an increased survival and growth rate. The containerized tree seedling is, however, smaller than the bare-root seedling and it should therefore be used only on sites where the competition from grass or shrubs is less severe.

It should not be forgotten that large investments are required for the reforestation of cutover land. There are several stages in this operation which must be attended to, from the production of seedlings to the maintenance of reforested areas. Each of these stages is a link in a chain which is no stronger than its weakest link. At the present time, MERQ's reforestation program emphasizes quality in all its operational stages, so that a maximum amount of wood may be produced in a minimum of time.

CONCLUSION

Quebec has, over the past few years, developed an ambitious reforestation program which aims at supplying high-quality forest resources to the forest industry in 40 or 50 years. In the area of container production, we have chosen to develop our own system for the reasons outlined above. In view of the knowledge we have of containerized seedling production at the present time, MERQ has made a prudent compromise with respect to the type of seedling production it will use. Within the next few years we should be able to acquire considerable expertise in the area of containerized tree seedlings and we will be in a position to re-evaluate the situation in the light of this increased knowledge.

ACKNOWLEDGMENTS

The author would like to thank M. Gilbert Paine and Mr. John Conway for providing information and statistics on Canadian International Paper Company and Consolidated-Bathurst Inc., respectively.

THE STATUS OF CONTAINER PLANTING PROGRAMS IN CANADA

7. NEW BRUNSWICK

M.K. Barteaux and N.H. Kreibergl

Abstract.--The use of containerized seedlings is increasing rapidly in New Brunswick. Total production by forest industry and the province is expected to increase from 33 million seedlings in 1980 to 45.7 million by 1983. Of the 1983 production target, 55% (25 million seedlings) will be grown at three provincially operated nurseries.

Résumé.--L'utilisation des semis en mottes emballées se répand rapidement au Nouveau-Brunswick. On s'attend à ce que, d'ici 1983, la production totale de ce type de semis par l'industrie forestière et par la province passera de 33 millions qu'elle etait en 1980 à 45.7 millions. De ce chiffre, 55% (25 millions de semis) seront cultivés dans trois pépinières exploitées par la province.

INTRODUCTION

In relation to population, New Brunswick has the most intensive reforestation program of all Canadian provinces. This is an expression of the province's dependence on its widespread, fully utilized forest cover. The total forest area of 6.3 million ha is almost evenly divided between public and private ownership. The private freehold is again divided between large holdings (44%) and woodlots of less than 4,000 ha (56%).

Substantial financial support under the Forestry Sub-Agreement between the federal and provincial governments has enabled the province to establish and expand its reforestation system rapidly. By 1981 production had reached 30 million seedlings. The larger private freeholders have now achieved an annual planting rate of well in excess of 20 million seedlings and appear to be still expanding.

Because of the rapid program expansion, reforestation in New Brunswick has by no means settled into a fixed pattern. While the majority of the 50 million seedlings are outplanted by hand, the species mix and the type of planting stock are constantly changing as our experience grows.

As an illustration of the diversity of approach it is noteworthy that the private company most prominent in reforestation relies, at present, largely on bare-root planting stock, while other large private freehold operators use only various types of containerized stock. The province itself is moving from two-thirds containerized stock to total dependence on this type of stock on Crown lands.

In view of the rapidly changing situation, it is impossible to make long-term forecasts for the various reforestation programs in New Brunswick. However, it may safely be predicted that the magnitude of reforestation by planting will not likely be reduced in the next decade, and that the proportion of container planting stock to bare-root stock will likely continue to increase.

---

[1] Manager of Reforestation and Silviculture, and Superintendent of Nurseries, respectively, New Brunswick Department of Natural Resources, Fredericton, New Brunswick.

BIOLOGICAL AND MANAGEMENT CONSIDERATIONS

Each agency must be assumed to have a particular rationale for its containerized seedling production program. This rationale is not generally publicized or even enunciated in any definitive way. Consequently, the comments that follow represent the current views of the staff of the Forest Management Branch.

We have now used FH 408 paperpots for more than 10 years. Over this period we have tested many other containers (styroblocks, Kys-cubes, multipots, Finnpots, Spencer-Lemaire "Rootrainers" and several others) without ever seriously being tempted to abandon paperpots. In the nurseries we consider paperpots inexpensive and easy to handle, at all stages in the production sequence, from filling and seeding, watering, handling and overwintering to final transportation to the planting sites. Because of a fairly tightly scheduled program for growing, hardening and outplanting we have minimal problems with root intergrowth between containers. Our occasional examinations of root development in young plantations convince us that paperpot seedlings have as good root development as our bare-root seedlings.

Those concerned with reforestation are intuitively anxious about root form, above all because roots invariably lack the obvious, tidy symmetry of the upper parts of softwood seedlings. A related concern is whether the initial root system enables a given species to adapt to the soil of a given planting spot. A recent examination of the roots of outplanted container stock in young black spruce (*Picea mariana* [Mill.] B.S.P.) and jack pine (*Pinus banksiana* Lamb.) plantations indicates that seedlings started in paperpots are rather better rooted than bare-root seedlings. The more obvious deformations of roots of container-grown stock would appear to be attributable to unfavorable site conditions and faulty planting practices (shallow planting, excessive heeling-in). No final conclusion can be reached on the significance of root deformations in container-grown seedlings until we see the evidence from fully established plantations.

Program Objectives

The current reforestation rate of 30 million seedlings annually on Crown lands in New Brunswick is equated with industrial demand for wood and is designed to keep the most productive and most accessible portions of the annual cut-over area in full production. The forests of New Brunswick are fully utilized; there are no reserve areas to fall back on. Productivity per ha is low, while the consistency and the quality of the trees now being cut is often unsatisfactory. In conjunction with its reforestation program, the province is pursuing a sensible tree improvement program, the results of which are to be immediately incorporated into operational reforestation work.

A planting program based exclusively on the use of containerized seedlings will permit a long planting season, thereby providing steady work for experienced planters who will require minimal supervision.

For the time being, the provincial reforestation program encompasses only native species of softwood. Exotic species will be tested on a very limited experimental basis.

PRODUCTION

The area of greenhouse space available for containerized seedling production is summarized for forest industry and provincially operated nurseries in Table 1. Current (1980) and forecast (1983) seedling production figures are presented in Table 2, and planting programs in Table 3.

Table 1. Greenhouse areas available for containerized seedling production in New Brunswick, 1980.

Agency	No. of nurseries	Total growing area (m^2) Heated	Unheated
Forest industry			
Fraser[a]	1	-	3,600
Irving[b]	2	2,000	3,200
Geo. Pac.[c]	1	270	-
N.B.I.P.[d]	1	850	-
Valley F.P.[e]	1	300	-
Total	6	3,420	6,800
N.B. Natural Resources	3	17,000	6,000
Total, all agencies	9	20,420	12,800

[a] Fraser Companies Ltd., Edmundston, N.B.
[b] J.D. Irving Ltd., Juniper and Sussex, N.B.
[c] Georgia-Pacific Ltd., St. Stephen, N.B.
[d] New Brunswick International Paper Co., Dalhousie, N.B.
[e] Valley Forest Products, Ste. Anne de Nackawic, N.B.

Table 2. Current (1980) and forecast (1983) containerized seedling production in New Brunswick.

Agency	Production 1980		Production 1983		Container system(s) used[a]	Estimated current production by species[b] (%)					
	Heated (000,000)	Unheated (000,000)	Heated (000,000)	Unheated (000,000)		Sb	Sw	Sr	Pj	Pr	L
Forest industry											
Fraser	-	6.4	-	10.0	MP	80	20	-	-	-	-
Irving	3.0	-	7.0	-	SB/MP/PP	7	3	-	80	-	10
Geo. Pac.	1.2	-	1.2	-	SB	20	-	-	25	50	5
N.B.I.P.	2.0	-	2.0	-	SB/MP	70	-	10	10	-	-
Valley F.P.	0.1	-	0.5	-	PP/MP	50	-	-	-	-	50
Total	6.3	6.4	10.7	10.0							
N.B. Natural Resources	20.3	-	20.0	5.0	PP/MP	45	10	-	40	-	5
Total, all agencies	26.6	6.4	30.7	15.0		48.0[c]	10.5[c]	0.8[c]	34.3[c]	1.4[c]	5.0[c]

[a] Container system abbreviations: MP - multipot
SB - styroblock
PP - paperpot

[b] Species abbreviations: Sb - Black spruce
Sw - White spruce (*Picea glauca* [Moench] Voss)
Sr - Red spruce (*Picea rubens* Sarg.)
Pj - Jack pine
Pr - Red pine (*Pinus resinosa* Ait.)
L - Eastern larch (*Larix laricina* [Du Roi] K. Koch)

[c] Weighted means

The provincially operated nurseries grow two closely scheduled crops of FH 408 paperpot seedlings annually in heated greenhouses. A winter crop of spruce (mainly black spruce) is grown indoors for 21-24 weeks before being shipped in spring after a few weeks of hardening-off. This is followed by a summer crop of jack pine (with some eastern larch) grown for 12-14 weeks for shipping in late summer. Both crops are shipped in prime condition and are not held long enough to allow the roots to become intertwined or active seedling roots to grow outside the paperpot.

The province will expand its production of containerized seedlings from 20 to 25 million by 1983 (Table 2) and to 30 million by 1984. The additional seedlings will be raised in unheated greenhouses. We recognize that such seedlings will require a longer growing period to reach an acceptable size--probably 1 1/2 growing seasons--and that the paperpot may consequently not be suitable. For this reason, we plan to use a solid-walled container to grow plug seedlings with a rooting volume of at least 100 cm^3 and not more than 10 cm deep. Our insistence on a rather shallow container is based on the fact that the main species planted become established and prosper in the uppermost few centimetres of the forest floor. This venture into the use of unheated greenhouses reflects our growing concern over heating costs, which last winter (1980-1981) were in the order of $26 per thousand seedlings.

Table 3. Current (1980) and forecast (1983) planting of containerized and bare-root planting stock in New Brunswick.

Agency	Planting 1980 Containers (ha)	Planting 1980 Bare-root (ha)	Planting 1983 Containers (ha)	Planting 1983 Bare-root (ha)
Forest industry				
Fraser	3,500	-	6,500	-
Irving	1,400	5,400	3,300	4,100
Geo. Pac.	600	-	600	-
N.B.I.P.	1,000	-	900	-
Valley F.P.	47	12	235	-
Total	6,547	5,412	11,535	4,100
N.B. Natural Resources	7,055	4,485[a]	10,980[b]	2,665[c]
Total, all agencies	13,602	9,897	22,515	6,765

[a] Includes 683 ha planted on small private freehold lands
[b] Includes 380 ha planted on small private freehold lands
[c] Includes 525 ha planted on small private freehold lands

THE STATUS OF CONTAINER PLANTING PROGRAMS IN CANADA

8. NOVA SCOTIA

R.E. Bailey[1]

Abstract.--Nova Scotia is rapidly expanding its planting program to increase productivity and offset wood shortages caused by spruce budworm. Production of nursery stock will increase from 14 million seedlings in 1981 to 28 million by 1984. Over 70% of the planting stock produced in 1984 will be container grown, primarily in heated greenhouses.

Résumé--La Nouvelle-Écosse se hâte d'élargir son programme de plantation pour augmenter sa production de plants et compenser la pénurie de bois causée par les ravages de la tordeuse des bourgeons de l'épinette. La production de plants en pépinières, qui était de 14 millions en 1981, atteindra 28 millions d'ici 1984, et, cette même année, plus de 70% du matériel sera produit en mottes emballées, surtout dans des serres chauffées.

INTRODUCTION

In Nova Scotia, planting of nursery stock is increasing at a rapid rate. In the 1970s total production of bare-root and container-grown seedlings was less than 5 million per year. In 1981 approximately 14 million seedlings were produced and planted (Table 1). In 1982 production is expected to be 16 million seedlings and, by 1984, total production will reach 28 million. This will be sufficient to reforest 9,300 ha per year, or one-third of the total area of softwoods cut each year in Nova Scotia. Surveys indicate that the remaining two-thirds will regenerate naturally.

Of the 1984 target of 28 million seedlings, 30% will be produced by the forest industry and the remaining 70% by provincial nurseries. Of the stock produced, 85% will be red spruce *(Picea rubens* Sarg.), black spruce (*P. mariana* [Mill.] B.S.P.), white spruce *(P. glauca* [Moench] Voss) and Norway spruce *(P. abies* [L.] Karst); the remaining 15% will be red pine *(Pinus resinosa* Ait.), white pine (*P. strobus* L.), jack pine (*P. banksiana* Lamb.) and larch *(Larix* spp.).

CONTAINER PRODUCTION

It will be seen (Table 1) that the ratio of containerized to bare-root stock will increase from the present 50% to 70% by 1984. With the exception of approximately 2 million seedlings grown in Nisula Rolls, all container-grown stock is produced, and will be for the forseeable future, in the relatively new 65 cm^3 67-cavity Can-Am multipot container. The seedlings produced in these containers will be grown for two seasons prior to outplanting, the first season in the greenhouse and the second in an outside holding area. Seedlings produced in this fashion are well rooted, sturdy and roughly 20 cm tall.

MANAGEMENT CONSIDERATIONS

The rapid expansion in nursery stock production and planting is largely an outcome of the depredations of the spruce budworm *(Choristoneura fumiferana* [Clem.]) in Nova Scotia and the present and future losses in softwood volumes resulting from its activities. The planned reforestation program, in combination with an intensified spacing and protection program, will eliminate the projected wood deficit and therefore avoid the necessity of cutting back on forest industry harvesting operations. Plantations are ex-

---

[1] Director of Reforestation and Silviculture, Nova Scotia Department of Lands and Forests, Truro, Nova Scotia.

pected to produce approximately 150% more wood per ha annually, on average, than natural stands, and should be harvestable at 30 to 40 years rather than 60 to 80 years of age.

The decision to emphasize the planting of container-grown stock in the reforestation program is based on two factors. First, container-grown seedlings are cheaper and easier to plant than bare-root stock: a 50% advantage in planting productivity is not uncommon. Second, we have found that survival and growth rates of multipot stock are acceptable, provided that:

- they are planted in humus microsites. (If this precaution is taken, susceptibility to frost-heave can be countered.)
- they are adequately protected from browsing and weed competition. (Browsing by rabbits is one of the main factors affecting the survival and growth of planted stock in Nova Scotia. Experience has shown that rabbits can be persuaded not to venture into plantations if herbicides are applied 1 or 2 years after planting to remove all ground cover. With this cover removed, rabbits usually do not browse seedlings at distances greater than 20 m from the plantation edge.)

With respect to site preparation techniques, there are indications that the majority of sites prepared in the future will be recent softwood cutovers. The plan is to prepare these sites immediately after cutting with brush rakes mounted on skidders or bulldozers, or with rolling choppers. Preparation by these scarifiers results in very little disturbance of the LFH soil horizons, and provides the planter with adequate opportunity to select a desirable humus microsite at the required 2 m interval.

Types of scarification equipment and extent of use are summarized in Table 1.

Table 1. Forest nursery and site preparation statistics.

		Greenhouse area		Planting stock production						Site preparation equipment[a,b]	
				Bare-root		Container		Nisula			
Agency	Nursery	Heated	Unheated	1981	1984	1981	1984	1981	1984	1981	1984
		(m^2)		(000,000 seedlings)							
Industry											
NSFI[c]	Bras d'Or	-	-	-	-	-	-	-	-	2(50)	2(70)
	St. Andrews	-	4,640	-	-	2.8	3.5	-	-	3(50)	3(30)
Bowater[d]	Liverpool	278	278	-	-	0.4	0.6	-	-	-	2(?)
Scott[e]	Springhill	1,712	1,784	-	-	1.9	2.0	0.7	2.0	1(35)	1(<35)
										2(55)	2(>55)
										4(10)	4(?)
Subtotal		1,990	6,702	-	-	5.1	6.1	0.7	2.0		
Government											
	Lawrencetown	618	-	6.5	6.0	0.2[f]	1.8	-	-	1(38)	1(20)
										2(14)	2(40)
	Wittenburg	2,763	1,056	-	-	1.2	5.0	-	-	3(3)	3(30)
										4(3)	4(+)
	Strathlorne	4,350	-	0.5	2.0	-	5.0	-	-	6(29)	6(5)
										7(13)	7(5)
Subtotal		7,331	1,056	7.0	8.0	1.4	11.8	-	-		
Grand total		9,721	7,758	7.0	8.0	6.5	17.9	0.7	2.0		

[a] 1. Disks, 2. Brush rakes (D6, 7 and 8 with regular root rake blades) (C & H root rake mounted on a skidder), 3. Rollers, 4. Shark Fins, 5. Disk trenchers, 6. Finnish plow, 7. C & H plow

[b] Numbers within parentheses represent the percentage of the total area planted or prepared by the indicated piece of equipment

[c] Nova Scotia Forest Industries Ltd.

[d] Bowater Mersey Paper Co. Ltd.

[e] Scott Paper International Inc.

[f] Vegetative propagation experiment (produced but not planted)

THE STATUS OF CONTAINER PLANTING PROGRAMS IN CANADA

9. PRINCE EDWARD ISLAND

Glen Kelly[1]

Abstract.--A program of forest industry revitalization is under way on Prince Edward Island. An expansion of seedling production facilities began in 1978; the present producton capacity is 8 million containerized and bare-root seedlings per annum. Major species for reforestation are black spruce *(Picea mariana* [Mill.] B.S.P.), eastern larch *(Larix laricina [Du* Roil K. Koch) and red pine *(Pinus resinosa* Ait.).

Résumé.--Un programme de revitalisation de l'industrie forestière est en cours dans l'Île-du-Prince-Édouard. En 1978, on a entrepris d'agrandir les installations de production de semis, dont la capacité actuelle de production se chiffre à 8 millions de plants en mottes emballées et à racines nues par an. Les principales essences utilisées pour le reboisement sont l'épinette noire *(Picea mariana* [Mill.] B.S.P.), le mélèze laricin *(Larix laricina* [Du Roi] K. Koch) et le pin rouge *(Pinus resinosa* Ait.).

INTRODUCTION

The forests of Prince Edward Island were heavily depleted between 1720 and 1920 to clear land for agriculture and to provide lumber for shipbuilding. Unfortunately, past generations neglected to consider the consequences of over-utilization and deliberately high-graded the indigenous forest. Regeneration from inferior seed sources and continuous removal of high-quality material have combined to reduce much of the remaining forest area of 240,000 ha to stands of low commercial value.

Little was done to improve this situation until 1951, when a provincial forest service was established. From 1951 to 1978 the forest service carried out a small but effective reforestation program.

In 1978, a team of forest geneticists led by Dr. Bruce Zobel recommended an immediate expansion of seedling production facilities and concentration on three major species: black spruce (Picea mariana [Mill.] B.S.P.), eastern larch *(Larix laricina* [Du Roil K. Koch) and red pine *(Pinus resinosa* Ait.).

The fact that forest land in Prince Edward Island is 90% privately owned, and is distributed among 30,000 owners, requires that careful thought be given to seedling production systems, species selection, and planting stock specifications. On the basis of past demand for seedlings and the success of a forest management incentives program for woodlot owners begun in 1980, the Forestry Branch forecasts a steady increase in the demand for reforestation.

CONTAINER PRODUCTION

Production Statistics

The Forestry Branch of the Prince Edward Island Department of Agriculture and Forestry is the province's sole producer of containerized tree seedlings. The main production facility, located near Charlottetown, comprises two gutter-connected, steam-heated, double-poly greenhouses designed for year-round use, with a growing area of 3,700 m^2 (Fig. 1) and a growing capacity of 6 million trees. This nursery also produces 2 million bare-root seedlings annually on 45 ha.

---

[1] Greenhouse Supervisor, Forestry Branch, Department of Agriculture and Forestry, Charlottetown, Prince Edward Island

Figure 1. Production greenhouse complex, provincial forest nursery.

In addition to the above, two freestanding glass houses with a growing area of 340 m^2 plus an outplanting area of 12.5 ha are operated for the tree improvement program.

Our first greenhouse crop was sown in the fall of 1979 and produced 1.1 million black spruce seedlings. Production of containerized seedlings to date amounts to 4.2 million seedlings. It is expected that the demand for planting stock will increase to approximately 6 million seedlings per year by 1985, of which 4 million will be grown in containers.

Since containerized seedling production began in 1979, black spruce has been the major species produced, and has accounted for 74.2% of total production. Other species have been grown in lesser amounts, viz.: jack pine *(Pinus banksiana* Lamb.) (18.1%), white spruce *(Picea glauca* [Moench] Voss) (5.6%), larch *(Larix* spp.) (2.6%) and eastern white cedar *(Thuja occidentalis* L.) (0.5%).

Jack pine is produced in the greenhouse in preference to other species of pine because of its suitability as a summer crop, and the ease with which it can be grown. Though more suited to available planting sites, red pine is not adapted to greenhouse rearing, and is currently outplanted as 3-0 or 2-2 bare-root stock. Black spruce and eastern larch were chosen as major reforestation species because of the characteristics of their wood, their adaptability to various planting sites, their positive response to genetic manipulation, and their relative resistance to insects and disease.

It is expected that over the term of the current five-year plan the area planted annually to each of the three major species will be approximately equal, with the proportion planted to jack pine declining as bare-root red pine becomes available.

Container Systems

Strong public demand for planting stock in the early stages of the reforestation program required the adoption of an appropriate container system. The Forestry Branch has experimented with numerous container systems since 1974. Initially, the Japanese paperpot was employed, but it is now used only for the occasional production of tree improvement stock. In 1978 the Can-Am multipot, styroblock and Spencer-Lemaire "Rootrainer" were tested for use in the new producton greenhouse. The Spencer-Lemaire "Rootrainer" was eventually chosen for its ability to reduce root spiralling, its space efficiency, and the expected reductions in cost of delivery to the planting site of seedlings grown in the folding trays (Fig. 2). Since then, Spencer-Lemaire "Rootrainers", with a rooting volume of either 32 or 48 cm^3, have been used exclusively.

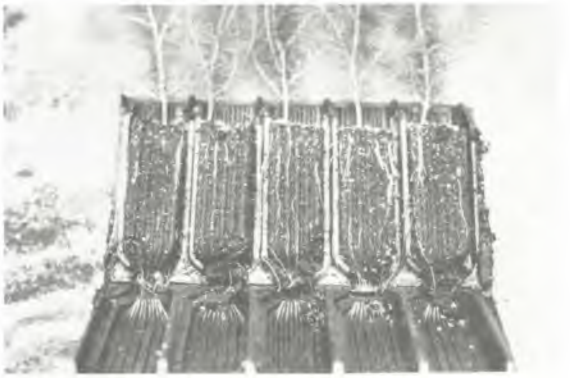


Figure 2. Black spruce grown in 48 cm^3 Spencer-Lemaire "Rootrainers".

It has become evident that planting stock specifications must be upgraded, and consideration has been given to the possibility of increasing the volume of container now used to approximately 130 cm^3. Although this will have an adverse effect on greenhouse capacity, it is felt that, in view of the problems accompanying the use of herbicides, larger seedlings may be the only alternative for overcoming competing vegetation on the more difficult sites.

Production Schedule

The greenhouses are capable of producing two crops annually and have been fully utilined to date to fill the pressing demand for planting stock. Completion of the second greenhouse provided much-needed flexibility, and will permit us to achieve our objective of producing larger seedlings that are better able to overcome site limitations encountered on private lands.

Winter crops are started in early December and remain in the greenhouse for a minimum of 16 weeks. Seedlings are removed from the greenhouse in early May and placed in a gravelled shade-area covered with nylon shade cloth. They are held in this holding area for a minimum of two weeks before shipping to the planting site. Winter crops are normally culled in the field.

Summer crops are overwintered for planting the following spring. They are sown in early June and seedlings are grown for approximately 10 weeks before removal from the greenhouse. The seedlings are then matured in the shade-area until late fall, when the shade cloth is lowered to cover the trays. Slotted barriers are set up at approximately 9 m spacing throughout the holding area to ensure an adequate snow cover and thereby reduce the incidence of wind burn to seedlings. Early-flushing species, such as jack pine, are graded and wrapped in early March and stored at approximately 2 °C until shipping. Overwintered black spruce is graded, wrapped and shipped as needed without intermediate cool storage.

An automated filling line, modelled after similar machines in Scandinavia, is employed for the filling and sowing of trays. Extended daylength is provided in the greenhouses by incandescent lamps. Seedlings are watered by means of self-propelled electric irrigation booms (Fig. 3), and fertilizers and pesticides are introduced into the irrigation water through an automatic metering device.

Figure 3. Self-propelled electric irrigation boom watering 12-week-old black spruce.

Greenhouse Design and Energy Conservation

Following the province's lead in domestic energy conservation, the Forestry Branch has incorporated into its greenhouse operations a number of measures to increase energy efficiency. The double-poly cover is in itself a tremendous improvement over conventional glass construction. Also, gutter-connected greenhouses reduce relative heat losses and facilitate the collection of rain water, which is used later for irrigation. An energy curtain installed in both greenhouses serves the dual function of reducing heat losses in winter and reducing light and heat levels in summer. A system of movable bench tops incorporated into the second greenhouse has increased space utilization to 90% (Fig. 4).

Figure 4. Movable bench tops in new greenhouse. Each bench measures 2.4 m x 29 m and is moved by a hand crank.

As part of a project funded by the Department of Rural and Economic Expansion (DREE), the greenhouses will be provided with Duvant downdraft gasifiers to reduce oil consumption for heating. These gasifiers produce a clean wood gas which is low in particulates and is suitable for use in either a standard boiler or a diesel-type electric generator. Initially, gas will be consumed as required to maintain greenhouse temperatures, and any excess will be burned off. However, it may be possible to use the surplus gas to generate up to 0.5 megawatts of electricity.

On the basis of current estimates, the cost per million BTU generated from oil on Prince Edward Island is $7.00, whereas that from wood is only $3.00. The total cost of the gasifier project is about $400,000. The units are expected to become operational during the winter of 1982-1983.

PLANTING OPERATIONS

A total of 450 ha was planted with containerized seedlings in 1980. This figure is expected to increase to 1,100 ha by 1983. More containerized seedlings may be grown if it is found desirable to eliminate the nursery seedbed stage for certain species. No bare-root stock of the three major species was planted in 1980 and it is not expected that production will reach capacity until 1984.

All planting operations for containerized seedlings are carried out during the spring, either by Forestry Branch crews or by contractors. Planting costs, as determined by the 1981 contractor prices, vary from 8 to 11 cents per tree depending on the size of planting site and its accessibility and trafficability. The fact that many sites are small and have poor access accounts for the high cost.

Mechanical site preparation of some kind is required before planting. Techniques and equipment vary, but the machines most commonly used are the C & H plow, Rome disc plow, bedding plow and modified agricultural plow. Site reclamation work is often required to improve drainage and/or remove undesirable vegetation.

In adopting three major species for reforestation we have endeavored to match species to site wherever possible. There are suitable sites for yellow birch *(Betula alleghaniensis* Britton) and sugar maple *(Ater saccharum* Marsh.) as well. Trials are therefore under way to determine whether these and other species can be grown in the greenhouse and outplanted successfully.

We are confident that, with a better knowledge of site preparation techniques and the eventual availability of various types of planting stock, we will be able to improve the success of the province's reforestation program.

THE STATUS OF CONTAINER PLANTING PROGRAMS IN CANADA

10. NEWFOUNDLAND

George Ross and Thomas McDonough[1]

Abstract.--Container planting programs were initiated in 1979, and are still being expanded, particularly in insular Newfoundland. Primary emphasis is on black spruce (*Picea mariana* [Mill.] B.S.P.), which accounts for approximately 98% of all seedling production. The Spencer-Lemaire "Rootrainer" and Can-Am multipot are the principal container systems being used.

Résumé.--Les programmes de plantation de plants en mottes emballées ont débuté en 1979, et on les élargit encore, en particulier sur l'île, à Terre-Neuve. L'intérêt principal porte sur l'épinette noire (*Picea mariana* [Mill.] B.S.P.), pour laquelle on produit environ 98% de tous les plants. Les principaux systèmes d'emballage utilisés sont le "Rootrainer" de Spencer-Lemaire, et le système à pots multiples de Can-Am.

INTRODUCTION

The province of Newfoundland began planting containerized tree seedlings in 1979. The paperpot system used at that time was found to be unsatisfactory, and has since been replaced with the Spencer-Lemaire "Rootrainer" and Can-Am multipot systems. Annual production from the six existing greenhouses is one million seedlings. Construction has started on a new facility consisting of 34 greenhouses which will have a single crop capacity of 5 million seedlings. It is anticipated that container-grown seedlings will eventually make up half the total provincial planting stock production.

PRESENT FACILITIES

Production facilities for growing containerized seedlings have been established at Goose Bay in Labrador, Mount Pearl on the Avalon Peninsula, and Wooddale in central Newfoundland. All the production from these facilities has been used in insular Newfoundland, but it is anticipated that container outplanting will be started in Labrador in the near future. Total growing space is 3,558 m^2.

Three Vary steel arch and three wooden arch greenhouses are in current use. Two of the steel arch houses are covered with fibreglass, and the other houses are covered with double layers of polyethylene. Oil-fired hot water or forced air furnace heating is used.

FUTURE DEVELOPMENTS

The first phase of a new container complex was started in December, 1980 at Wooddale. When completed in 1983, this complex will consist of 34 double-poly-covered greenhouses (29.3 m x 7.9 m), connected to a central headerhouse and storage area (45.7 m x 15.2 m) by a 192 m service way. This will bring the total area of growing space at Wooddale to 7,870 m^2. The first phase calls for the construction of the main headerhouse and 10 of the greenhouses. This construction should be completed by 1 September, 1981 and put into production in December of the same year. Projected capacity for this first phase is 1.4 million Spencer-Lemaire seedlings per crop. We anticipate that two crops per year will be grown in the greenhouses.

---

[1] Forest Improvement Specialist and Nursery Manager, respectively, Forest Management Branch, Department of Forest Resources and Lands, St. John's, Newfoundland.

CONTAINERS, EQUIPMENT AND SPECIES

The Mount Pearl greenhouse facility and the Goose Bay operation both utilize Can-Am multipots to grow black spruce seedlings. These pots have a volume of 55 cm^3. All of the soil loading is done by hand at both sites and the trays are seeded with a modified Lannen seeding head and gritting machine.

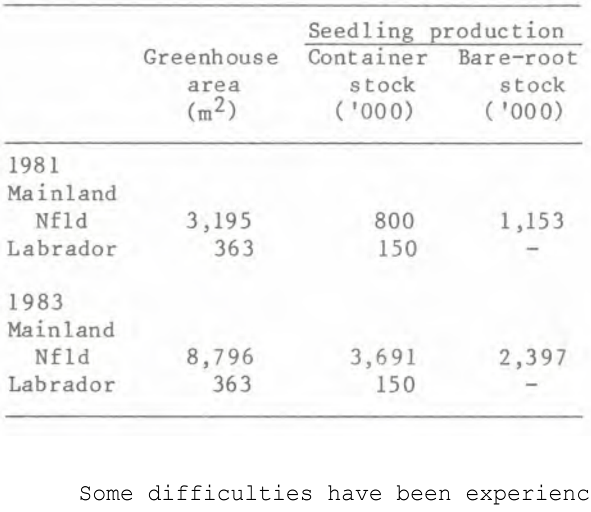
At Wooddale, the Spencer-Lemaire "Rootrainer-5" (55 cm^3) is used to grow black spruce, which forms 99% of the crop, and some red pine (*Pinus resinosa* Ait.). Only black spruce is grown in Labrador. In 1981, the three nurseries produced approximately 1 million black spruce seedlings in containers (Table 1). It is projected that total production of black spruce container stock will reach 3.8 million by 1983.

SEEDLING STANDARDS

While results of current research and development are pending, the following seedling standards recommended by Carlson (1979) are being used:

Seedling height	12-15 cm
Dry weight - shoots	565 mg
roots	185 mg
Root collar diameter	2.0 mm
Root dry weight vs. container volume	40 mg/cm^3 (minimum)

Table 1. Production statistics for Newfoundland.



	Greenhouse area (m^2)	Seedling production Container stock ('000)	 Bare-root stock ('000)
1981			
Mainland Nfld	3,195	800	1,153
Labrador	363	150	-
1983			
Mainland Nfld	8,796	3,691	2,397
Labrador	363	150	-

Some difficulties have been experienced in attaining these standards, especially with low seedling dry weights. Modified fertilizer and water regimes and longer growing periods may rectify the problem.

OUTPLANTING

While nurseries traditionally are the responsibility of the provincial government in Newfoundland, outplanting of nursery stock is carried out by both industry and government. Most container outplanting has been on scarified sites, although some experimentation with container-grown seedlings is under way on burned sites. Shark fins and barrels, SFIs, Brackes, and TTS disk trenchers were used for scarification prior to 1981 with varying results. An Eden Slash Rake, Young's Teeth, and a C & H Plow were obtained in 1981, but none of the areas treated with this newer machinery have yet been planted.

Early evaluations of the first three years of container planting indicate that planters have paid insufficient attention to microsite selection, and consequently there have been nutritional difficulties and problems with frost heaving. Both governmental and industrial field foresters agree that a larger container-grown seedling could be advantageous in Newfoundland conditions.

CONTAINERS AND TREE IMPROVEMENT

The provincial plus-tree program has been affected to a certain extent by the current budworm epidemic in Newfoundland. For this reason and others, a program of vegetative propagation of bare-root and container-grown black spruce superseedlings has been started with initially promising results. Some of the early propagants will be used in the province's first seed orchard now under development. Less promising but still acceptable results are being obtained with the vegetative propagation of older plus-tree material.

LITERATURE CITED

Carlson, L.W.
1979. Guidelines for rearing containerized conifer seedlings in the Prairie Provinces. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-214. 62 p.

STATISTICAL SUMMARY OF CONTAINERIZED SEEDLING AND BARE-ROOT PROGRAMS IN CANADA: 1980 SITUATION AND PROJECTIONS FOR 1983[1]

J.H. Smyth and K.L. Ramsay2

				Greenhouse area			
		Number of nurseries		Private		Government	
Province	Types of container currently used[a]	Private	Government	Heated (m^2)	Unheated (m^2)	Heated (m^2)	Unheated (m^2)
British Columbia	1,2	-	8	23,435	3,255	27,645	3,660
Alberta	4	2	1	5,471	-	13,780	-
Saskatchewan	4,6	-	4	-	-	1,383	-
Manitoba	6	-	1	-	-	642	-
Ontario	4,5,6,7	5	6	1,790	509	10,146	2,887
Quebec	1,2,3,6,8	2	2	1,083	-	9,988	-
New Brunswick	6	6	3	3,420	6,800	17,000	6,000
Nova Scotia	8	4	3	1,990	6,702	7,331	1,056
Prince Edward Island	4	-	1	-	-	4,040	-
Newfoundland	4,8	-	3	-	-	3,558	-

[a] Container types: 1 = BC/CFS Styroblock 2A; 2 = BC/CFS Styroblock 4A; 3 = BC/CFS Styroblock 8; 4 = Spencer-Lemaire "Rootrainer"; 5 = FH 308 paperpot; 6 = FH 408 paperpot; 7 = Leach container; 8 = Can-Am Multipot.

---

[1] Compiled from provincial status reports.

[2] Senior Economist and Economist Technician, respectively, Great Lakes Forest Research Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario.

Province	1980 containerized seedling production		1983 production targets (000)	1980 area planted		1983 planting targets	
	Heated (000)	Unheated (000)		Container (ha)	Bare-root (ha)	Container (ha)	Bare-root (ha)
British Columbia[a]	58,000[b]		95,000[c]	19,651	-	80,000[e]	-
Alberta	13,960		16,030	11,030	526	16,023	12,628
Saskatchewan	2,600		20,000	x	x	x	x
Manitoba	502	-	1,700	400	700	4,000 to 4,500[6]	
Ontario	10,587	4,015	24,841	5,387	26,863	11,750	32,086
Quebec	1,900	-	11,300	788	13,363	4,795	20,240
New Brunswick	26,600	6,400	32,300	13,602	9,897	22,515	6,765
Nova Scotia	6,500[b]		17,900[d]	4,650[g]	4,650[g]	6,510[g]	2,790[g]
Prince Edward Island	1,100	-	4,000	450	-	1,100	-
Newfoundland	950[b]	-	3,841	x	x	x	x

[a] British Columbia also has an additional 7,085 m^2 (private) and 19,815 m^2 (government) shadehouse or open compound growing area.

[b] 1981 production

[c] 1985 production target

[d] 1984 production target

[e] 1985 planting target

[f] Range for both containerized and bare-root planting target

[g] Estimated figures

x = Not reported

THE STATUS OF CONTAINER PLANTING PROGRAMS IN THE NORTHERN UNITED STATES

1. NORTHEASTERN UNITED STATES

John R. Scholtes[1]

Abstract.--Over 80% (53 million ha) of all forest land in the northeastern United States is under nonindustrial private ownership. Private planting depends heavily on bare-root planting stock grown in state-operated nurseries. These nurseries accounted for 70% of the total of 136 million seedlings produced in 1981. Fewer than 5% of these were containerized seedlings, which were produced primarily in forest industry and private nurseries.

Résumé.--Plus de 80% (53 millions d'ha) de toutes les régions forestières du nord-est des États-Unis appartiennent à des particuliers et ne servent pas à des fins industrielles. Ces particuliers comptent surtout sur le matériel de reproduction à racines nues des pépinières gérées par l'État, et ces dernières ont fourni 70% des 136 millions de semis produits en 1981. Moins de 5% de ces plants étaient en mottes emballées. Ce sont surtout les pépinières privées et l'industrie forestière qui produisent des plants de ce genre.

This report covers container production in the northeastern area of the United States with the exception of the three Great Lakes states of Michigan, Minnesota and Wisconsin. These three states are covered in a separate report (Aim 1982).

The USDA Forest Service's Northeastern Area includes the states from Maine to Minnesota, south to Missouri and east to Maryland. There are 20 states in all, with a total area (land and water) of 172.1 million ha. Approximately 38% of this area (65.7 million ha) is classified as forest land.

One of the most striking features of land use in the Northeastern Area is that over 80% (52.4 million ha) of all forest land is under nonindustrial private ownership. Only about 8.4% (5.5 million ha) of forest land is federally owned.

This private ownership factor has had a strong influence on the development of seedling production and planting programs within the area. The small, nonindustrial private landowner depends heavily on bare-root seedlings grown in state-operated nurseries. Eighteen of these 20 states have at least one state nursery. Some states have as many as three small nurseries. State-owned nurseries accounted for nearly 70% of the total of 136 million seedlings produced in the Northeastern Area in 1980 (Table 1). Production of containerized seedlings amounted to less than 5% (5.8 million seedlings) of this total, most of them (97%) being produced in forest industry and private nurseries.

A total of 57,680 ha of forest land were replanted in 1980, the greater portion (61%) of this planting being on privately owned nonindustrial lands (Table 2).

The remainder of this report deals with individual states in which container stock is commercially produced for reforestation purposes.

---

[1] Nursery and Reclamation Specialist, Resource Management Staff, Cooperative Forestry, USDA Forest Service, Broomall, Pennsylvania.

Table 1. Seedling production by stock type and agency in the Northeastern Area (fiscal year 1980)[a]

Agency	Seedling production 1980 Bare-root(000)	Containerized (000)
Publicly operated nurseries		
federal	9,340[b]	93[b]
state	93,245[c]	98[c]
other (SCS, etc.)	10,000[c]	--
public subtotal	112,585	191
Private nurseries		
forest industry	1,464[c]	3,356[c]
private	10,045[c]	2,261[c]
private subtotal	11,509	5,617
Total, all agencies	124,094	5,808
Grand total	129,902	

[a]Excludes states of Michigan, Minnesota and Wisconsin
[b]Reforestation and Timber Stand Improvement Report for fiscal year 1980, USDA Forest Service
[c]Annual Cooperative Forestry Accomplishment Reports for fiscal year 1980, USDA Forest Service

Table 2. Planting by agency in the Northeastern Area (fiscal year 1980)[a]

	Area planted (ha)
Public forest lands	
federal	6,238[b]
state	4,244[c]
local	2,944[c]
public subtotal	13,426
Private forest lands	
forest industry	8,188[c]
other industry	897[c]
nonindustrial	35,351[c]
private subtotal	44,436
Total, all agencies	57,862

[a]Excludes states of Michigan, Minnesota and Wisconsin.
[b]Reforestation and Timber Stand Improvement Report for fiscal year 1980, USDA Forest Service.
[c]Annual Cooperative Forestry Accomplishment Report for fiscal year 1980, USDA Forest Service.

STATE-BY-STATE REPORT

Maine

Five nurseries produce containerized stock in Maine--the state nursery, two private nurseries and two owned and operated by forest industry. In 1980 these nurseries produced about 2.5 million seedlings for reforestation as follows: black spruce *(Picea mariana* [Mill.] B.S.P.) 1,144,000; white spruce *(P. glauca* [Moench] Voss) 416,000; red spruce *(P. rubens* Sarg.) 200,000; various larches *(Larix* spp.) 375,000; red pine *(Pinus resinosa* Ait.) 161,000; jack pine *(P. banksiana* Lamb.) 156,000; and white pine *(P. strobus* L.) 16,000.

The type of container varies from nursery to nursery. Only one nursery uses several types of container, among which are the FH 308 and FH 408 Japanese paperpots, Can-Am Multipots, and Styrofoam quarter blocks 2 and 4 in.^{3} (32.8 and 65.6 cm^3).

Vermont

Only one private nursery in Vermont raises forest seedlings in containers. The greenhouse is just coming on line, and although there was no production in 1980, plans call for a production of 50,000 seedlings annually. Seedlings will be grown in both styroblocks and multipots supplied by the purchaser.

Missouri

One large private nursery is growing a small amount of Paulownia *(Paulownia tomentosa)* for several southern lumber firms. The seed is sown in flats and then transplanted to Jiffy 7 pots within about 2 weeks. After 6 or 7 weeks the plants are 15-20 cm tall and are ready for shipment. These fragile, fast-growing seedlings are very difficult to handle and ship, and can be compared with young tomato plants in this respect.

Production targets for 1983 call for an increase at only one of the seven nurseries covered in this report. This would increase production for this area by about one million seedlings.

The types of greenhouses in use at the seven nurseries include traditional style glass, both wood and steel frame double-poly, and corrugated fibreglass. The double-poly house is by far the most common. The other types of house are all provided with an inner skin of polyethylene to help insulate them against heat loss. Heat sources include oil, oil with wood backup, and propane. The Missouri nursery claims solar energy as its sole heat source for growing Paulownia. The rest of the nurseries may be located in the wrong climates.

CONCLUSION

There is a fair amount of interest in growing and planting containerized stock in the Northeastern Area. The forest industry is the largest producer of containerized planting stock, although this accounts for a relatively small portion of total seedling production by all agencies (2.58%) (Table 1). Lack of funding for most state nurseries is evident even in their bare-root operations. Lack of capital to embark on container programs is probably the major reason that containerized seedling production is not more prevalent in this area.

Even though care must be exercised in the culture and handling of containerized planting stock, this type of planting product is considered much hardier than bare-root stock. It seems likely that the relatively inexperienced nonindustrial forest landowners might have greater establishment success if they were purchasing and planting container stock. The long transportation distances, lack of proper bare-root delivery systems, and the inexperience of handlers and planters are all strong arguments for the greater use of container stock in the Northeastern Area.

LITERATURE CITED

Alm, Alvin A.
1982. The status of container planting programs in the northern United States. 2. Lake States--Minnesota, Wisconsin, Michigan. p. 63-65 in J.B. Scarratt, C. Glerum and C.A. Plexman, *Ed.* Proceedings of the Canadian Containerized Tree Seedling Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. O-P-10.

THE STATUS OF CONTAINER PLANTING PROGRAMS IN THE NORTHERN UNITED STATES

2. LAKE STATES--MINNESOTA, WISCONSIN, MICHIGAN

Alvin A. Alml[1]

Abstract.--About 6 million containerized seedlings were grown in the Lake States in 1981. Container stock was planted on about 2,500 ha or about 8% of the area planted with bare-root seedlings. Reforestation programs will increase by 1983 but the percentage of container use will remain nearly constant. The primary objectives of use are to meet planting stock shortages and to extend the planting season.

Résumé.--Quelque 6 millions de semis en récipients ont été cultivés dans les états des Grands Lacs en 1981. Des récipients ont été plantés sur 2500 ha, soit 8% de la superficie plantée de semis à racines nues. Les programmes de reboisement augmenteront d'ici 1983, mais le pourcentage d'utilisation de récipients demeurera presque constant. Les objectifs principaux sont de répondre à la pénurie de semis de plantation et de prolonger la saison de plantage.

INTRODUCTION

Container plantings in the Lake States were begun with Ontario tubes in 1967 as part of a Minnesota research program. Research has continued with other types of container stock planted under a range of conditions on which various site preparation techniques have been applied. In Michigan a related research program is concerned with development of accelerated optimal growth (AOG) seedlings cultured in greenhouses. These research programs have demonstrated the feasibility of using containerized seedlings in operational plantings. However, container planting did not become operational in the Lake States until 1977 when Potlatch Corporation of Cloquet, Minnesota constructed its first containerized seedling greenhouse. This greenhouse has since been expanded to four times its original size. It was followed by construction of a container greenhouse at Rhinelander, Wisconsin in 1978 by Consolidated Papers, Inc. This company has since supplemented its greenhouse with a shade house to expand production. In 1979, Mead Paper built its container greenhouse at Escanaba, Michigan.

1981 CONTAINER PRODUCTION

The three forest industry greenhouses mentioned above produced about 3.26 million seedlings in 1981 in two crops (Table 1). This was about 58% of the 5.6 million total production of container seedlings for 1981 in the Lake States. An additional 1.91 million or about 34% were produced by two commercial greenhouse operations in Minnesota. These were sold to forest industries and to public forestry agencies. The remaining seedlings produced for operational programs in the Lake States were grown in small public agency greenhouses. In addition, there is a commercial greenhouse in Michigan that grows about 850,000 seedlings annually in containers, but these are primarily for purposes other than reforestation.

About 80% of the seedlings produced in the Lake States were grown in styroblocks, mostly styroblock-2s. Producers maintained that they selected this system because it was economically competitive and efficient to use. Research results and the experience of other producers were also important in their selection decision. The Mead Paper greenhouse in Michigan uses Spencer-Lemaire "Rootrainer 5s", primarily because more seedlings

---

[1] Professor, College of Forestry, University of Minnesota, St. Paul, Minnesota.

Table 1. Containerized seedling production plus area planted in 1981 and projected for 1983, by agency, in the Lake States.

	Forest industry[a]	Federal agencies[b]	State and county	Other private[c]	Commercial greenhouses	Total
Heated greenhouse area (m^2)	2,449	398	37	0	2,360	5,244
Seedling production						
1981 (000)	3,260	407	25	0	1,910	5,602
1983 (000)	3,800	800	330	0	1,610	6,540
Area planted in 1981						
Containers (ha)	1,728	630	138	0	-	2,496
Bare-root (ha)	2,051	4,629	5,900	19,535	-	32,115
Planting target for 1983						
Containers (ha)	2,448	656	398	0	-	3,502
Bare-root (ha)	2,226	5,511	9,314	25,990	-	43,041

[a] Includes only industries that used both containers and bare-root stock in 1981.
[b] USDA Forest Service and Bureau of Indian Affairs.
[c] Includes industries with no container program in 1981 and nonindustrial private landowners.

can be grown per square metre with this system. A greenhouse operated by the Bureau of Indian Affairs at Redby, Minnesota uses the FH 315 paperpot system because of the "package" features. It also notes the advantage of not having to bring anything back from the field to clean up.

About 60% of the containerized seedlings grown in the Lake States in 1981 were red pine *(Pinus resinosa* Ait.). White spruce *(Picea glauca* [Moench] Voss) and black spruce *(P. mariana* [Mill.] B.S.P.) made up an additional 26%. The remainder were equally divided among jack pine *(Pinus banksiana* Lamb.), white pine *(P. strobus* L.) and miscellaneous species. There is increasing interest in the Lake States in the use of exotic and hybrid larches *(Larix* spp.), which made up the bulk of the miscellaneous total.

PLANTING PROGRAMS

About 34,610 ha of land in the Lake States were planted for reforestation purposes in 1981. Containerized seedlings comprised about 7% of this planting. Nearly 56% of the total area planted or about 19,535 ha was in private ownership. (The total figure includes plantings by forest industries that used no containers in 1981.) The forest industries that had both container and bare-root programs planted 3,779 ha or about 10% of the total. Other public agencies planted the remainder: federal, 5,259 ha and state and county, 6,038 ha.

Much of the planting in the Lake States is done by hand planting crews from the southern United States. These crews operate as contractors on a bid basis. They are well trained, experienced planters and commonly average 3,000 to 4,000 trees per 8-hr day. The favored planting tool seems to be the hoedad for both container and bare-root stock but planting tubes such as the Pottiputki are also used. Planting machines are used in the Lake States area where terrain and site conditions permit.

A variety of mechanical site preparation techniques are being used for container planting sites. The most common ones are disking, spot scalping with equipment such as the Leno and Bräcke scarifiers, and the use of various V-blades and plows. Roller chopping has been tried and most recently the TTS disk trencher has been used. There is also a considerable amount of site conversion, and this usually requires shearing or grubbing with the debris raked into windrows. The mechanical work is often accompanied by herbicide application either before or after planting. But there is a real need for more information on the use of herbicides with containerized seedlings.

REASONS FOR CONTAINER USE

The major reason given by agencies in the Lake States for using containerized seedlings relates to the shortage of bare-root nursery stock. This shortage is a result of the recent years of drought which have affected nursery production. In addition, reforestation programs have been accelerated in recent years. A second reason given by these agencies was the realization that containers add flexibility to planting programs. Container users are able to extend the normal planting season into the summer months. They also have additional flexibility in that they can cut down on production lead time and shorten the interval between harvesting and reforestation. They can also schedule planting when moisture conditions in the field are near optimum. The third most frequently cited reason was the opportunity containers provided for the more efficient use of genetically improved seed. This consideration will likely become more important in the future as tree improvement programs expand and seed orchards begin seed production.

In general, container users are pleased with survival and growth results achieved to date. There have been failures with containers in the Lake States, but many of these have been the result of poor seedling quality or inadequate site preparation. More information is needed about site prescription relating conditions to selection of site preparation method and type of seedling. However, before this can be accomplished, specifications will have to be developed so that the size and condition of container-grown seedlings can be better described.

FUTURE TRENDS

Reforestation programs will continue to expand in the Lake States in the immediate future. It is projected that the area of land reforested by planting will increase by about 35% between 1981 and 1983. About 8% of the total area planted in 1983 will be planted to container stock (i.e., nearly the same percentage as in 1981). Most of the additional container-grown seedlings will be planted by the three forest industries which operated container greenhouses in 1981.

Even though research programs have been under way for a number of years, operational container use is still in its infancy in the Lake States. Most of the early use has been in Minnesota. Planting of containerized seedlings in that state accounted for about 58% of the 1981 total planted in the Lake States.

To date, the only operational container programs by public agencies have been in Minnesota. Several counties are involved in container planting, and in 1981 there were relatively large plantings in both national forests in Minnesota. The Minnesota Department of Natural Resources also started a container planting program in 1981. Nearly all of the container seedlings used by these agencies were grown by the two commercial container greenhouses in the state.

The Bureau of Indian Affairs in Minnesota has been operating its container greenhouse on the Red Lake Reservation for several years and will double production by 1983. Containerized seedlings have also been tested in Minnesota for mineland reclamation plantings. They have the advantage of being easier to plant on difficult sites, and survival has been good. The Iron Range Resources Commission in Minnesota is currently constructing a greenhouse facility for producing container stock. Erie Mining Company has also had some container trials and is interested in additional plantings.

Container planting programs have not grown as rapidly in Wisconsin and Michigan as in Minnesota. This may be a result of Minnesota's research program which has been conducted in cooperation with the various forestry agencies. However, both state and federal organizations in Wisconsin and Michigan have indicated a strong interest in the use of containerized seedlings and may initiate programs in the future, depending on budgets and demand for planting stock.

It is likely that container use in the Lake States will continue to expand. This expansion will take place as more information becomes available, particularly that relating to survival and growth of the plantings now being established. The growth rate will also depend on whether or not the production of bare-root nursery seedlings can keep pace with the acceleration of planting programs in the Lake States. The continued recognition of the advantages that containerized seedlings offer in extending the normal planting season will be a key factor.

The author would like to express his sincere appreciation to the many cooperators who supplied data and information for this paper.

THE STATUS OF CONTAINER PLANTING PROGRAMS IN THE NORTHERN UNITED STATES

3. NORTHWESTERN UNITED STATES

Thomas D. Landis[1]

Abstract.--Production of containerized seedlings in the northwestern United States has increased from less than 5% to over 20% of total nursery production in the last decade. Thirty-four container nurseries in six states contain over 130,000 m^2 of growing space and in 1980 produced over 62 million seedlings. Seedling production is projected to exceed 73 million trees by 1983.

Résumé.--Au cours de la dernière décennie, les plants en mottes emballées sont passés de moins de 5% à plus de 20% de la production totale des pépinières dans le nord-ouest des États-Unis. Dans les six États de cette région, les 34 pépinières de plants en mottes emballées représentent une superficie de culture de plus de 130 000 m^2 et, en 1980, elles ont produit plus de 62 millions de semis. D'ici 1983, on prévoit que cette production dépassera 73 millions de semis.

INTRODUCTION

It is over 10 years since northwestern nurseries began producing tree seedlings in containers. Containerized seedling production in this region has increased from fewer than 1 million seedlings in 1970 to over 60 million in 1980. Much has changed in container nursery technology over the past decade but the role of containerized seedlings in reforestation is well established.

The purpose of this paper is to examine the container nursery industry in the northwestern United States. Information was gathered through questionnaires sent to container nurseries, telephone conversations, visits and previous nursery reports. Many of the views expressed in this paper are the opinions of practising nurserymen and reflect the unique aspects of their particular operations. It should also be stressed that these statistics are based on survey data and are therefore relative values.

RATIONALE FOR CONTAINERIZED SEEDLING PRODUCTION

Program Objectives

Prior to 1970, most tree seedlings used for reforestation were bare-root, produced at one of the 20 nurseries in the northwest. These bare-root nurseries were relatively large and produced seedlings for use by their own agencies as well as under contract for small forest operations. The newly developed technology of growing tree seedlings in containers spawned a new generation of smaller container nurseries which were often operated by newcomers to the tree nursery business.

Container nurseries were developed to meet a variety of program objectives. For land management agencies, the primary objective was to supply a low-cost, healthy seedling for reforestation. Often, containerized seedlings were used to supplement bare-root seedling production by supplying hard-to-grow species on a shorter rotation. Private container nurseries entered the market on a contract basis to meet the growing demand for seedlings. Containerized seedlings are particularly suitable for tree improvement pro-

---

[1] Western Nursery and Greenhouse Specialist, USDA Forest Service, Lakewood, Colorado.

grams and many nurseries produce genetically improved seedlings or rooted cuttings. An additional objective in some areas is to provide a suitable industry for government agency work and to utilize the local work force more fully.

Biological Considerations

Container nurseries offer several biological advantages over bare-root nurseries. Greenhouses permit more complete control over the growing environment and, as a result, seedlings can be "custom grown" to meet specific needs.

Many foresters feel that container seedlings have better field survival and growth than bare-root, stock, especially on harsh sites; others report ease of planting as an advantage. Containerized trees are more resistent to poor handling practices in the field and suffer less root disturbance and transplant shock.

Containerization is a definite advantage for species that are difficult or impossible to grow as bare-root stock. Western hemlock *(Tsuga heterophylla* [Raf.] Sarg.), redwood *(Sequoia* spp.), larch *(Larix* spp.), cedar *(Thuja* spp.), and true fir *(Abies* spp.) have frustrated bare-root nurserymen for many years because of low seed germination, slow growth, disease problems or poor rooting habits. Species such as fir with consistently low seed germination may be started as germinants to optimize stocking. Valuable improved seed from trees such as rust-resistant western pine *(Pinus monticola* Dougl.) can be started in the same manner to obtain more seedlings from a small seedlot. Slow-growing species such as Engelmann spruce *(Picea engelmannii* Parry) can be grown to shippable size in one year in a greenhouse, whereas bare-root seedlings require 3 years. Transplanting small containerized seedlings to a bare-root bed for an additional year's growth ('plug-one') is proving popular for producing hard-to-grow species.

Managerial Considerations

One of the most important advantages of container nurseries is that they are able to operate at relatively low production levels. Several container nurseries in the northwestern area are operating at an annual production level of about one million seedlings, which would be uneconomical for a bare-root nursery. The difficulty of finding or affording top-quality agricultural land and the high operating overhead make small bare-root nurseries impractical. Also, a relatively low capital investment is required to bring a container nursery into operation in comparison with a bare-root nursery.

The inherently shorter crop rotations and the ability to produce a year-round crop is another advantage of container nurseries. Short rotations offer land managers more flexibility in planning and permit quick production for emergency plantings (e.g., after fires). Containerized seedlings are also used frequently to make up for shortages in bare-root production. From an economic point of view, short rotations and continuous production create a favorable cash flow pattern for private nurserymen.

Containerized seedlings can add substantial flexibility to a reforestation program. One nursery considered container crops more reliable than bare-root stock, while several operations considered the ability to outplant in the fall a prime advantage. Containerized seedlings are also easier to interplant on understocked lands and large containerized seedlings are more tolerant of plant competition. Where animal predation is a problem, seedlings can be grown in special containers with a protective mesh surrounding the foliage.

CONTAINER SYSTEMS

Northwestern nurseries are evenly divided in their preference for Leach containers and styroblocks as container systems.

Proponents of the Leach system cite good growth and seedling density, and the ability to consolidate filled cells after sowing and during grading. The ability to ship the seedling in the individual container and the reusability of the container are other advantages of Leach cells. Protection of the root plug during handling and shipping is important when a dibble is used during outplanting.

Styroblock advocates like the low cost, the variety of cell sizes and reusable features of that container. Ease of handling and better seedling growth were frequently mentioned. The insulating properties of the styrofoam provide some heat and frost protection for the root plug.

The size of container chosen ranged from 41 to 492 cm^3, and nurserymen cited outplanting site severity and customer preference as factors determining their choice. West coast nurseries produce most of their seedlings in containers with volumes of 41-82 cm^3, whereas

Table 1. Container nursery statistics for the northwestern United States.

			Nursery Capacity		Seedling Production	
			(000 m^2)		(000,000 trees)	
State	Owner	No.	Heated	Unheated	1980	1983
Alaska	government	2	1.73	0	1.31	3.10
	industry	0	0	0	0	0
	private	0	0	0	0	0
	total	2	1.73	-	1.31	3.10
Idaho	government	2	4.14	0	4.60	4.80
	industry	1	3.53	0	1.60	2.40
	private	0	0	0	0	0
	total	3	7.67	0	6.20	7.20
Montana	government	2	0.49	0	0.85	0.85
	industry	2	1.14	0	0.71	0.71
	private	2	0.24	0	0.12	0.16
	total	6	1.87	-	1.68	1.72
North Dakota	government	1	0.27	0	0.02	0.04
	industry	0	0	0	0	0
	private	0	0	0	0	0
	total	1	0.27	0	0.02	0.04
Oregon	government	1	1.56	0	1.00	1.00
	industry	3	46.82	2.79	22.30	28.00
	private	6	31.79	6.22	11.22	11.92
	total	10	80.17	9.01	34.52	40.92
Washington	government	3	3.85	1.90	2.40	2.90
	industry	4	15.51	0.23	10.70	10.70
	private	5	7.12	1.86	5.08	6.10
	total	12	26.48	3.99	18.18	19.70
Regional totals	government	11	12.04	1.90	10.18	12.69
	industry	10	67.00	3.02	35.31	41.81
	private	13	39.15	8.08	16.42	18.18
	Grand total	34	118.19	13.00	61.91	72.68

Interior nurseries prefer the larger (66-164 cm^3) sizes. The largest containers measure 492 cm^3 and are produced for shelterbelt plantings in the Great Plains Region. The smallest (41 cm^3) container seedlings are now being used to produce 'plug-one' transplants.

In the final assessment, the choice of container system is dependent upon the objectives and goals of the particular nursery. There is no single container that will fit all needs.

CURRENT NURSERY SITUATION

The six states in the northwestern region contain 34 containerized seedling nurseries (Table 1). In all states except Oregon and Washington, the majority of container nurseries are run by government agencies. Forest industry nurseries and other private nurseries account for 18 of 22 container facilities in Oregon and Washington; such facilities are obviously popular in this timber-oriented region.

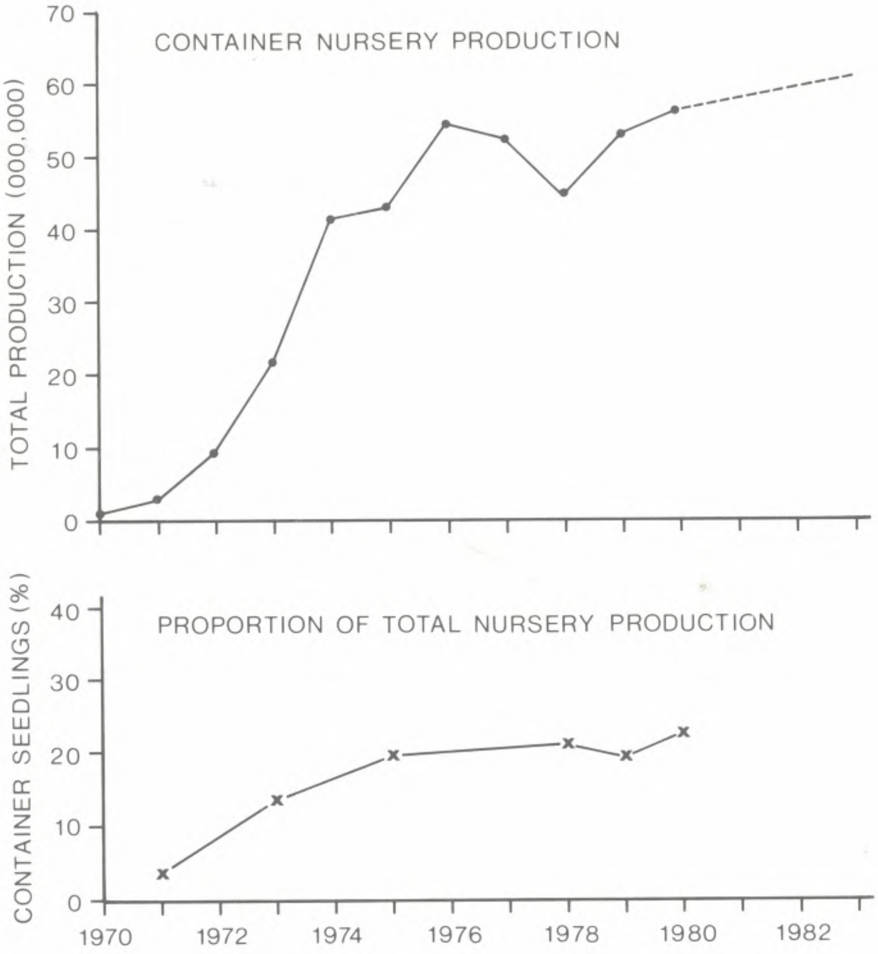


Figure 1. Container nursery trends in Oregon and Washington.

Container nurseries in the northwestern border states boast a total capacity of over 130,000 m^2 of growing space (Table 1). Heated greenhouses are the rule in all states except Oregon and Washington, where a few unheated structures are used. The distinction between heated and unheated facilities is vague, however, because many container nurseries use greenhouses with permanent roofs but sidewalls that roll up. These modified greenhouses provide supplemental heat during germination and early growth but not later in the growing season when the open ventilation provides cooling.

In 1980, container seedling production exceeded 62 million trees in the six—state region (Table 1). Oregon and Washington, which have the most nurseries, produced 52.8 million seedlings or 85% of the regional total. One interesting sidelight of these statistics is that while Alaska produces only 1.3 million containerized seedlings, this figure constitutes 100% of its nursery production. The scarcity of good nursery soil and the short growing season prevent bare—root nursery operations in that state.

OUTLOOK FOR CONTAINER NURSERIES

Container seedling production in the six northwestern states is projected to exceed 73 million trees by 1983 (Table 1). This anticipated production is a continuation of an upward trend, as evidenced by data from Oregon and Washington (Fig. 1). The exponential growth of the early 1970s was followed by a drop in production in the late 1970s and then a gradual increase.

In the Pacific Northwest, containerized seedlings increased from less than 5% of total nursery production to over 20% in 1975 (Fig. 1). Since that time, the proportion of containerized to bare—root seedlings has remained fairly constant at about 22%. This stable trend is verification of the fact that containerized seedlings play a significant role in northwestern nursery production.

HIGHLIGHTS OF THE SOUTHERN CONTAINERIZED FOREST TREE SEEDLING CONFERENCE

John C. Brissette[1]

Abstract.--This conference focused on growing and using container stock for reforestation in the southern United States. Many types of containers and facilities are used but none on a large scale. As a supplement to bare-root stock, containerized seedlings offer rapid production, extended planting season, and superior performance in certain situations.

Résumé.--Cette communication était centrée sur la culture de plants en mottes emballées et leur utilisation pour le reboisement dans le sud des États-Unis. De nombreux types de contenants et d'installations y sont employés mais aucun sur une grande échelle. À titre de supplément aux semis à racines nues, les semis en mottes emballées offrent les avantages d'une production rapide, d'une plus longue saison de plantation et d'un rendement supérieur dans certaines situations.

INTRODUCTION

The Southern Containerized Forest Tree Seedling Conference was held August 25-27, 1981, at the Hyatt Regency Hotel in Savannah, Georgia. The conference was sponsored by the USDA Forest Service's Southern and Southeastern Forest Experiment Stations and the Southeastern Area, State and Private Forestry. Other co-sponsors were the Silvicultural Working Group of the Society of American Foresters, the Georgia Cooperative Extension Service and the Georgia-Pacific Corporation.

The objective of the conference was to describe and discuss the technical state-of-the-art of growing and planting containerized tree seedlings in the southern United States. The program sought to develop alternative approaches to container production and to examine the potential for expanding the operational use of containerized seedlings for reforestation.

The conference consisted of 2 days of technical sessions, a 1-day field trip, and exhibits by manufacturers and distributors of containers and related supplies. It was attended by 125 people from throughout the United States, with representatives from Canada and Sweden also present.

The technical papers were divided into three basic categories: growing quality containerized seedlings; production facilities and handling methods; and uses and performance of containerized stock. The field trip consisted of a visit to an operational shade-house complex used to produce loblolly pine (*Pinus taeda* L.) and outplantings of containerized stock ranging from their first to their seventh season in the field.

DISCUSSION

In the south last year, 1 billion bare-root seedlings were produced in industry and public forest tree nurseries. In contrast, only about 6 million containerized seedlings were produced. While there is much interest in containerized seedlings there is also some resistance to their use and skepticism about

---

[1] Conference Cochairman; Nursery and Tree Improvement Specialist, USDA Forest Service, Southeastern Area, State and Private Forestry, Jackson, Miss.

their value to southern forestry. What follows is a sampling of the major points discussed by the participants about the various aspects of growing and using containerized tree seedlings.

Growing Quality Containerized Seedlings

Many different container types and growing systems are in use, and while no one type or system is considered optimum all have certain advantages and disadvantages. The choice of system depends on the situation and management objectives, but several can be used on an operational basis.

Only 12 to 16 weeks are needed to produce plantable containerized southern pine seedlings, but they may be grown longer if they are intended for planting on adverse sites. While seedling size is correlated with container size, seedling density seems to have more effect on size than does root volume or depth.

Getting seedlings into the proper physiological condition for outplanting is extremely important, especially in situations in which multiple crops are grown each year. The need to synchronize seedling physiology with natural conditions before outplanting is a major cultural difference between container and bare-root seedling production.

While container production does provide greater flexibility than bare-root production it also requires more planning and foresight. To an extent, containerized seedlings can be viewed as individuals, while in nursery beds bare-root seedlings must be considered as populations. This distinction allows the grower of container stock to make the most efficient use of seed and to reduce the proportion of cull seedlings produced.

Production Facilities and Handling Methods

As with containers, many types of growing facility are in use. In the south, quality seedlings can be grown in less controlled environments than in the west, the northeast, or Canada. Throughout much of the region shadehouse facilities are all that are required.

Current operations in the south are on an experimental or pilot scale basis and production costs tend to be twice those for bare-root seedlings. A shadehouse container nursery of a 3 to 5 million seedling capacity could be cost effective, however, and competitive with bare-root production costs. There are no operations of this size in the south at present.

One major advantage of containerized seedlings over bare-root stock is that they can be held in the containers until conditions are right, without the need for elaborate storage facilities. Almost all operations depend on reusable containers, however, and this may cause problems when contract crews are used for planting.

Handling and shipping of containerized seedlings pose major problems. Although these procedures could be mechanized, the current diversity of container types and growing systems has precluded any serious developmental work. Mechanization of both growing and handling systems could greatly increase the use of containerized stock in the south.

Uses and Performance of Containerized Stock

Much of the skepticism about containerized seedlings stems from the notion that they can replace bare-root stock. The current artificial regeneration effort in the south exceeds 500,000 ha annually but is not sufficient to meet projected future needs. Clearly, as another reforestation tool, containerized stock has its greatest potential as a supplement to bare-root seedling production.

One important use of containerization is in producing species that tend to have poor field survival. Longleaf pine *(Pinus palustris* Mill.), for example, is a deep, taprooted species, and conventionally lifted nursery stock suffers from transplant shock. As bare-root stock it generally has poorer survival than the other southern pines. However, container-grown longleaf pine seedlings tend to be more uniform, to begin height growth sooner and to have better survival than bare-root seedlings.

Another major use of containerized stock is for planting under adverse site conditions where adequate survival cannot be expected for bare-root seedlings. On many sites, containerized seedlings have survived better than, and grown as well as, bare-root stock, even though they may be smaller. Inoculating containerized seedlings with mycorrhizae has made them especially valuable for reclamation of severely disturbed sites.

Perhaps the most important use of containerized seedlings in the south has been to extend the planting season. The majority of tree planting for reforestation in the south occurs from December through March. The use of containerized stock can extend that season to virtually the entire year if adequate soil moisture and favorable temperatures are available after planting. In years when spring drought results in poor initial survival of bare-root stock, containerized seedlings can be interplanted that same season to ensure adequate stocking. Likewise, after fire or other devastation, containerized stock can be produced quickly to reforest the affected areas. Containerized seedlings can also be planted, when conditions are acceptable, on sites that are excessively wet or dry during the normal bare-root planting season.

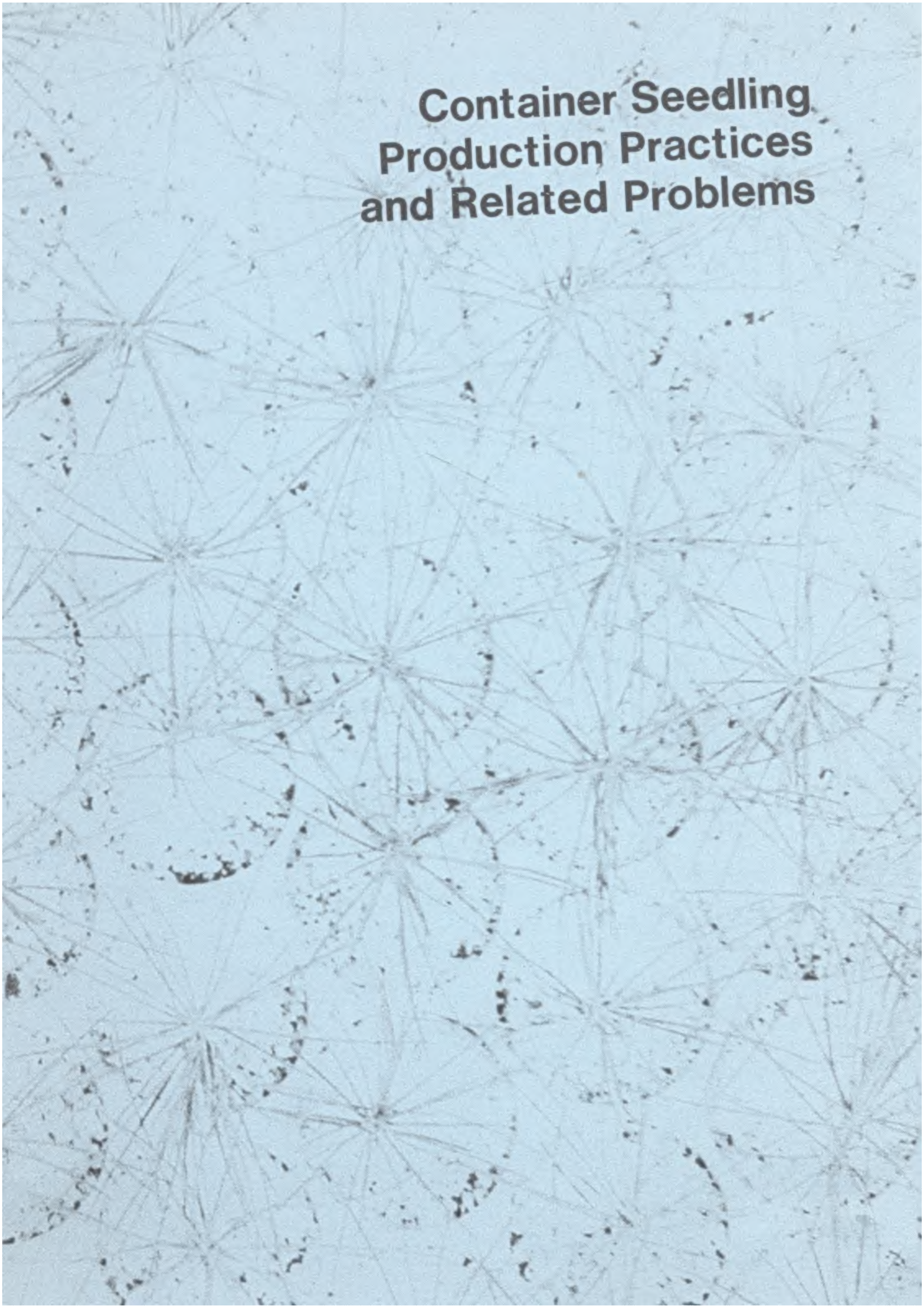
Tree improvement programs are into the second and even third generations throughout the south and containers have proven to be an excellent method of growing seedlings for genetic studies. Under the more controlled conditions, seedlings can be grown more uniformly and the most efficient use can be made of valuable or limited seed supplies. Also, genetic tests are easy to lay out with containers. With adequate planning, trees grown in genetic studies can be produced and outplanted in the season following seed harvest --a year earlier than bare-root trees.

Because seedlings can be studied individually when grown in containers, much can be learned about their physiology that will also apply to bare-root seedlings. Such insights are valuable for improving the quality of seedlings grown by either method.

SUMMARY AND CONCLUSIONS

The use of containerized seedlings will expand steadily in the south because of the advantages they offer and because of the tremendous reforestation requirements of the region. Used as a supplement to bare-root stock, containerized seedlings will extend the planting season, improve survival on adverse sites, as well as survival of difficult species, and improve uniformity of physiological and genetic testing. Mechanization of growing, handling and planting methods will offer opportunities for large-scale container nurseries, and containerized stock will become an important component of reforestation programs.

Container Seedling Production Practices and Related Problems



ENVIRONMENTAL CONTROL OF SEEDLING PHYSIOLOGY

Richard W. Tinus[1]

Abstract.--The greenhouse container nursery offers a degree of control of seedling physiology that the outdoor bare-root nursery cannot match, but this potential can be realized only by a thorough understanding of seedling environmental requirements and the procedures for providing them.

Résumé.--Une pépinière de plants en mottes emballées permet de bien mieux contrôler la physiologie des semis qu'une pépinière en plein air de plants à racines nues, mais il faut pour cela une connaissance parfaite des exigences écologiques des semis et les moyens d'y satisfaire.

The principal difference between the outdoor bare-root nursery and the greenhouse container nursery is in the degree to which the environment can be manipulated to control seedling growth. Seedling genetics are fixed by seed source and cannot be manipulated in the nursery.

In nature, trees receive signals from the environment that tell them when to germinate, grow vigorously, set bud and become dormant, become cold hardened, and break bud. In the greenhouse, we use these same signals to grow the seedlings according to our schedule, not nature's. In this way we can optimize conditions to minimize growing time, thereby achieving a desired seedling size much more quickly than if the seedling were exposed to less controlled conditions (Tinus 1971).

SEED PREPARATION

Seed for the container nursery should be the finest available. Ideally, germination should be prompt and 100% complete, but no seed lot is that good. As germination decreases, an increasing proportion of containers remain empty, unless they are multiple seeded. It is usually worth recleaning the seed to raise germination above 75% rather than wasting a lot of seed and accepting large numbers of multiple seedlings, as these must be thinned to one anyway (Belcher 1978).

Transplanting is feasible during the short period after germination before lateral roots have developed, but it is laborious and often results in stunted seedlings with root deformities. Transplanting should not be adopted in preference to the use of high-quality seed.

Some seedlots can be used dry as they come from the freezer, but in many instances, seed pretreatment is necessary to insure prompt germination (Anon. 1974). In order to germinate, dry seed needs first to imbibe water and, second, to have a supply of oxygen for aerobic respiration. Soaking for 12-48 hours in aerated warm water is usually beneficial and may be all that is required. If not, the next stage is usually cold stratification in which the seed is stored at 1-5 °C and kept moist and well aerated for anywhere between 7 and 150 days, depending on species and seed origin. For instance, jack pine (*Pines banksiana* Lamb.) generally requires no stratification. Lodgepole pine (*P. contorta* Dougl.), red pine (*P. resinosa* Ait.) and ponderosa pine (*P. ponderosa* Laws.) require 30-60 days' stratification only if the seed has been stored for a year or more. Stratification of spruce seed generally does not increase germination capacity but frequently increases germination energy. Alternating day and night temperatures and light at 500 lux or more often enhance spruce germination. During stratification, the necessary processes for breaking seed dormancy are completed; these include completion of embryo development, decrease in germination inhibitors, increase in germination promotors, and activation of enzymes. Sometimes stratifica-

---

[1] Plant Physiologist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Bottineau, North Dakota.

tion can be shortened or eliminated by treatment with hormones such as gibberellic acid or cytokinin (Bonner 1972, Webb and Wareing 1972). In other cases special treatments are required, such as warm stratification before cold stratification, or chemical or abrasive treatment to render the seed coat permeable. However it is done, adequate time must be allowed for presowing treatments so that germination is prompt and complete.

SEED GERMINATION

The seed is sown in a container filled with growing medium and covered with a coarse-textured material that is usually different from the growing medium. The covering should protect the seed from drying and excessively high temperatures, inhibit weed and moss growth, prevent the seed from being dislodged by water or wind, and not interfere with seedling emergence. The two most commonly used materials are granite grit and perlite. Although both serve the purpose well, grit is preferred wherever the containers will be exposed to wind or heavy rain. Many hardwoods can be covered with growing medium, because they grow rapidly and their broad leaves quickly shade out weeds. Some preformed blocks of growing medium are intended to be used without the seed being covered, which is feasible if humidity can be kept sufficiently high.

During germination, the most critical variables are temperature and availability of moisture. Temperature optima for germination vary considerably. Temperature should be maintained at or slightly below optimum. The slightly lower temperature is often preferable because it decreases hypocotyl elongation and results in a sturdier seedling. A high light intensity (50% full sunlight) also helps. A light-colored seed covering is preferred, because it helps keep surface temperatures down. Additional shading may also be necessary.

Standard conditions for germination tests are usually 30°C (daytime) at 500 lux for 8-16 hours, and 20°C for the remainder of the 24-hour period. These conditions are not necessarily optimal for germination. Germination of coastal Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) may be predicted from heat sums over a wide temperature range from 4° to 28°C. The higher the temperature, the faster the germination (Bloomberg 1978). *Betula nana*, a Scandinavian birch, germinated well between 15° and 24°C constant day/night temperatures. Temperature fluctuation of 3°C improved germination at 12-15°C but made no difference at higher temperatures (Junttila 1970). Fraser (1971) found that white spruce *(Picea glauca* [Moench] Voss) germinated best at constant temperatures of 18-22°C, with some variation between seed origins. Fluctuating temperatures were not tested. Godman and Mattson (1980) found temperatures just above freezing optimum for germination of northern red oak *(Quercus rubra* L.).

Until it has developed a fairly deep root system, the seedling is very susceptible to surface drying; therefore, humidity must be kept high and waterings must be frequent. At this stage seedlings are very susceptible to damping-off, although the use of a sterile medium and good greenhouse sanitation generally help to prevent any problem. The need to maintain low water stress must be balanced against the need to let the surface dry as soon as possible to reduce the risk of damping-off. Fungicides are sometimes used routinely as prophylactic measures, but unless disaster is fairly certain without fungicides being applied, I recommend against using them except when a specific need arises. In addition to the risks of reducing root growth and killing mycorrhizal fungi, there is the danger of creating fungicide-resistant strains of pathogens. This has already happened with *Botrytis* spp. (Gillman and James 1980).

During germination, the seedling is supplied with food and mineral nutrients stored in the seed. Hence, mineral nutrients do not need to be supplied by the medium; in fact, keeping such nutrients low, particularly nitrogen, helps minimize pathogen growth. High light intensity and supplemental carbon dioxide are not beneficial at this time. However, total darkness is not recommended either. Some seeds germinate better in light (Smith 1975). In addition, light helps to dry the foliage and pot surface, and this further reduces the chance of fungal infections and keeps the hypocotyl short and sturdy.

JUVENILE GROWTH

Light Requirements

As soon as the food reserves in the seed are used up, the environmental needs of the seedling change. Adequate but not excessive light becomes paramount, because the seedling must now provide its own photosynthate. Inadequate light, which may occur at low sun angles in winter, during extended periods of cloudy weather, or with dirty or discolored greenhouse covering, slows growth. Stem diameter and foliage area are reduced more than height. Excessive light results in unnecessary moisture stress and, in extreme cases, may cause chlorosis by solarization (Ronco 1970).

Shading to reduce excess light is cheap and easy. Adding high-intensity light to increase photosynthesis is expensive and generally not cost effective. It is usually better to plan the growing schedule to avoid the need to add high-intensity supplementary light.

Light required for photosynthesis should not be confused with the low-intensity light used to lengthen the photoperiod, which is one of the most important tools the greenhouse grower has to control growth. When daylength is longer than a critical number of hours, woody plants will continue height growth or may be induced to break bud. When daylength is shorter than a critical number of hours, the plants will set bud. For a given species, the farther north or higher the elevation of its origin, the stronger its reaction to photoperiod, and the longer the daylength required to prevent dormancy (Junttila 1980). The longer a seedling has been growing without a dormant period, the longer the critical daylength. Since the critical daylength is usually not known for a given group of seedlings, the safest and surest way to prevent bud dormancy is to give them the equivalent of a 24-hour day (Tinus and McDonald 1979).

There are several important differences between the quality of light required for photosynthesis and that required for dormancy prevention. For the latter, wavelengths shorter than 550 nm are of no value, and wavelengths between 700 and 770 nm reverse the effect of red light (600-700 nm). As red light intensity increases from zero, there is a threshold below which there is no photoperiodic growth response. Above the threshold, height growth increases rapidly with light intensity and then tapers off at an upper intensity limit above which there is no further response. For the majority of species, full response can be obtained with 400 lux (even less for some species [Arnott 1974, 1976, 19791), which is two orders of magnitude less than what is required for maximum photosynthesis.

The light required for photosynthesis provides energy for synthesizing carbohydrates, and this is why the light intensity must be high and continuous. In contrast, light for dormancy control acts as a trigger; it requires very little energy and may be intermittent (Cathey and Campbell 1977). The photoperiod control lights can be on as little as 3% of the time, provided that no single dark period is longer than 30 minutes. Since the intensity and duration of light required for dormancy control are minimal, it is not only economically feasible to provide this amount of light but, under most conditions, it is important to do so (Tinus and McDonald 1979).

Temperature

Temperature is also important in determining growth rate, bud set, and bud break. Optimum growing temperatures for many species have been determined (Tinus and McDonald 1979). Many species e.g., lodgepole pine[2], will continue height growth over a wide range of temperatures provided that the photoperiod is sufficiently long. Others, such as bur oak *(Quercus macrocarpa* Michx.), may set bud in response to cool nights regardless of photoperiod.

Species differ in the minimum age or size at which they can set bud. Engelmann spruce *(Picea engeZmannii* Parry) and white spruce are capable of setting bud in the cotyledon stage, and they should be started on extended photoperiod as soon as they germinate. On the other hand, pines will generally not set bud until they have made substantial epicotyl growth.

Nutrients

After the seed coat is shed, the seedling must be provided with mineral nutrients, particularly nitrogen. The best way to provide them is "according to need", which is easier said than done (Mills and Jones 1979, Brown 1980). Each element needed has a specific role to play in plant metabolism, and the quantity available to the plant must not only be adequate, but must also be in balance with the other mineral nutrients. The provision of a balanced and adequate supply of nutrients is an important function of the growing medium. Nutrient ions may be present in three forms: in the soil solution, adsorbed on the exchange complex, or as a slightly soluble solid. The plant takes up nutrient ions from the soil solution, but exchangeable and solid forms provide a reservoir that can greatly increase the available supply without raising the salt concentra-

---

[2] Tinus, R.W. 1976. Growth of white spruce and lodgepole pine under various temperature and light conditions. Unpubl. Rep. to Alberta Dep. Energy and Nat. Resour., Edmonton. 19 p. (Under coop. agreement 16-573-CA with USDA For. Serv.)

tion. Some ions also act as buffers to keep the pH in a favorable range. Control of pH is important for maintaining nutrient ion availability, promoting the development of mycorrhizae, and suppressing pathogens. Detailed recipes for preparation of nutrient solutions are available in Tinus and McDonald (1979) and Carlson (1979).

Growth Medium

As the seedling root grows downward, the texture and composition of the growing medium become important. Roots must be able to penetrate the medium easily. Both adequate water supply and good aeration are necessary. High cation-exchange capacity is desirable, and addition of solid mineral nutrients and inoculation with mycorrhizal fungi may also be desirable. The medium should contain no toxic materials or pathogens.

To date, peat alone or mixed with vermiculite has been the overwhelming favorite, because it meets the above criteria well. Nevertheless, the search for other materials goes on, either for manufacturing convenience or because of an abundance of a cheap local material.

Containers

Sooner or later, the seedling roots strike the container wall. The container itself is an important component of the seedling environment, because it determines the size and shape of the root system (Hiatt and Tinus 1974, Biran and Eliassaf 1980). Container volume determines the size of tree that can be grown in the container; container shape is important for the production of an unentangled root system that will promote rapid field establishment and windfirmness. The container and its support structures also determine bed density. Here, there is a direct conflict between production economics, which dictates maximum number of trees per unit area, and seedling biology, which requires ample growing room to produce seedlings of adequate diameter. High density seedlings may be sufficiently tall, but they will be spindly and their photosynthetic area will be inadequate. Tightly packed crowns also promote foliar disease.

In rigid, impermeable-walled containers, vertical ribs or grooves, lack of sharp horizontal corners, and an egress hole at the bottom for air pruning, are almost universally used to produce a vertical root system without spiralling roots. The container is removed before outplanting, leaving the roots free to grow into the surrounding soil. Unfortunately, most of the new roots develop from growing points at the very bottom of the plug, leaving the seedling with an inadequate surface lateral root system that may lead to twizzling and toppling of older trees (Tinus 1978). A new technique to increase the number of surface lateral roots by treating the container walls with latex paint containing copper carbonate appears promising (Burdett 1978, McDonald et al. 1980).

Containers with walls permeable to roots prevent root spiralling in a manner different from impermeable-walled containers. Where it is possible for roots to grow from one container into the next, the roots must be broken cleanly at the container wall to separate the containers for planting. Therefore, seedlings must generally be limited to a small size to ensure that the roots broken are not very strong and only a small portion of the root system is lost. Containers may also be separated by an air space which the roots do not cross. The seedlings are ready to plant when the roots emerge from the containers, and they should not be held longer.

EXPONENTIAL GROWTH

After the seedling is firmly established, provided that growing conditions are near optimum, it begins growing exponentially, i.e., the bigger it gets the faster it grows. This takes place either continuously or in a series of sequential flushes. The key to growing a large seedling in a short time is to keep it growing exponentially until it is as tall as desired. If the seedling sets bud and becomes dormant prematurely, it may be impossible to meet height specifications on schedule. If it is necessary to meet bud chilling requirements to obtain another flush of height growth, the crop will likely be an economic disaster.

The environmental requirements for exponential growth are usually much the same as for juvenile growth, except that optimum temperatures are often a few degrees higher, and as the crowns close, the seedlings can use higher light intensity. Elevated CO2 levels increase growth, especially in cold weather when the greenhouse can be kept closed, provided that nothing else limits growth. For maximum growth rate, it is important that as many environmental factors as possible be optimized, since a number of factors often act synergistically (Tinus 1977).

HARDENING

Before a seedling can be moved out of the greenhouse to the holding area or planting site, it must be in proper condition to withstand a less favorable environment. In maritime climates and sometimes in continental climates as well, it is possible to transplant an actively growing succulent tree seedling directly to the field; however, survival is usually better if dormant seedlings are planted.

There are two stages in the hardening process: dormancy induction and cold hardening (Alexander and Havis 1980). The first stage is induced by shortening the daylength and reducing temperature about 5-10 °C below optimum for growth. For some species this is all that is required, whereas others also require drought stress. The seedlings are first leached to remove nitrogen. Then water is withheld until moisture stress reaches 15 bars or higher, depending on ecotype. The seedlings may be rewatered with a low N nutrient solution as needed. If they show signs of breaking bud again, they may need another drought stress. Induction of dormancy in some species such as Siberian larch *(Larix sibirica* Ledeb.) is difficult, and drought stress must start up to 3 weeks before the seedlings have reached the desired height.

During the first stage of hardening, buds are set. It is important that the buds be given enough time to develop adequately, because in many species the primordia laid down in the bud constitute most if not all of the cells for the next flush of growth (Owens and Molder 1973, 1976a, 1976b, 1979; Young and Hanover 1977). At the same time stem diameter and lignification increase, greatly increasing the sturdiness of the seedling and its chances of survival in a hostile environment. A flush of root growth commonly occurs at this time, thereby reducing the shoot:root ratio. It has also been my experience that during rapid height growth few if any mycorrhizae appear on the roots, even though the growing medium was inoculated before seeding, and the seedlings show increased vigor and freedom from pathogens because of the inoculation. However, with the reduced stem growth and increased root activity, mycorrhizal structures appear.

High CO2 can be beneficially maintained during the first stage of hardening of most conifers, but it must be shut off to begin hardening of deciduous species, as high CO_2 retards leaf abscission.

At this point, seedlings are "summer dormant" and prepared to withstand full sunlight, drought stress, wind, and even a light frost. They are ready to be outplanted during the summer or early fall. Many species in this condition should not be spring planted, because they will not break bud until the following year. They should be planted not later than 4 weeks before the soil temperature falls below the minimum for root growth (about 5 °C).

The only additional change to initiate the second stage of hardening is to lower the temperature to just above freezing and shut off supplemental CO2, if that has not already been done. The seedlings should be on short days, but they must have light because, during hardening, metabolic changes occur that require photosynthate. Under these conditions the seedlings will develop cold hardiness and become resistant to hard frosts, but to develop full hardiness, they must experience subfreezing temperatures. Seedlings should be subjected to frost only after being held for at least 2 weeks at temperatures just above freezing. Depending on how they will be overwintered and where and when they will be planted, they may not need to be fully cold-hardened.

The other function of low temperature is to meet bud chilling requirements. After the bud becomes fully dormant, it frequently will not break dormancy when the seedling is returned to favorable growing conditions. Prolonged chilling releases bud dormancy. After the necessary chilling period, it is only low temperatures, sometimes aided by a short photoperiod, that keep the buds from breaking (Litzow and Pellett 1980).

OVERWINTERING

Once fully hardened, seedlings can be stored in the dark if necessary, but light is usually beneficial. In cold climates container nurserymen have frequently raised beautiful seedlings only to have them damaged during overwinter storage (Desjardins and Chong 1980).

There are three principal causes of overwinter damage, the most obvious of which is low temperature. Containerized seedlings are more susceptible to low temperature damage because the roots, the most sensitive part of a hardened seedling, are above ground. To avoid damage, the seedlings must have had adequate time under proper conditions to harden sufficiently and be adequately protected against lethal temperatures.

The second cause of winter damage is desiccation. When the rootball is frozen, seedlings may not be able to replace moisture as fast as it is lost. Desiccation can be avoided by preventing the rootball from freezing. If freezing is unavoidable, moisture loss can be retarded by using moisture barriers and minimizing temperature fluctuations, or perhaps by supplying moisture to the tops as well as the roots.

Finally, rodents and diseases may damage seedlings. Mouse damage may be eliminated by preventing mice from gaining access to the crop. The second best approach is to minimize suitable pest habitat, and to bait and trap. Foliage molds are more likely to develop if the seedlings are in the dark, too wet, or much above freezing. Disease during the winter is insidious, because the rot and mold fungi responsible can grow at low temperatures, but the seedling cannot, and its internal defenses are minimal. The crop generally receives less attention and supervision over winter, and the damage is often not quickly evident.

SPRING CARE

If the crop is overwintered in a greenhouse, it must be watched carefully in late winter for signs of bud swell. In late winter it becomes difficult to keep day temperatures in a greenhouse below 10°C, and the seedlings begin to deharden. Before the first sign of dehardening, the trees must be moved to alternative storage, either in a cooler or in a lathhouse outdoors. Under most circumstances the seedlings should not be allowed to break dormancy before they are outplanted. Even if budbreak does occur in the nursery, often the seedlings are still plantable, but more care in transit is needed to avoid damaging the new growth. Often it is better to hold the seedlings until the new flush of growth is complete and the new growth hardened. Full sunlight, drought stress, and low N can be used to keep the seedlings from outgrowing their containers.

PITFALLS

A decade ago, the number of container-grown seedlings in North America was negligible. Today, containerized seedlings account for about 12% or 150 million of all forest tree seedlings produced. Such an achievement would be impossible without the extensive information we now have on seedling biology. However, certain problems resulting from the conflict between the needs of seedling biology and production economics or from poor management practices tend to recur frequently (Tinus 1982).

The selection of too small a container may keep nursery and planting costs low, but what really counts is the cost of an established seedling free to grow. It is better to start with a large enough container, even if it looks too expensive. After the planting system succeeds, then see if a smaller one will do. Frequently, a variety of sizes will be needed to handle different species and different planting sites.

There is often a great temptation to cut short the hardening process to save operating costs, because during hardening there is often little change in the appearance of evergreen seedlings, and there are no quick, readily available tests for monitoring the degree of hardening. Currently, the best assurance is adequate time under proper hardening conditions.

Every nursery should keep careful and detailed records of all cultural operations and seedling growth. If anything goes wrong, these records are invaluable for determining the cause quickly and prescribing corrections.

If the system works, don't tamper with it. Any proposed change should be tested in a small way before it is applied to the entire nursery. Unfortunately, it is not uncommon that after two successful crops a nurseryman may think he is an expert and entitled to remold the growing regime at will. Frequently, when called upon to help, I find the nursery is no longer doing the things that originally made it successful.

LITERATURE CITED

Alexander, L.A., and Havis, J.R.
1980. Root temperature effects on cold acclimation of an evergreen Azalea. Hort. Sci. 15:90-91.

Anonymous.
1974. Seeds of woody plants in the United States. USDA For. Serv., Washington, D.C. Agric. Handb. 450, 883 p.

Arnott, J.T.
1974. Growth response of white-Engelmann spruce provenances to extended photoperiod using continuous and intermittent light. Can. J. For. Res. 4:69-75.

Arnott, J.T.
1976. Container production of high elevation species. p. 12 *in* Proc. Joint Meet. West. For. Nursery Counc. and Intermt. Nurserymen's Assoc.

Arnott, J.T.
1979. Effect of light intensity during extended photoperiod on growth of amabilis fir, mountain hemlock, and Engelmann spruce seedlings. Can. J. For. Res. 9:82-89.

Belcher, E.W.
1978. Aspects of seed quality. p. D-54 to D-59 *in* Comb. Proc. West. For. Nursery Counc., Intermt. Nurserymen's Assoc., Seed Processing Workshop. USDA For. Serv., State and Private For., Region 5, San Francisco, Calif. 306 p.

Biran, I., and Eliassaf, A.
1980. The effect of container size and aeration conditions on growth of roots and canopy of woody plants. Sci. Hort. 12:385-394.

Bloomberg, W.J.
1978. Heatsum-emergence relationship in Douglas-fir seedlings. Can. J. For. Res. 8:23-30.

Bonner, F.T.
1971. Stimulation of germination by gibberellins. I. Preliminary work. South. For. Exp. Stn., For. Tree Lab., State College, Miss. 36 p.

Brown, J.H.
1980. Survival and growth of seedlings of Scots pine provenances at varying nutrient levels. Ohio Res. and Dev. Ctr. Res. Bull. 1120, 15 p.

Burdett, A.N.
1978. Control of root morphogenesis for improved mechanical stability in container-grown lodgepole pine. Can. J. For. Res. 8:483-486.

Carlson, L.W.
1979. Guidelines for rearing containerized conifer• seedlings in the Prairie Provinces. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-214. 62 p.

Cathey, H.M. and Campbell, L.E.
1977. Light frequency and color aid plant growth regulation. Am. Nurseryman, CLXLVI(10):16-18, 108-114.

Desjardins, R.L. and Chong, Calvin.
1980. Unheated environments for overwintering nursery plants in containers. Can. J. Plant Sci. 60:895-902.

Fraser, J.W.
1971. Cardinal temperatures for germination of six provenances of white spruce seed. Dep. Fish. For., Can. For. Serv., Ottawa, Ont. Publ. 1290. 10 p.

Gillman, L.S. and James, R.L.
1980. Fungicidal tolerance of *Botrytis* within Colorado greenhouses. Tree Plant. Notes 31(1):25-28.

Godman, R.M. and Mattson G.A.
1980. Low temperatures optimum for field germination of northern red oak. Tree Plant. Notes 31(2):32-34.

Hiatt, H.A. and Tinus, Richard W.
1974. Container shape controls root system configuration. p. 194-196 *in* R.W. Tinus, W.I. Stein, and W.E. Balmer *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No.68.

Junttila, Olavi.
1970. Effects of stratification, gibberellic acid and germination temperature on the germination of *Betula* nana. Physiol. Plant 23:425-433.

Junttila, Olavi.
1980. Effect of photoperiod and temperature on apical growth cessation in *Salix* and *Betula.* Physiol. Plant 48:347-352.

Litzow, M., and Pellett, H.
1980. Relationship of rest to dehardening in red-osier dogwood. HortSci. 15(1):92-93.

McDonald, S.E., Tinus, R.W. and Reid, C.P.P.
1980. Root morphology control in forest tree seedling containers. p. 40-45 in Proc. Intermt. Nurseryman's Assoc. and West. For. Nursery Assoc. Combined Meet. USDA For. Serv. Gen. Tech. Rep. INT-109, Ogden, Utah.

Mills, H.A. and Jones, J.B., Jr.
1979. Nutrient deficiencies and toxicities in plants. Nitrogen. J. Plant Nutr. 1(2):101-122.

Owens, J.N. and Molder, Marje.
1973. Bud development in western hemlock. I. Annual growth cycle of vegetative buds. Can. J. Bot. 51:2223-2231.

Owens, John N. and Molder, Marje.
1976a. Bud development in Sitka spruce. I. Annual growth cycle of vegetative buds and shoots. Can. J. Bot. 54:313-325.

Owens, John N. and Molder, Marje.
1976b. Development of long-shoot terminal buds of western white pine *(Pinus monticola).* Can. J. Bot. 55:1308-1321.

Owens, John N. and Molder, Marje.
1979. Bud development in *Larix occidentalis.* I. Growth and development of vegetative long shoot and vegetative short shoot buds. Can. J. Bot. 57:687-700.

Ronco, Frank.
1970. Influence of high light intensity on survival of planted Engelmann spruce. For. Sci. 16(3):331-339.

Smith, Harry.
1975. Phytochrome and photomorphogenesis. 235 p. McGraw-Hill, New York, N.Y.

Tinus, R.W.
1971. A greenhouse nursery system for rapid production of container planting stock. 1971 Annu. Meet. Am. Soc. Agric. Eng. Pap. 71-166, 17 p.

Tinus, R.W.
1977. Production of container grown hardwoods. p. 126-136 *in* Proc. Internat'l Nursery Assoc. Meet. State and Ext. For., Kansas State Univ., Manhattan.

Tinus, R.W.
1978. Root system configuration is important to long tree life. Internat'l Plant Propagators Soc. Comb. Proc. 28:58 62.

Tinus, Richard W., and McDonald, Steven E.
1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. Gen. Tech. Rep. RM-60, 256 p.

Tinus, Richard W.
1982. Future of greenhouse container nursery systems in the south. p 149-152 in Richard W. Guldin and James P. Barnett, *Ed.* Proceedings of the Southern Containerized Forest Tree Seedling Conference. USDA For. Serv., Southern For. Exp. Stn., New Orleans, La. Gen. Tech. Rep. 50-37.

Webb, D.P. and Wareing, P.F.
1972. Seed dormancy in *Acer:* Endogenous germination inhibitors and dormancy in *Acer pseudoplatanus* L. Planta (Berlin) 104:115-125.

Young, Eric and Hanover, James W.
1977. Development of the shoot apex of blue spruce *(Picea pungens).* Can. J. For. Res. 7:614-620.

THE FUNDAMENTALS OF CONTAINER SEEDLING PRODUCTION

E. Van Eerden[1]

Abstract.--Experimental and operational production of container stock during the last 10 years has repeatedly demonstrated that seedlings of required morphological and physiological characteristics will be produced only if the principles of containerization are closely adhered to. Mass production of seedlings in small containers at close spacing will continue to yield positive results if the hard-won lessons of the past are put into practice.

Résumé.--Au cours des dix dernières années, la culture expérimentale et à grande échelle de semis en motte emballées permis à maintes reprises de démontrer qu'il n'est possible d'obtenir les caractéristiques morphologiques et physiologiques désirées que si on se conforme étroitement aux principes de ce type de culture. La production à grande échelle, à l'aide de petits contenants peu espacés, continuera de donner des résultats positifs si on met en pratique l'expérience durement acquise par le passé.

INTRODUCTION

Much of the information that will be presented at this meeting has been reported previously at the 1974 Denver symposium (Tinus et al. 1974), in several manuals, and in numerous other technical reports and articles. In addition, a large body of operational experience has been amassed during the last decade. Accordingly, the saying "to understand the past is to know the future" might be expected to apply to the subject under discussion at this symposium. In reality, however, we do not always capitalize on the experience of our past accomplishments and mistakes. The thin line between success and failure is frequently overlooked, and the potential benefit and intricacies of controlled environment growing are generally not fully appreciated. Thus, it seems that we have not yet heeded the words of an early philosopher who said, "the best fertilizer on any farm is provided by the farmer's footsteps". In my presentation, I intend to retrace some of the footsteps of our experience by highlighting the key ingredients for successful containerized forest seedling production.

PLANTING STOCK STANDARDS A PREREQUISITE

The ability to manipulate stock size and quality of container-grown seedlings through controlled environment culture holds the promise of "tailoring" stock to specific site characteristics and requirements. Morphological and physiological quality standards are indispensable prerequisites for realizing that promise. However, in spite of voluminous nursery records and a plethora of reports on the performance of various stock types, current stock specifications frequently reflect opinions rather than a sound interpretation of past experience. For the most part, such specifications are limited to a designation of species, stock and/or container type, and age class.

Preoccupation with the "numbers game", compounded by the effects of periodic crop failures and inventory fall-down, often leaves no alternative but to go "potluck" and to take what is available. As a result, stock is frequently shipped and planted with

---

[1] Container Systems Coordinator, Silviculture Branch, Ministry of Forests, Victoria, British Columbia.

little regard for size and quality, and irrespective of any standards that may have been specified.

The significance of various physiological criteria for seedling performance remains to be determined for many species. Sufficient information is available, however, to define preliminary morphological standards. In setting such standards, it should be considered that the potential for rapid early growth is of greater consequence than initial survival, especially for stock destined for rich sites. From my experience in the boreal and sub-boreal forests of British Columbia, this built-in potential for rapid early growth is particularly important for white spruce *(Picea glauca* [Moench] Voss). The notion that white spruce is inherently subject to planting check is a myth. Lack of rapid early growth reflects deficiencies in site preparation and/or planting stock size and quality, with the latter being the primary cause of poor initial growth. Hence, Armson's (1976) observation that "standards must be based on the best growth attained and not on the average, or mediocrity will result", applies to nursery stock as much as it does to plantations.

Experience in British Columbia has shown that container-grown seedlings of the minimum standards presented in Table 1 are both attainable and suitable for a wide range of forest conditions throughout the boreal and sub-boreal forests. Sites subject to heavy brush invasion may require significantly larger planting stock, although the details of producing such stock need not concern us here. The important point is that the nurseryman is provided with the site-specific stock specifications at the time the sowing request is made.

THE CONTAINER

Despite many years of experimental and operational production with a variety of containers, misconceptions about containerization persist. Let us deal with some commonly held views about containerization at the outset:

1) Container-grown stock has the intrinsic ability to compensate for shortcomings in nursery practice, stock size and quality, handling, storage and transport, site preparation, and planting.

   This statement is false.

2) The larger the container, the better the planting stock will be.

   This statement is also false.

3) Containers cause root deformation which, in turn, may lead to instability, basal sweep and toppling.

   Although this statement may be valid for some species growing under certain environmental and climatic conditions, notably some of the pines, or in containers of faulty design, no significant economic losses of boreal and sub-boreal species grown in containers have yet been reported in Canada. In reality, the risk of root deformation and subsequent plantation failure is no less significant for other nursery production and planting techniques.

4) Container stock can be used to extend the planting season.

Table 1. Minimum standards for container-grown white spruce and lodgepole pine *(Pinus contorta* Dougl. var. *latifolia* Engelm.) in British Columbia.

		Minimum specifications						
		Primary		Secondary				
Species	Size class	Height (cm)	Root coll. diam. (mm)	Shoot dry weight (g)	Root dry weight (g)	Total dry weight (g)	Shoot:root ratio	Container equivalent required[a]
White spruce	small	12.5	2.2-2.5	0.8	0.4	1.2	1.5-2.0	PSB 211
	medium	17.0	2.5-3.0	1.0	0.5	1.5	1.5-2.0	PSB 313
	large	20.0	4.0-4.5	3.0	1.5	4.5	1.5-2.0	PSB 415
Lodgepole pine	-	12.5	2.2	0.7	0.3	1.0	1.0-1.5	PSB 211

[a]PSB 211 - Styroblock-2A cavity.
PSB 313 - Styroblock-4A cavity.
PSB 415 - Styroblock-8 cavity.

While this statement is generally true, extension of the planting season through the use of container-grown stock represents a relative advantage only. Although adverse climatic conditions do take their toll of container stock, the effects are generally not as severe as they are for bare-root stock. Performance of stock under specific climatic and weather conditions is a function of seedling condition rather than stock type *per se.*

The desired characteristics of seedling containers are well documented, notably by Kinghorn (1974). In summary, for a container to be biologically acceptable, it must:

1) have a cavity volume and spacing which permit seedlings to be grown to a size and quality dictated by site requirements. Cavity volumes of 40 to 60 cm^3 and a spacing of 700 to 1100 $cavities/m^2$ are generally satisfactory for the production of a size and quality of stock suitable for most sites. Only if the biological limits of a certain size of container have been fully exploited can use of larger containers be justified. If this is the case, care should be taken to ensure that any increase in cavity volume is accompanied by a concomitant increase in cavity spacing. In the interest of cost-effectiveness, transplanting from initially small to successively larger containers or transplant beds may be a preferred method of production for large stock.

2) protect stock and root systems in the nursery.

3) prevent pot-binding and extension of roots below the container through proper container design and provision for air-root pruning; minimize cross-over of primary laterals by vertical ribs on cavity walls. A facility for mechanical or chemical pruning of primary laterals at the point of contact with the container wall would be a desirable feature for some species.

4) prevent roots from growing into container walls, and/or into adjacent cavities.

5) minimize the risk of contamination and sanitation problems. Designs which permit the accumulation of growing medium, grit, or other material between blocks or trays are unacceptable in this respect.

To be logistically and economically acceptable, containers must:

1) be relatively inexpensive;

2) be modular in design to permit efficient mechanized loading, seeding, and handling for a variety of cavity sizes and spacings, and require only minor modifications of equipment during the preparation or growing phases to accommodate various container sizes;

3) be of such a composite size and contain such a number of cavities that efficient manual handling, where required, is feasible;

4) permit ready extraction of seedlings without injury prior to planting;

5) facilitate high rates of planting productivity without compromising planting quality.

THE NURSERY PHYSICAL PLANT

Capital Investment

At present, 30 to 40% of container seedling production costs are due to interest charges on investment and working capital. Consequently, there is an urgent need to minimize investment in equipment and growing facilities. The argument that high interest costs simply reflect the present realities of doing business does not lessen their impact. There are already examples in North America of excessive capital investment in container-growing facilities leading to closure of those facilities and a return to bare-root practice. Therefore, if container production is to remain an economically viable seedling production system, we must be vigilant and prudent in our selection of and investment in container nursery physical plant.

Of the factors that influence the design, development, and location of a nursery, those that have the greatest impact on costs are, fortuitously, also the most flexible. Species, planting stock standards, container dimensions, required environmental conditions, and logistics are relatively fixed, but growing facilities, crop schedules, and nursery location can be varied to suit various biological and economic objectives.

Growing Facilities

In designing and building growing facilities, we should always ask ourselves to what extent the natural environment needs to be modified.

Experience in public and some private nurseries in British Columbia has demonstrated that the environmental conditions of low-cost plastic houses are suitable for production of white spruce and logepole pine in most locations. They can be operated with minimal heating and the use of natural ventilation by rolling up the plastic sidewalls, as recommended by Towning and Turkewitsch (1980). Double poly-covered houses not only minimize heating costs but also preclude the need for additional expenditure on shading equipment by providing about 30% shade, which is ideal for the early growth phase of spruce.

The costs of plastic houses are less than half those of glass or fibreglass houses. Sullivan (1975), addressing the Tennesee Valley Greenhouse Vegetable Workshop, when interest rates were much lower than they are today, reached similar conclusions. He noted that annual variable operating costs are largely unaffected by the type of growing facility. Furthermore, he observed that annual fixed production costs for temporary plastic houses, including depreciation and maintenance of various types of greenhouses, were \$3.87/m^2, in comparison with \$3.77 and \$5.27 for glass and fibreglass houses, respectively, and that initial capital costs for plastic houses were one-third those of glass greenhouses. Sullivan concluded that in times of scarce capital, low-cost plastic houses are clearly the preferred alternative, and that savings in initial capital cost for growing facilities might profitably be applied to other components of the production unit. Irrigation equipment is a good example; undue economies in the selection of an irrigation system can prove disastrous, both directly and indirectly. Although the magnitude of the investment involved in 1981 is much greater, Sullivan's observations are as valid today as they were in 1975.

In addition to provision of a suitable growing environment, it must be recognized that the nursery business is essentially a materials handling business. Consequently, it is important that a facility be designed for maximum efficiency in the flow of materials (Sheldrake and Sayles 1974) and use of labor. Most commonly, the equipment and labor are taken to the crop (Short 1975). The other approach, transporting the crop to the machinery and labor, requires construction of special facilities and, hence, increases capital costs. In British Columbia, most government nurseries employ the first option of moving the equipment and labor. This low capital investment approach works effectively for many locations in the province and will, undoubtedly, work elsewhere also.

Greenhouse Benching

The subject of bench systems is one of continuing controversy. The type of benching not only affects plant quality and root form, depending on whether it provides for air-root pruning, but can also have significant effects on the cost of crop processing and greenhouse management.

Unlike many horticultural operations, production of forest tree seedlings is a non-profit or, at best, a low profit/unit industry. Once germinated and thinned, seedling crops are rarely handled until shipping. As a consequence, the need for walkways is minimal, permitting high efficiency in the use of floor space. Although the use of stationary crop support systems obviously requires some degree of compromise in labor efficiency, experience in government nurseries in British Columbia indicates that some of the more sophisticated rolling bench systems used in horticultural nurseries cannot be justified in forest container nurseries if capital costs are to be minimized. In addition to being expensive, such systems may also create storage problems during annual cleanup operations. The aluminum stringer bench system which is widely used in government nurseries in British Columbia has proven cost-effective, and culturally and logistically suitable.

Equipment versus Labor

Opinions vary widely on the extent to which capital investment should substitute for labor. Short (1975) suggests that the potential gain associated with replacement of labor by capital is limited, because it is often difficult and expensive to replace delicate hands and a trained eye. As Tinus and McDonald (1979) point out, it is important to evaluate both the short-term and long-term implications of mechanization by considering the following two questions:

1) Is equipment needed to meet biological requirements?

2) If it is not, is it prudent to save on labor?

In characterizing the forest nursery business as comprising brief periods of high volume, high employment, and intense activity, the same authors advise that short-term jobs can be accomplished efficiently through intensive application of labor, and that, if activities are long-lasting or continuous, mechanization becomes more feasible. Here lies the key for deciding which tasks to mechanize and which activities to leave to manual labor. Experience in British Columbia serves to illustrate the point. Until mechanized equipment for container filling, seeding and seed covering was developed, these operations posed serious impediments to the further development and expansion of container production. Not only were those operations exceedingly expensive when done manually, but they were slow and precluded completion of sowing within the short time necessary to produce uniform and good quality crops. It was therefore essential that mechanized equipment be developed, to ensure that the job of sowing was done quickly and efficiently. This same reasoning, however, cannot be applied to seedling extraction and preparation for storage, shipment, or planting. Grading and culling are essential in the production of high-quality stock, and are best carried out at the nursery by trained workers to ensure that they are done in a well organized and efficient manner. There is no merit in shipping empty cavities and cull seedlings to the field.

Energy Considerations

The cost of energy in greenhouse operations is a major topic, and will be addressed by another speaker at this Symposium (Cameron 1982). My remarks in this area will therefore be brief.

With the continued increase in energy costs, it is essential that the design and location of container nurseries be such that energy consumption is minimized. In addition, cultural schedules should be adopted that will minimize the amount of heating required. In British Columbia, this requirement has traditionally been satisfied by locating container nurseries in the climatically more favorable regions of the province, and by employing single-crop schedules which capitalize on a somewhat extended normal growing season. However, with the recent introduction of the concept of local seedling production, nurseries are now being established in regions with less than optimum climates as well. Indications are that the use of double-poly-covered and free-standing houses, together with single cropping, will circumvent the need for extensive heating in those areas.

Notwithstanding the logistical advantages of localized production, it may be preferable to produce or start stock in localities with more favorable climates--perhaps even at distant locations--and to transport the finished product if heating costs become prohibitive. As was pointed out by Perkins et al. (1975), the rising cost of fuel for transport will never match the energy costs of heating and cooling of greenhouses, with the latter always significantly greater.

It appears that efforts to minimize energy consumption in the greenhouse industry have focussed largely on energy conservation in traditional and standard facility designs. While these efforts are laudable, I believe that much more could be accomplished through development of new greenhouse designs and through innovations in cultural practices and schedules.

Nursery Physical Plant: A Synopsis

Critical evaluation of fixed and variable costs, prior to construction (Perkins et al. 1975), is essential to ensure that container stock production remains an economically viable seedling production system. Such analyses should include capital investment projections, the costs and benefits of tradeoffs between labor and equipment, and energy budgets for various types of facilities in different climates.

CONTAINER SEEDLING CULTURE: BASIC INGREDIENTS

Intensive Management

In the introduction to their Nursery Soil Management Manual, Armson and Sadreika (1974) state that "production of seedlings in a nursery represents an intensive form of management". The principle embodied in this statement is of even greater consequence in the production of container stock than it is in bare-root culture.

For economic reasons, container systems used in forestry typically utilize small containers at close spacing. Such mini-plant pots confine seedlings to an environment which is characterized by narrow limits of reserves and tolerances, in which reserves of water and nutrients are rapidly depleted while excesses of any kind quickly predispose seedlings to injury or even mortality (Van Eerden 1974). The effects of inadequate facilities, poor equipment, water quality, and imperfect environmental conditions can, to a large extent, be compensated for by the application of sound cultural practices. However, failure to recognize the fundamental principle that container seedling crops require intensive management will inevitably lead to failure and negate the promise of consistent and reliable production of high-quality seedlings that container growing offers.

Administrative responsibilities and the problems associated with the complexities of running a large operational nursery should never be accepted as a legitimate excuse for deficiencies in cultural practices.

Production Schedules

Multi-cropping and winter growing are controversial subjects, not only with respect to forest seedling production, but also in the horticultural industry. On the horticultural side, the desire for year-round growing obviously stems from an interest in lower per unit costs and higher net annual profits. On the forestry side, multi-cropping is probably similarly motivated, as well as an attempt to play the "numbers game" with limited resources. However, as Sullivan (1975) points out, double cropping can result in higher break-even requirements for large operations and can be uneconomical for nurseries with less than 4600 m^2 of capacity. In my view, this conclusion probably applies to forest nurseries as much as it does to horticultural operations.

Although imaginative techniques (e.g., rotation of crops between facilities with varying degrees of environmental control, or the development of a fully mechanized transplanting system for transplanting stock from mini-containers) and the application of other technological advances hold some promise, it is doubtful that multi-cropping and winter growing are feasible at the current stage of development.

Towning and Turkewitsch (1980) have recommended that greenhouses be closed from December through February. As it takes a minimum of 30 to 32 weeks at about 20 °C to grow seedlings to required specifications, I am left to conclude that multi-cropping and winter-growing have limited value in present forest seedling container practices.

Single cropping during a somewhat extended "normal" growing season currently provides the only biologically optimum and cost-effective operational production schedule. This approach will ensure that crops can be grown to required specifications in relatively low-cost facilities with minimal consumption of energy.

Growth Monitoring

The collection of growth data, including periodic measurement of height, root collar diameter, and dry weights is useful not only for training or historical purposes but also for providing the beginnings of a quality control program. Once sufficient growth data have been collected and standard growth curves have been prepared for a particular combination of species, container, growing facility, and cultural regime, nurserymen have the basic ingredient for tracking growth at any point in the crop cycle. In other words, growth records in the form of standard growth curves provide a management tool which can be used to alter growth through cultural manipulation. Accordingly, monitoring of seedling growth on the basis of standard growth curves is highly recommended.

Test Programs

The use of untested materials and equipment, and unquestioning acceptance of the instructions and guarantees of suppliers and manufacturers, in many instances have proven to be an open invitation to disaster. The dictum "Let the buyer beware" is not to be taken lightly. Unqualified modification of proven cultural techniques, biological materials and equipment should be viewed as highly speculative; without prior testing, such changes carry a very significant risk. Frequently, techniques and materials which have proven satisfactory for production of seedlings in relatively unlimited soil volumes are not suitable for the production of seedlings in the mini-plant pots used in forestry (Kinghorn 1971). Therefore, a testing and pilot production program must always precede the introduction of new or modified materials, techniques and equipment into operational production.

Sanitation

Many of the pest problems encountered in forest tree seedling container nurseries reflect deficiencies in crop monitoring and cultural practice. This applies not only to weeds, including mosses, algae, and liverworts, but also to insects and diseases. Generally, development of a pest problem requires (1) a susceptible host, (2) a pest organism, and (3) a suitable environment (Sutherland and Van Eerden 1980). Experience in British Columbia indicates that most pest problems are preventable. More often than not, major problems occur only if a suitable environment is created through lack of proper crop management. For example, injury from fertilizer burn, overwatering or underwatering, lack of a proper seed covering, and scattering of dead plant materials have created conditions under which pests can become established. As has been emphasized by Sutherland and Van Eerden (1980), the key to nursery pest management lies in prevention through sound cultural and sanitation practices.

Seed and Sowing: An Urgent Problem

The effects of poor seed quality and, in some cases, poor quality control during the sowing operation, together with culls, constitute the most serious problem in present container practices in Canada. As a result of these problems, an average of 30 to 35% of unproductive cavities and growing space is not uncommon.

Although multiple sowing can help to reduce the number of unproductive cavities, the cost of thinning and wasted seed is high, and the problem of unproductive space remains. Notwithstanding the potential improvements associated with better quality seed and more efficient sowing, I believe that the concept of mechanized transfer of mini-container transplants offers the only promising solution to this serious problem. If the technique is developed into a cost-effective system, I can foresee the day when all container stock, or bare-root stock for that matter, will be started in mini-containers, eliminating the problem of unproductive space and unduly costly production. Not only will such a system eliminate the blank cavities due to germination failure, but it will also permit early culling and thereby eliminate the carrying of culls through the full rotation. Therefore, I suggest that any developments in this area deserve our collective support.

SUMMARY

It is said that success foreshadows the beginning of failure and that failure signals the beginning of success. If the fundamentals of container growing are clearly understood and if the principles of intensive and least-cost management are rigorously applied to produce seedlings according to predetermined size and quality standards, success is assured. If, on the other hand, these same principles are abandoned, for whatever reason, the result will surely be failure.

The costs of container seedling production must not, of course, be considered in isolation but should be considered from the perspective of the total costs of plantation establishment. Nonetheless, the high capital investment requirements characteristic of container production are of concern, and no effort must be spared in exploring cost-effective alternatives. The ever-present temptation to substitute sound crop husbandry with never-ending investment in physical plant and equipment must be resisted, if container seedling production is to remain economically feasible.

At present, single cropping during an extended normal growing season appears to provide the only proven and rational production schedule for most Canadian container nurseries. However, efforts to extend the use of growing facilities through development of biologically and economically acceptable techniques of multi-cropping must proceed unabated.

I hope that I have been successful in identifying the causes of failure and the ingredients for success. If we are willing to learn from the lessons of the last decade, I believe that past failures do indeed signal the beginning of future success in container seedling reforestation.

LITERATURE CITED

Armson, K.A.
1976. Keynote Address. p. 1-4 in Proceedings of the Plantation Establishment Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Symp. Proc. 0-P-5.

Armson, K.A. and Sadreika, V.
1974. Forest tree nursery soil management and related practices. Ont. Min. Nat. Resour., Div. For., For. Manage. Br. 177 p.

Cameron, S.I.
1982. Conserving energy in container greenhouses. p 91-108 in J.B. Scarratt, C. Glerum and C.A. Plexman, *Ed.* Proceedings of the Canadian Containerized Tree Seedling Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. 0-P-10.

Kinghorn, J.M.
1971. Foreword. In Matthews, R.G. Container seedling production: a provisional manual. Dep. Environ., Can. For. Serv., Victoria, B.C. Inf. Rep. BC-X-58. 48 p.

Kinghorn, J.M.
1974. Principles and concepts in container planting. p. 8-18 in R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. 68.

Perkins, D.Y., McCombs, C.L., Norton, J.D. and Dillard, J.G.
1975. Production economics. p. 137-139 in Proceedings of Tennessee Valley Greenhouse Vegetable Workshop. Chattanooga, Tennessee, 18-20 March, 1975.

Sheldrake, R., Jr. and Sayles, R.M.
1974. Plastic greenhouse manual--planning, construction, and operation. Cornell Univ., N.Y. State Coll. Agric. and Life Sci., Dep. Veg. Crops, Ithaca, N.Y. 21 p.

Short, T.H.
1975. Greenhouse mechanization in perspective. p. 78-80 in Proceedings of Tennessee Valley Greenhouse Vegetable Workshop. Chattanooga, Tennessee, 18-20 March, 1975.

Sullivan, G.H.
1975. Economic trends and expected changes in the greenhouse vegetable industry. p. 30-35 in Proceedings of Tennessee Valley Greenhouse Vegetable Workshop. Chattanooga, Tennessee, 18-20 March, 1975.

Sutherland, J.R. and Van Eerden, E.
1980. Diseases and insect pests in British Columbia forest nurseries. B.C. Min. For./Can. For. Serv., Victoria, B.C. Joint Rep. No. 12. 55 p.

Tinus, R.W. and McDonald, S.E.
1979. How to grow tree seedlings in containers. USDA For. Serv., Rocky Mount. For. and Range Exp. Stn. Gen. Tech. Rep. RM-60. 256 p.

Tinus, R.W., Stein, W.I. and Balmer, W.E., *Ed.*
1974. Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. 68, 458 p.

Towning, D.J. and Turkewitsch, A.
1980. Energy efficient greenhouse design and operation. Growers Technical Consultants, Mississauga, Ont. Report prepared under contract to Dep. Agric., Ottawa, Ont. DSS Contract No. 0752-01843-0-1908.

Van Eerden, E.
1974. Growing season production of western conifers. p. 93-103 in R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

CONSERVING ENERGY IN CONTAINER GREENHOUSES

Stewart I. Cameron[1]

Abstract.--Energy conservation can significantly offset the escalating fuel cost of winter-grown container stock. Costs are discussed, and a procedure is presented for choosing among the many cultural and structural alternatives available with the aid of illustrative data from a computer model developed at the Maritimes Forest Research Centre. Future research needs and industry trends are suggested.

Résumé.--L'économie d'énergie peut contrer de facon importante l'augmentation du prix du combustible nécessaire pour chauffer les serres en hiver. On discute des prix et on présente, à l'aide de données explicatives obtenues avec un modèle informatisé mis au point au Centre de recherches forestières de Maritimes, une méthode permettant de choisir parmi les nombreuses possibilités offertes en matière de culture et de construction. On fait entrevoir les besoins à venir en matière de recherche et les tendances dans l'industrie.

INTRODUCTION

The greenhouse has a 2000-year-old history (Hanan et al. 1978). The energy-conscious designs of a century ago indicate that fuel consumption has been a concern in previous times (Fig. 1), and that the greenhouse industry has responded by producing efficient structures and improved growing methods. Similarly, there is much that the container nurseryman can do to conserve energy in the greenhouse.

Rising energy costs are stimulating rapid changes in containerized tree seedling culture methods. Alternatives to winter-grown crops produced for early summer planting are being investigated. The spring/summer period is being used for stock production, followed by overwintering and planting the next year. However, information is not available for determining if energy cost savings are sufficient to offset possible adverse effects on stock quality and survival. Overwintering and accelerated late spring/summer growth rob the nurseryman of a valuable asset--the use of the greenhouse to

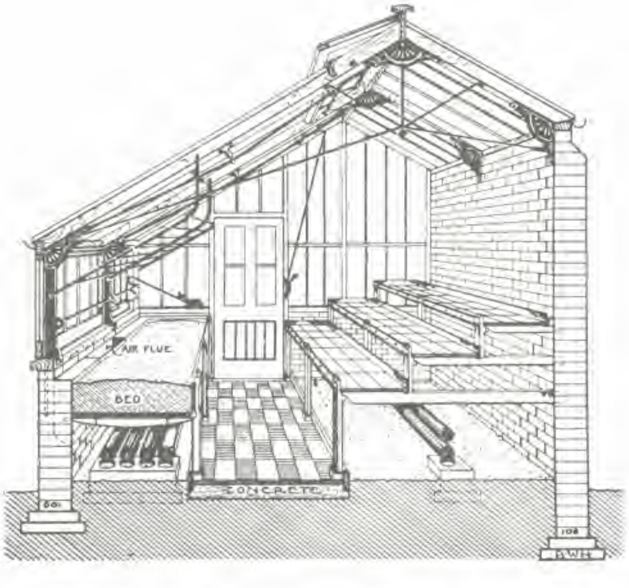


Figure 1. An energy-conserving greenhouse available as a kit from a 19th century manufacturer. Source: Clegg and Watkins 1978.

---

[1] Biologist, Maritimes Forest Research Centre, Canadian Forestry Service, Fredericton, New Brunswick.

tailor crops to the increasingly specific requirements of the field planting manager. In opposition to current trends, the winter container greenhouse may well remain a significant cultural tool. This parallels the experience of greenhouse vegetable and flower growers, who have realized that increasing the quantity and quality of products whose yields and quality are already high is accomplished by optimally fine-tuning the environment to the crop - a situation for which a greenhouse is ideally suited.

Various publications list in excess of 50 modifications applicable to container seedling greenhouses (see Appendix 1), some of which require substantial capital outlay. The problem is: where does the nurseryman start? Two risks immediately become apparent. Application of an inappropriate method (or combination of methods) may have negative effects or may simply be an investment wasted if the high cost of a modification is not offset by the fuel dollars saved over its lifetime. Every greenhouse operation differs and will require a different package of options to arrive at an optimal solution.

Methods for calculating approximate fuel requirements and the effects of a number of energy-saving strategies are available elsewhere (see Appendix 2). The intent of this presentation is to:

a) provide a perspective on the problem by examining current and projected crop cost data;

b) suggest a method by which the grower may choose among the many conservation alternatives available;

c) indicate the degree of savings that are reasonably possible; and

d) attempt to predict some future industry responses to increasing energy costs.

THE COMPUTER MODEL

As an aid in attempting to identify the important aspects of winter container growth, a computer model has been developed at the Maritimes Forest Research Centre (MFRC) to simulate a greenhouse under winter conditions.

Our objectives are to develop a combined research and consumer-oriented tool for both in-house use and distribution to outside agencies (if demand exists) to meet the following requirements:

a) the ability to predict the energy impacts of conservation alternatives applicable to containerized tree seedling greenhouses in the Maritimes and elsewhere;

b) sufficient simplicity (in a modular format for use with different greenhouse types) to run at low cost, yet with enough detail to allow minor structural and cultural details to be studied; and

c) the capability ultimately for use with a physiologically based tree seedling growth model.

Such models, though not routinely used by the forest nursery sector, are not new, and have been employed in various forms for a number of years (Takakura et al. 1971, Kimball 1973, Hallman 1974, Rotz 1977, Chandra 1979, Kindelan 1980).

The model consists of a series of conventional engineering equations which describe heat gain or loss through the various greenhouse components (cover, perimeter, side/endwalls, etc.). The mathematical analogue is run hourly, using 24-hour blocks of data, through the required portion of a computer weather file. Weather data of two types may be used: either Atmospheric Environment Service (AES) computer tape archives or output from a previously developed weather simulator (Degelman 1974). The latter format allows a greenhouse at any location to be used provided there is a weather station nearby which records mean monthly values, as opposed to AES hourly data files which are available for only a restricted number of weather stations. Although the computer language (APL) and format are substantially different, in concept the MFRC model resembles a similar program developed at the Pennsylvania State University (Rotz 1977).

Current improvements being attempted or planned are in the areas of perimeter heat loss, an improved solar radiation generator, incorporation of snowfall and wind direction, a radiant energy component in double PE (polyethylene) cover R-values, and humidity generation as a function of crop physiology.

The existing model runs specifically for single quonset and ridge-and-furrow double PE greenhouses. Future development plans include the addition of simple solar radiation models for glass and fibreglass structures, and, if demand warrants, translation into FORTRAN.

GROWING COSTS

Some winter crop costs (mid-January seeding) representative of those incurred in the Maritimes are shown in Figure 2. The sum of the six categories--fuel, container system (FH 408 paperpot), casual labor, electrical, peat and grit, and fertilizer--yields total direct growing costs of approximately $55.00 per thousand seedlings. Less direct costs--those of management salaries, equipment and structure depreciation, and nursery maintenance--would add $30 to $50 to such direct costs. Fuel oil constitutes slightly over 40% of direct growing costs, and probably represents 25% of total (direct + indirect) seedling costs at current Maritime prices. The recent Canadian oil pricing agreement will allow energy prices to rise rapidly in the coming years to approach more closely world prices. Clearly, if winter container crops are to remain a significant component of the planting schedule, there is ample incentive for energy conservation.

RANKING ALTERNATIVES

Generally, conservation methods may be weighted according to their implementation costs, which range from nil to many dollars per square metre of growing area. Fuel savings can be visualized as occurring incrementally: i.e., each time an energy-saving strategy is put in place, there is a reduction in fuel use, leaving a total to be affected by the next proposed method. Therefore, the ranking of alternatives will be on the basis of:

a) no cost
b) minimal to low cost
c) high cost, with substantial energy savings.

There is no simple way to order alternatives accurately within cost classes. However, as a general guideline, within a group of methods, those whose ratio of initial cost to amount of fuel saved is low are probably preferable.

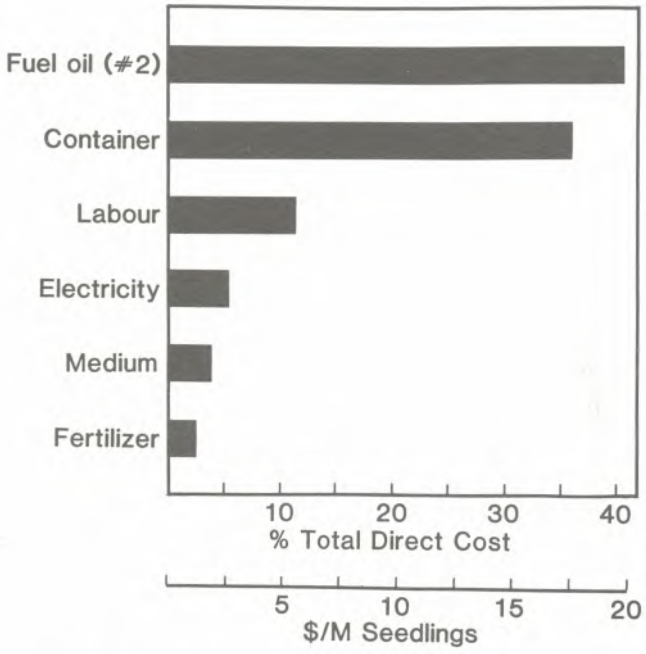


Figure 2. Representative direct winter container crop costs.

A CASE EXAMPLE

The following greenhouse will serve as an illustration: a 9 x 29 m single quonset type, double-PE covered structure located in the Fredericton area (annual total of approximately 4700 18°C heating degree days). Endwalls are insulated to full height, and sidewalls to 1.22 m with R-10 to R-12[2]. A growing regime is implemented to produce a crop for early June planting. If stock is to meet size requirements, germination must commence at the end of the first week of January, although the boilers are on from 1 September to provide heat to the working area and prevent damage to pipes in the greenhouses. The heating regime can then be broken into four periods as shown in Table 1.

Table 1. A typical winter crop heating schedule.

Period	Inclusive date	Day/night temp (°C)	No. of days
Off-season	1 Sept - 6 Jan	7/7	128
Germination	7 Jan - 22 Jan	24/24	16
Growing	23 Jan - 31 Mar	21/18	68
Hardening	1 Apr - 30 Apr	4/4	30
Total	1 Sept - 30 Apr	-	242

During a typical year, this greenhouse would be predicted by the computer model to require a seasonal total of 352.1 million BTU, or, in terms of no. 2 fuel oil, 14,770 L at a service efficiency of 65%. (Service efficiency differs from combustion efficiency in that all boiler and piping losses are included.)

---

[2] Refer to Appendix 3 for conversion factors.

Following the increasing-cost method previously outlined to rank the various energy conservation schemes results in a variety of options--by no means an inclusive list--which could be applied to this greenhouse. Each cost class may be further divided into structural and cultural components as is shown in Table 2.

No-cost Methods

Structural modifications are only a minor factor in an existing greenhouse, but can be applied effectively in planning a new facility. The cultural aspect of these modifications consists primarily of tailoring temperature requirements so as not to impair crop growth or quality, but to minimize energy use during the coldest periods.

The effect on energy use of varying the temperatures for each heating period throughout the model year for the Fredericton area greenhouse is shown in Tables 3 to 6.

Off-season

Heating requirements during the idle period prior to germination are substantial, as can be seen from monthly totals, only because of the length of time over which the heating system must maintain a minimal temperature to prevent freezing damage to water or heating lines.

During the off-season period, especially in early fall, boiler service efficiency, i.e., the ratio of the heat usefully delivered to where it is required to the amount of oil used at a given combustion efficiency is very low. Daytime requirements at the lower set temperatures are routinely supplied by the sun (data not shown). Even with lower boiler water temperature settings, there will be long idle periods when heat is not required, and large boiler and piping losses will result. Therefore, consideration should be given to partial or complete system draining, and boiler shutdown for at least part of the heating period.

If heat is not required for the headerhouse area, one interesting alternative, not currently in wide practice, to boiler draindown is the inclusion of ethylene glycol (antifreeze) in the heat transfer system, provided that it is compatible with the boiler used. The use of antifreeze allows shutdown well into the coldest part of the year until heating is required for snow removal.

Table 2. Ranking of some energy conservation methods according to cost.

Cost	Modification examples	
	Structural	Cultural
1. None	- few, if any, in an existing greenhouse (caulking, sealing cracks) - E-W siting, natural windbreak, choice of heating system (new complex only)	- lower off-season temperature or drain heating system - optimize germination temperatures - lower day/night temperatures - lower hardening temperatures
2. Low ($\$5.40/m^2$)	- frequent boiler testing and tuning, retention burner head - side/endwall insulation	- supplementary CO_2 on time control - altered fertilization and watering with basic soil analysis (pH, salts)
3. High ($\$5.40$-$\$54.00/m^2$)	- thermal blanket - combined boiler insulation and stack draft damper - microprocessor control of greenhouse environment	- routine soil/plant nutrient analysis - supplementary CO_2 light-modulated, monitored by IR gas analysis
4. Very high ($>\$54.00/m^2$)	- change to alternative fuels: wood, peat, solar, etc. - relocate nursery site to use waste heat	- select improved seedlots showing rapid growth - minicomputer environmental control at the plant level

Table 3. Heating requirements for the off-season period.

Date	Day/night temp. (°C) 7/7	4/4	2/2
	(BTU x 10^6)		
1 Sept - 30 Sept	2.0	1.5	1.5
1 Oct - 31 Oct	7.5	3.2	1.3
1 Nov - 30 Nov	22.1	13.6	6.8
1 Dec - 31 Dec	50.9	40.1	28.8
1 Jan - 6 Jan	9.3	7.4	5.4
1 Sept - 22 Jan	91.8	65.8	43.8

Germination

Optimal germination temperatures provide cultural benefits as well as energy savings. Temperatures too high or too low are inhibitory, and at less extreme values, necessitate the use of greatly lengthened time periods to complete emergence, especially in species such as white spruce (*Picea gZauca* [Moench] Voss) which are slow to germinate (Fraser 1970, 1971).

The energy necessary for germination at different times and temperatures is indicated in Table 4. The data used are for black spruce (*Picea mariana* [Mill.] B.S.P.) (Fraser 1970, Hallett, unpubl. data[3]).

Table 4. Energy requirements for germination at different temperatures.

From 7 Jan to	Germination: Day/night temp. (°C)	Germination: Days	Germination: Energy	Days[b] at 18/16 °C	19-day energy total
			(BTUx10^6)		(BTUx10^6)
16 Jan	29/29[a]	10	51.5	9	81.1
18 Jan	27/27	12	56.6	7	79.9
22 Jan	24/24	16	69.9	3	79.3
25 Jan	21/21	19	75.0	0	75.0

[a] May be inhibitory to some provenances.
[b] Additional days required to compare all germination temperatures over an equal time.

It is evident that energy requirements for germination vary greatly because of the lengthened time at lowered temperatures. However, overall heating demand corrected to the same time-base by adding growing day contributions (last two columns, Table 4) differs less, except at the lowest temperature used. Germinating at the highest non-inhibitory temperature (in this example 27°C) would be more cost-effective than using the lowest value, as the crop would be advanced by one week in development, and total growing time would be shortened accordingly.

Growing

It has been suggested that controlled diurnal temperature fluctuation during the growing period is beneficial for growth (Pollard and Logan 1975).

The impact on energy use of different day temperatures during the growing period, with a common night temperature, is shown in Table 5.

The high and low temperature values in Table 5 are generally considered to be outside the optimal growing range for most species. Of the less extreme values, the lowest, 18°C, represents an optimal choice. During long overcast periods in mid-winter a low day set point temperature ensures that seedling "legginess" is minimized, yet is adequately high to maintain a good photosynthetic rate (D'Aoust 1980). Further, higher daily temperatures are rapidly attained if clearing occurs.

Similar data (Table 6) can be presented to describe the effect of varying night temperatures.

Table 5. Energy requirements at different day temperatures during the growing period from 19 Jan to 31 Mar.

Day/night temp.	Seasonal energy required: Day[a]	Night[b]	Total
(°C)	(BTU x 10^6)		
27/16	47.0	148.0	194.9
24/16	39.9	147.5	187.4
21/16	33.4	147.1	180.5
18/16	27.5	146.7	174.3
16/16	22.1	146.4	168.5

[a] Day is defined as the period when light outside the greenhouse exceeds 8 $BTUh^{-1}ft^{-2}$ (2500 lux).
[b] Slight differences in nightly totals are due to thermal lag effects of day temperature on ground heat losses.

---

[3] R.D. Hallett, Dep. Environ., Can. For. Serv., Maritimes Forest Research Centre, Fredericton, N.B.

Table 6. Energy requirements at different night temperatures during the growing period from 19 Jan to 31 Mar.

Day/night temp.	Seasonal energy required		
	Day[a]	Night[b]	Total[b]
(°C)	(BTU x 10^6)		
18/18	27.8	163.5	191.3
18/16	27.5	146.7	174.2
18/13	27.2	130.0	157.1
18/10	26.8	113.2	140.0

[a] Day defined as in Table 5.
[b] Daily totals are slightly influenced by thermal lag in ground losses.

Lower night temperatures promote favorable shoot:root ratios (Larson 1974, Pollard and Logan 1975). Data for black spruce are lacking, although a general recommendation for temperatures as low as 10 °C has been given (Armson and Sadreika 1979) and some Maritime growers have used this temperature in the past without ill effect although results are undocumented. Therefore, the more conservative estimate of 16 °C given for white spruce might be applicable, though not as energy efficient.

Hardening

The spring hardening period has, because of the lateness of season, minimal impact on total fuel use. Total energy demand for the model month of April at day/night temperatures of 7/7, 4/4 and 2/2 °C is 13.9, 8.3, and 4.0 million BTU, respectively. Because of its energy efficiency value and favorable effects on hardening, the lowest above-freezing temperature would be preferable.

The low-energy growing schedule

Combining the four phases in the schedule summarized in Table 7 has dramatic effects on fuel consumption.

Each period of both the typical and the energy-conserving regimes, and seasonal totals, are shown in Figure 3.

The total fueling necessary with slightly lowered temperatures is reduced to 278.5 million BTU per season, or 11,680 L of oil at 65% efficiency, a saving of 21%.

Table 7. An energy-efficient winter crop heating schedule.

Period	Inclusive date	Day/night temp (°C)	No. of days
Off-season	1 Sept - 6 Jan	2/2	128
Germination	7 Jan - 18 Jan	27/27	12
Growing	19 Jan - 31 Mar	18/16	72
Hardening	1 Apr - 30 Apr	2/2	30
Total	1 Sept - 30 Apr	-	242

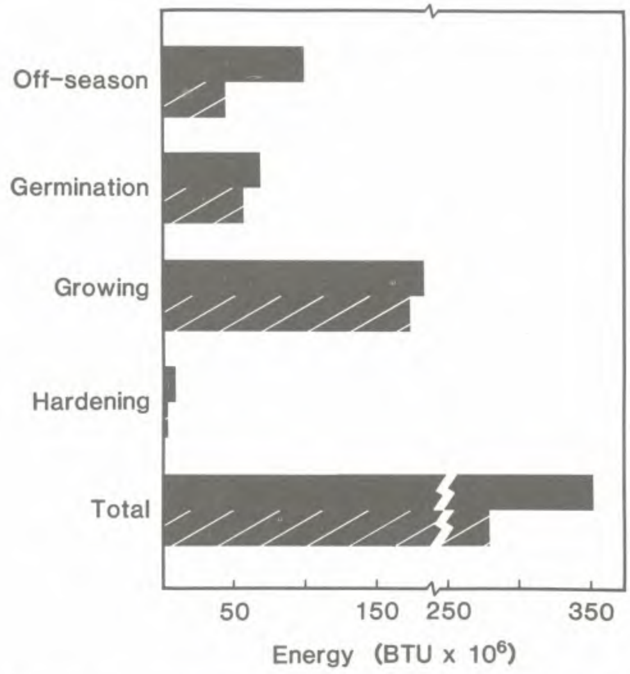


Figure 3. Comparison of the typical and energy-conserving cultural regimes for winter stock. Solid bars: typical regime; hatched bars: energy-conserving regime.

Low-cost Methods

Aside from the arbitrary capital cost limit of $5.40/m², low cost options as defined here also recover their initial cost in one, or at most two, growing seasons. According to Table 2 (and Appendix 1), a variety of measures of moderate cost can be implemented to lower fuel consumption, depending upon the state of existing structure and cultural conditions.

Structural modifications

One of the most important, yet often forgotten, components of the greenhouse system is the boiler and piping network. For the sake of simplicity, the current example --the Fredericton area greenhouse--is considered to be a well insulated structure containing modern boilers equipped with fuel retention nozzles providing an 85% combustion efficiency. If the boiler system is serviced twice yearly--prior to and at the end of the heating season--a drop in combustion efficiency of 5% or more is possible. Extra service calls and routine efficiency testing incur only moderate costs. If seasonal average combustion efficiency can be increased by 3-5%, fuel savings will pay for the extra service costs. For the example greenhouse, an increase in service efficiency to 70% reduces fuel requirements from 11,680 L to 10,870 L.

Cultural modification

Routine on-site soil nutrient testing is performed at most Maritime nurseries. However, the use of supplementary CO2 as a winter cultural method has yet to be exploited, although the benefits are adequately documented (Tinus and McDonald 1979). Since supplementary CO2 can cause nutrient deficiency under a standard fertilization schedule, the addition of slow-release fertilizer to the growing medium represents a moderate cost item which, in the absence of detailed nutrient analysis, would provide a safety margin. (This fertilization method used alone has been shown at Maritime nurseries to accelerate significantly the growth of winter spruce crops.) For the purpose of energy modelling, the impact of these two methods, taken either separately or in combination, can be conservatively estimated by assuming that germination can be delayed by two weeks.

Low-cost summary

As a consequence of implementing low-cost methods, the cultural schedule and energy requirements would be altered as shown in Table 8.

Structural and cultural improvements taken singly or in combination would save significant amounts of energy. As previously indicated, an increase in boiler service efficiency from 65 to 70% would reduce fuel requirements (using the 11,680 L of the energy efficient regime shown in Table 7 as the base) by 7% to 10,870 L; cultural modification alone (assuming 65% service efficiency) would reduce fuel requirements to 10,590 L, and the combination would lower fuel requirements by 16% to 9,820 L.

Table 8. The cultural regime and energy requirements resulting from low-cost modification.

Period	Inclusive date	Day/ night temp.	Days	Energy
		(°C)		(BTUx10^6)
Off-season	1 Sept - 20 Jan	2/2	142	63.5
Germination	21 Jan - 1 Feb	27/27	12	50.9
Growing	2 Feb - 31 Mar	18/16	58	133.4
hardening	1 Apr - 30 Apr.	2/2	30	4.0
Total	1 Sept - 30 Apr	-	242	251.9

High-cost Methods

The third class of alternatives has high capital outlay, and initial cost recovery routinely requires a number of years. If funding limits the number of methods which can be implemented yearly, standard capital costing and discounting methods are used to choose among options. Straight or discounted payback is *not* sufficient to make the choice (see Capital Costing).

Structural modification

Choice of the second building modification is based on the thermal properties of a greenhouse. Using the combined low-cost regime (Table 8, 70% service efficiency), modelled heating data may be broken down according to structural component (Fig. 4).

As expected, most of the energy loss (75%) occurs through the double PE cover, and even a small improvement in the overall cover R-value, especially at night, would be of benefit. To reduce such losses, the 300-year-old technology (Hix 1974) of thermal screens or blankets drawn at night is being reintroduced. A variety of blanket materials (Fig. 5) and tracking systems are available.

Strictly from an energy conservation viewpoint (and ignoring problems such as frost accumulation and drip), the most efficient material appears to be the aluminized/ white, non-porous type, installed so that the

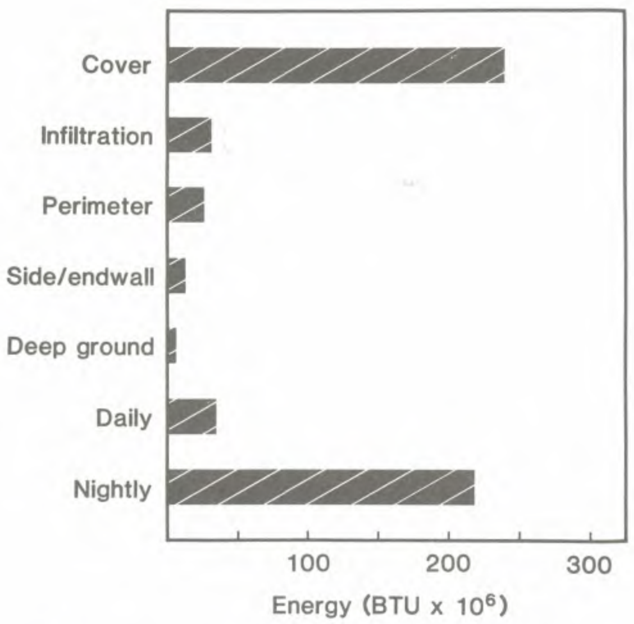


Figure 4. Energy losses through each of the major structural components, and by day and night (as defined in Table 5).

aluminized surface faces outward (Simpkins et al. 1976, Chandra and Albright 1980). If care is taken to install the system so that air leakage around the edges is minimized, considerable seasonal fuel savings in the range of 30 to 35% are possible (White 1978). The timing of blanket deployment is equally important. The model defines the day period as those hours when outside illumination (prior to interception of the double PE cover) exceeds 2500 lux because, below this level, light reaching the crop is insufficient to be usable for growth (Seginer and Albright 1980). Therefore, retracting a curtain after dawn or deploying it prior to dusk represents a reasonable compromise between crop needs and fuel reduction.

Cultural modification

Unfortunately, the energy impact of cultural alternatives in the high-cost classification is difficult to predict because our knowledge of container stock physiology is still incomplete. The "upper limit to seedling growth" (Larson 1974) has yet to be defined.

Current state-of-the-art cultural improvements centre around the optimal tailoring of the environment to the crop. Recent developments in microprocessor technology allow much more than simply the precise control of temperature and humidity. Elevated CO2 levels (measured by infrared gas analysis) modulated with venting temperature according to light intensity, variable lowering of rates (ramping) to night set temperatures whose levels can also be set according to previous day conditions, and even the modulation of nutrition by means of constant fertilization are all being practised either operationally or on an experimental basis with crops whose requirements are well defined (Mulder and Bot 1980). For container seedlings, the use of microprocessor control would necessarily be coupled, in the absence of a crop growth model, with frequent detailed soil and foliar analysis at considerable expense.

If we speculate, then, on the energy impact of growth acceleration due to a well controlled environment, a conservative estimate for the example greenhouse might have two components. First, the one month hardening period could be decreased by one week by improved cultural control. Second, the growing period might be decreased by one week by the combined influence of an improved CO2/nutritional regime.

High-cost summary

Using a thermal blanket (R2.0) coupled with the low-cost cultural regime (see Table 8) for the whole of the heating period, the model predicts a seasonal heat loss of 159.7 million BTU, a 6,230 L requirement (at 70% service efficiency). The saving--37%--is substantial, though undoubtedly an overestimate, since factors such as snowfall and imperfect curtain edge seals are not included. (If the curtain were used only during the active growing period to prolong its service life, heat loss would rise to 186.2 million BTU, consumption would increase to 7,270, and savings would diminish to 26%.)

As previously mentioned, the estimated net effect of high-cost cultural methods is to delay germination by two weeks and hardening by one week, resulting in the growing schedule shown in Table 9. This delay is only slightly less efficient than that which would result if a thermal blanket were used. The 170.4 million BTU demand is equivalent to seasonal fuel use of 6,640 L. It is notable that off-season heating under this growing regime accounts for almost one-half of the total fuel use. Boiler and piping draining, or antifreeze addition, if feasible, could reduce costs still further.

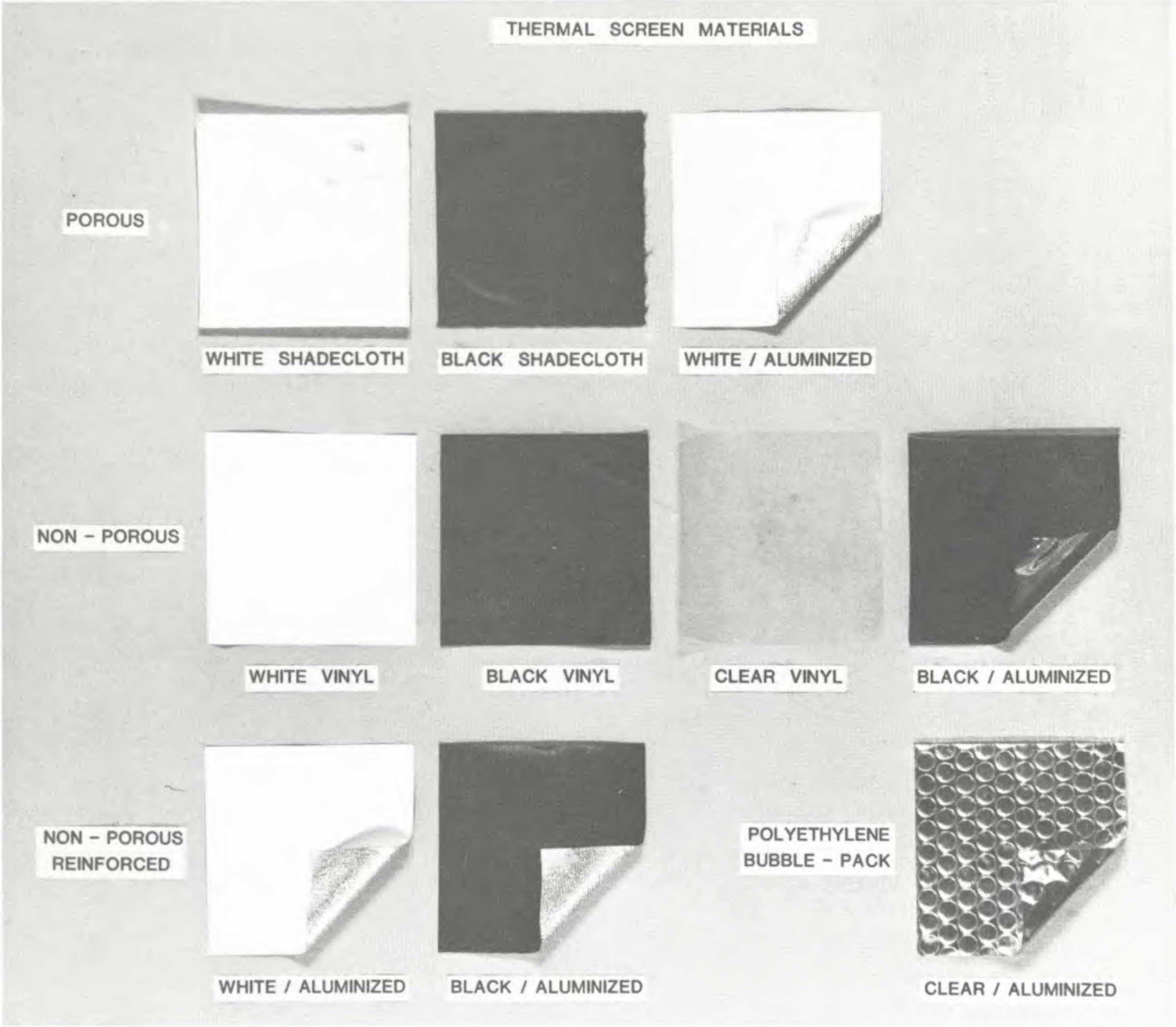


Figure 5. Some thermal screen materials used for energy conservation.

The combination of the two energy-conserving methods reduces heating use significantly. Off-season, germination, growing, hardening and total heating requirements are reduced to 45.9, 33.1, 63.8, 2.3, and 145.0 million BTU, respectively, for an annual projected fuel consumption (70% service efficiency) of 5,650 L. If we recall that the initial fuel requirement for the greenhouse with neither cultural nor structural improvements is 14,770 L, such methods are very significant.

Very High-cost Modification

Highly capital-intensive methods are not yet routinely considered viable even at current energy prices. Most of these options will not reduce fuel consumption sufficiently to justify their high cost (especially if the other methods previously described have been applied incrementally).

Where exploitable waste heat sources already exist, there is excellent potential for placement of new facilities to defray heating

Table 9. A proposed cultural regime resulting from high-cost modifications.

Period	Inclusive date	Day/ night temp	Days	Energy
		(°C)		(BTUx10^6)
Off-season	1 Sept - 3 Feb	2/2	157	79.1
Germination	4 Feb - 15 Feb	27/27	12	51.7
Growing	16 Feb - 7 Apr	18/16	51	36.4
Hardening	8 Apr - 30 Apr	2/2	22	3.1
Total	1 Sept - 30 Apr	-	242	170.4

Table 10. Possible combinations of energy-saving strategies used in the Fredericton greenhouse. (It is assumed that methods are applied incrementally according to cost.)

	Structural Options[a]				
Cultural options	No change	+	Low cost	+	High cost
			(L)		
No change	14,480 (100%)		13,730 (93%)		8,460 (57%)
+					
No cost	11,680 (79%)		10,870 (74%)		7,290 (49%)
+					
Low cost	10,590 (72%)		9,820 (66%)		6,230 (42%)
+					
High cost	7,290[b] (49%)		6,640 (45%)		5,640 (38%)

[a] The no-cost option is omitted because of its inapplicability.

[b] This specific combination, though calculated, has not been discussed in the text.

costs (Ball 1981), but the transfer of preexisting complexes to such sites remains questionable. Of course, should conventional energy sources cease to be readily available at any cost, either alternative fuels and/or waste heat sources have immediate value if winter growing is to continue.

Cultural methods in this cost category are not ordinarily considered for container seedling production facilities. The use of such methods requires that the crop have a high per unit value, and that increased crop costs are either passed on to the buyer, compensated by the resulting increase in product quality, or returned in some measure through crop production increases which cannot be achieved by any other method (e.g., growing a September-seeded crop under HID lighting).

Overall Heating Reduction

Each cost category outlined previously affects overall energy use, as has been demonstrated. Putting the various options together in different combinations is an important step in defining which package to use. Not every greenhouse operation will be the same as the Fredericton example. One method of indicating all the combinations is to tabulate all the options as shown in Table 10, on the assumption that they are applied in order of ascending cost.

The summary for the Fredericton example indicates that potential fuel savings can range over a very wide spectrum from a low of 7% up to 62%.

Such ordering facilitates choosing between alternatives, and may be used either between or within cost groups. Although choosing rigorously among the no-cost and low-cost options may initially be trivial, eventually, after a series of such choices, energy costs will he reduced to a low level. Then, even low-cost methods become significant because of the length of time taken for cost recovery.

Capital Costing

As was noted previously, every greenhouse operation differs culturally, structurally, and climatically. The lack of a common starting point makes a universally applicable package of energy-conserving recommendations impractical. Further, since many energy-saving methods require high initial investment (or alternatively may never justify their expense on the basis of savings regardless of the first cost), and since in any business the supply of money is not unlimited, some measures must be chosen while others are excluded. In an attempt to apply a simple common denominator for all situations, the "payback method" is commonly--and incorrectly--used to determine which of a group of energy-reducing options is best.

Figure 6. Some different lighting systems used for photoperiodic lighting: a) static incandescent; b) mobile incandescent; c) mobile VHO fluorescent.

A discussion of the mechanics of capital costing is beyond the scope of this paper. It is a powerful tool for assessment of the real costs and profits associated with the various combinations of alternatives which comprise energy conservation packages. The use of capital costing methods allows the nurseryman to select which package is best tailored to his objectives. The spectrum of such objectives may legitimately range from lowering oil use maximally on a cost-recovery-only basis--i.e., investment sufficient to equal the oil dollars saved (applicable to a restricted energy supply situation) --to maximizing the profitability of a commercial nursery operation. A thorough treatment of capital costing is contained in many standard references such as Fleischer (1969).

ELECTRICITY: A FORGOTTEN COST

The topic of energy conservation is incomplete if electrical consumption is not considered. Winter-growing electrical costs (see Fig. 2) result primarily from the running of the heating system and the use of lighting to prevent dormancy.

Most nurseries are classed by the power utility as industrial users, and therefore are subject to a different billing calculation than the residential user. In its simplest form, the monthly bill has two components. A "peak demand" charge is levied for the highest number of kilowatt-hours (KWH) used at any one time, and a total use or "energy" charge, similar to that levied on a homeowner, is added to account for the total number of KWH used over the month.

Reduction of greenhouse heating requirements can directly influence electrical costs. The decreased demand for hot water (or steam) results in less running time for the various pumps and valves associated with the boiler and heat distribution network.

The type of supplementary lighting used (Fig. 6) may also result in widely different power consumption.

The three systems (static incandescent, mobile incandescent, and mobile fluorescent) have power requirements (including the irrigation cart motor in the latter two) of 7.7, 1.2, and 0.9 KW, respectively. If these systems are active for an average of two hours per night for the months of January through March, seasonal costs at current New Brunswick rates[4] would be approximately \$60, \$9, and \$7, respectively, on the basis of KWH consumption alone, or \$204, \$32, and \$24, respectively, if demand is assumed to be directly increased by their use.

FUTURE TRENDS

As was noted earlier, greenhouse energy consumption can be greatly lessened. Currently, the extent of the reduction is limited more by a lack of knowledge of seedling growth processes and quality indices than by technical restraints. However, because energy use can still be significantly cut, the large number of options available using a winter growing schedule for growth and conditioning will remain too attractive to be ignored.

In the Maritimes, current levels of winter container stock production will probably be maintained or even expanded for several reasons: first, the predicted future

---

[4] 1981 rates are \$6.25 per KW demand and \$0.0434 per KWH.

wood shortage in some regions; second, the more intensive use of genetically superior seedlings for both seed orchards and outplanting, where a relatively small decrease in time to rotation or flowering more than compensates for the extra front-end costs; and third, the high capital and labor cost penalty incurred by not making year-round use of existing facilities.

Substantial innovation in planning for expanded production is likely in the future. Large-scale contracting-out of nursery functions will increase, where centralized companies or cooperatives, set up specifically for the purpose, will be given responsibility for providing seedlings for outplanting. The economies of scale would allow such groups to research growth and quality improvements intensively in addition to monitoring and producing stock. Also, a large operation would permit allocation of the substantial capital associated with, for instance, locating near and using waste heat sources. (Such an installation on a small scale exists already at a heavy water plant in Nova Scotia, and another demonstration unit has been proposed by the electrical utility in New Brunswick for installation near a thermal generating station.) Indeed, should energy availability, as opposed to cost, become critical to the extent that "non-essential" energy users are actively discouraged from operating, such a facility might be the only alternative available to the grower for winter-grown stock.

It appears that, even in the midst of an on-going energy crisis, current winter container culture systems are unlikely to disappear. Because large-scale containerized seedling production is a relatively recent phenomenon, the container nurseryman is at an advantage or disadvantage, depending upon one's point of view. Unlike the horticulturalist, he potentially can effect greater energy savings because there is much greater scope for cultural improvement arising from a better understanding of basic physiology. However, fuel cost and/or availability may limit the allowable time for development of optimized cultural systems. Energy conservation may just allow the grower an extended period of grace.

LITERATURE CITED

Armson, K.A. and Sadreika, V.
1979. Forest tree nursery soil management and related practices. Ont. Min. Nat. Resour., Toronto, Ont.

Ball, V.
1981. Exhaust heat-Saskatchewan-exciting! Grower Talks 44:1-13.

Chandra, P.
1979. A time-dependent analysis of thermal energy and moisture exchanges for greenhouses. Ph.D. Thesis, Cornell Univ., Ithaca, N.Y.

Chandra, P. and Albright, L.D.
1980. Analytical determination of the effect on greenhouse heating requirements of using night curtains. Trans. Am. Soc. Agric. Eng. 23:994-1000.

Clegg, P. and Watkins, D.
1978. The Complete Greenhouse Book. Garden Way, Charlotte, Vt.

D'Aoust, A.L.
1980. La physiologie des semis d'épinette noire *Picea mariana* (Mill.) B.S.P. en contenants. Dep. Environn., Serv. Can. For., Ste-Foy, Que. Inf. Rep. LAU-X-35.

Degelman, L.O.
1974. A weather simulation model for building energy analyses. Dep. Agric. Eng., Penn. State Univ., University Park, Pa.

Fleischer, G.A.
1969. Capital Allocation Theory: the Study of Investment Decisions. Appelton-Century-Crofts, New York, N.Y.

Fraser, J.W.
1970. Cardinal temperatures for germination of six provenances of black spruce seed. Dep. Environ., Can. For. Serv., Chalk River, Ont. Inf. Rep. PS-X-23.

Fraser, J.W.
1971. Cardinal temperatures for germination of six provenances of white spruce seed. Dep. Environ., Can. For. Serv., Ottawa, Ont. Publ. No. 1290.

Hallman, R.G.
1974. Cost of raising containerized trees in the United States. Part A: A computer program. p. 412-427 *in* R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.* Proc. North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. 68.

Hanan, J.J., Holley, W.D., and Goldsberry, K.L.
1978. Greenhouse Management. Springer-Verlag, New York, N.Y.

Hix, J.
1974. The Glasshouse. MIT Press, Cambridge, Mass.

Kimball, B.A.
1973. Simulation of the energy balance of a greenhouse. Agric. Meteorol. 11:243-260.

Kindelan, M.
1980. Dynamic modeling of a greenhouse environment. Trans. Am. Soc. Agric. Eng. 23:1232-1239.

Larson, P.R.
1974. The upper limit of seedling growth. p. 62-76 in Tinus, R.W., Stein, W.I. and Balmer, W.E., *Ed.* Proc. North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. 68.

Mulder, W.P. and Bot, G.P.A., *Ed.*
1980. Symposium on Computers in Greenhouse Climate Control. Wageningen, The Netherlands. Acta Hort. 106.

Pollard, D.F.W. and Logan, K.T.
1975. Prescriptions for the aerial environment of a plastic greenhouse nursery. p. 181-191 in Proc. 12th Great Lake States For. Tree Improvement Conf. USDA For. Serv., Gen. Tech. Rep. N6-26.

Rotz, C.A.
1977. Computer simulation to predict energy use and system costs for greenhouse environmental control. Ph.D. Thesis, Dep. Agric. Eng., Penn. State Univ., University Park, Penn.

Seginer, I. and Albright, L.D.
1980. Rational operation of greenhouse thermal—curtains. Trans. Am. Soc. Agric. Eng. 23:1240-1245.

Simpkins, J.C., Mears, D.R. and Roberts, W.J.
1976. Reducing heat losses in polyethylene covered greenhouses. Trans. Am. Soc. Agric. Eng. 19:714-719.

Takakura, T., Jordan, K.A. and Boyd, L.L.
1971. Dynamic simulation of plant growth and environment in the greenhouse. Trans. Am. Soc. Agric. Eng. 14:964-971.

Tinus, R.W. and McDonald, S.E.
1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv., Rocky Mt. For. Range Exp. Stn., Gen. Tech. Rep. RM-60.

White, J.W.
1978. Energy research program at Penn State. Penn. Flower Growers Bull. 305:1-10.

APPENDIX 1

A Checklist of Energy Conservation Measures Potentially[a] Applicable to Container Greenhouses

	Method	Cost/savings[b]	Comments
1.	Lower off-season temperatures, drain heating system, or adding antifreeze	N-M/L-M	c
2.	Germination at an optimal high temperature for the least number of days	N/L	
3.	Pregermination of seed for several days prior to sowing to shorten germination period in the greenhouse	L-H/M	d
4.	Germination in a separate well insulated heated area, lit if necessary	H/H	d
5.	Lowering day and (more importantly) night temperature set points during the growing period	N/L	e
6.	Split-night temperature regime during the growing period	N/M-H	d,f
7.	Supplementary CO_2 on timer control during the growing period	L/M	
8.	Supplementary CO_2 controlled by gas analysis (IRGA) to maintain optimally high daily concentration(s)	H/H	g,h
9.	Elementary soil analysis (salts, pH) and attention to soil moisture by weighing the containers	L/M	h
10.	Frequent soil and foliar nutrient analysis and/or constant-feed fertilization methods (requiring close soil moisture control)	H/H	h
11.	Microprocessor control of greenhouse temperature, humidity, and CO_2	H/H	h,i
12.	Minicomputer control of the greenhouse total environment at the plant level	VH/H-VH	d,h,i
13.	HID (high intensity discharge) lighting for accelerated crop growth	VH/L	j
14.	Mobile boom-mounted lighting (or other type) on a night-break regime for dormancy prevention	L/M	
15.	Ridge-and-furrow (gutter-connected) complexes as opposed to single greenhouses	H/H	k
16.	An E-W greenhouse ridgeline as opposed to a N-S aligned structure	N(?)/L	k,l
17.	Wind-sheltered site and/or carefully designed natural windbreak	N-L/L-M	k,m
18.	Artificial windbreak using posts and snowfence or 50% porous netting/shade material	L/L-M	
19.	Single or double PE over a glass or FRP (fibreglass-reinforced polyester) greenhouse	L/H	
20.	Caulking between glasshouse panes with clear compound (Lapseal)	L/M	n

APPENDIX 1 cont'd.

	Method	Cost/savings[b]	Comments
21.	Replacement of glasshouse cover with double skin or double layer materials of higher R-values	H-VH/H	
22.	Use of longer-lived (3-5 yr) types of film plastics	L/L	o
23.	Use of infrared-reflective plastic films in place of PE for a double cover	L/L-M	p
24.	Insulate side/end walls to R10-12 with moisture-insensitive insulation	L/M	q
25.	Use of rigid sheet materials for perimeter subsoil insulation	L-H/L	r
26.	Seal between the bottom of the side/endwall and the foundation or soil	N-L/L	s
27.	Seal off all unused fan-openings, louvres, and vents, and insulate the openings, if possible	L/L	s
28.	Weatherstrip/seal large access doors to shipping/holding area	L/L	s
29.	White paint or reflective foil on interior side/endwall surfaces to reflect light to the crop	L/N-L	t
30.	Reflective surface behind finned pipe	L/L	t
31.	Forced air recirculation in the greenhouse to promote growth and minimize temperature stratification	L/L-M	
32.	Raise the crop level by use of benches or elevated pallets	L/N-L	h,u
33.	Under-bench polytube heating from unit heaters lowered to floor level	L/L-M	h,v
34.	Routine check of thermostat calibration, and use of an aspirated, shaded thermostat enclosure	N/L-M	
35.	Installation of a thermal screen (blanket) with care being taken to seal all edges and gaps	H/H	w
36.	Thermal screen deployment/retraction with a photocell in place of a timer	L/L	x
37.	Use of a snow-sensor for blanket retraction during snowstorms	L/L	y
38.	Central heating (boiler) system as opposed to individually fired unit heaters	H/L-M	z
39.	Regular boiler service, frequent efficiency testing and adjustment (if required) during the growing period	L/M	aa
40.	Installation of heat-retention burner nozzles to increase combustion efficiency of older units	L/M	
41.	Lower boiler water temperature as weather moderates in spring and fall	N/L	

APPENDIX 1 cont'd.

	Method	Cost/savings[b]	Comments
42.	Additional boiler jacket insulation to prevent boiler room or headerhouse overheating		
43.	Motorized stack draft damper installation in the boiler flue	H/L-M	bb
44.	Secondary heat recovery with an air-water flue heat exchanger or similar device	H/L	
45.	Turbulator installation in heat exchanger tubes to equalize flows and aid heat transfer	L-H/L(?)	d,cc
46.	Adequate combustion air intake ducting in an enclosed boiler room	L/L-M	dd
47.	Annual inspection of all pipes, valves, and circulating pumps	N/L	
48.	Insulation of all pipes and flanges where heat is not required (including underground lines)	L/L-M	
49.	Devise (and use) a written maintenance schedule, including a checklist	N/L-H	
50.	Use of an infrared internally fired heater in conjunction with lowered air temperatures	H/M-H	d,ee
51.	Solar-assisted or alternative fuel (coal, wood, peat, propane, etc.) heating system	VH/M-H	
52.	Movable benching (roller benches) or mobile pallet systems to increase effective growing area	H/N	ff

COMMENTS

a. All these methods have been proven effective to some degree. However, some are experimental while others may not justify their initial capital or annual maintanance costs solely on the basis of the annual energy savings in a particular growing regime and/or climate.

b. These are guidelines only. N - Nil; L - Low; M - Moderate; H - High; VH - Very High

c. The necessity for replacement of corrosion and scale inhibitors will add an annual maintenance cost to boiler service if draindown is used. Boiler manufacturer should be consulted to determine system compatibility with antifreeze.

d. Experimental technique whose cultural and/or conservation effects have not been well established.

e. Temperatures are lowered only to the point at which crop growth and/or quality remain unaffected.

f. The split-night temperature technique uses a moderately high set point for a short period, followed by a much lower temperature for the remainder of the night.

g. An infrared gas analyzer coupled with a photocell measuring greenhouse light levels is used to maintain high, optimal levels of CO_2 during the day.

APPENDIX 1 cont'd.

h. Energy conserving in the sense that crop cultural conditions are optimized, resulting in a delayed seeding time to achieve equal or better crop size and/or quality.

i. Microcomputer control may have substantial effects on quality and perhaps survival, but only if there is adequate information about the physiological requirements of the species grown.

j. HID lighting is, at present, used only for special crops.

k. This option is usually restricted to the planning of new nursery sites.

l. An E-W single greenhouse has better winter light interception than a N-S greenhouse. Alignment is not as critical in gutter-connected structures.

m. Savings vary according to average windspeed, type of greenhouse cover, how tight the greenhouse is (infiltration rate), and whether a shelterbelt is maintained (pruned, trimmed) as it matures.

n. Infiltration will be reduced more in older, looser glasshouses.

o. 3- to 5-year plastics are sometimes thicker (e.g., 10 mil) and may result in unacceptable light loss. Nonetheless, buying PE (or other plastics) is still buying oil, only in a different form.

p. PE is transparent to infrared (radiant) energy, and a significant component of nightly losses can be attributed to radiation to a clear sky on cold nights.

q. Fibreglass, cellulosic and certain types of foam insulation degrade when exposed to high humidity. Use of rigid sheet materials impermeable to water vapor is recommended.

r. Initial cost is variable depending upon the amount of labor associated With installation. Sites with a high water table require vertical installation, and perhaps even drain tile below the insulation. Well drained gravelly sites may have the insulation laid horizontally just below the surface, perhaps inside the greenhouse. Savings diminish with the use of raised benches, good snowcover (which acts as an insulator) and the size of the greenhouse (perimeter:floor area ratio).

s. CO2 is depleted more quickly in a tightly sealed greenhouse. Minimal ventilation or (preferably) supplementary CO2 will be required, especially on sunny days.

t. If foil-backed building paper is used, periodic replacement will be necessary, as the surface dulls (oxidizes) in high-humidity areas.

u. Removing the crop from the floor warms the root zone.

v. Under-bench heating warms the soil, promotes air-pruning and drying.

w. Of the wide variety of thin blanket materials available, a non-porous white/aluminized material (or one with a reflecting surface on both sides) is the most thermally efficient. The aluminized surface should face the coldest region, i.e., the outside. Condensation may be a problem if the blanket cannot be sloped to allow runoff. Fabrics with an internal mesh or scrim are probably more durable. Good edge and gap sealing are imperative for maximum efficiency. Thick materials (R 6-10) are available but are difficult to deploy and store.

x. Using a photocell ensures that morning retraction and nightly deployment do not occur until light conditions based on crop needs are correct. This minimizes loss of usable light to the crop, and increases thermal screen "on-time" since the material is in place during part of the day (for a brief period both after sunrise and before sunset).

APPENDIX 1 concl'd.

y. Use of a snow sensor permits the blanket to be retracted only during and after a storm to allow melting, rather than for the whole night period when snow is expected.

z. Depending upon the size of the complex, and relative costs of different fuels. Heating efficiency is easier to maintain in a centralized system and fuel change-over costs are lower.

aa. During long periods of low heating demand, boiler on-cycles occur infrequently, resulting in soot accumulation, and decreased overall service efficiency.

bb. This unit increases service efficiency during low heating demand periods by preventing the flow of draft air up the flue when the boiler is not firing, and the resultant cooling of internal heat exchange surfaces. It is less effective during times of almost continuous firing.

cc. Although the method is not new, its effectiveness in newer boiler models has been questioned.

dd. Size of the free opening required can be obtained from the boiler manufacturer.

ee. A highly experimental system which uses low-level radiant heat to warm plant surfaces rather than the greenhouse air. Effects on soil temperature when container stock is used are not known. Could perhaps be used with soil bed heating and flats on low pallets.

ff. No energy reduction, but rather a more efficient use of space to reduce unit crop cost.

APPENDIX 2

Useful References

Manuals:

Badger, P.C. and Poole, H.A. 1979. Conserving energy in Ohio greenhouses. O.A.R.D.C. Spec. Circ. 102. Ohio Coop. Ext. Serv., Ohio State Univ., Wooster, Ohio, 44691. ($2.00)

Blom, T., Hughes, J. and Ingratta, F. 1978. Energy conservation in Ontario greenhouses. Ont. Min. Food Agric., Publ. 65.

Correll, P.G. and Pepper, J.G. 1977. Energy conservation in greenhouses. Agric. Ed. Off., Agric. Hall, Univ. Delaware, Newark, Del, 19711. ($3.75).

Poole, H.A. and Badger, P.C. 1980. Management practices to conserve energy in Ohio greenhouses. O.A.R.D.C. Spec. Circ. 104. Ohio Coop. Ext. Serv., Ohio State Univ., Wooster, Ohio, 44691. ($2.50).

Ross, D.S., Roberts, W.J., Parsons, R.A., Bartok, J.W. and Aldrich, R.A. 1979. Energy conservation and solar heating for greenhouses. Northeast Reg. Agric. Eng. Serv. Publ. NRAES-3 Ext. Agric. Eng., Univ. Conn., Storrs, Conn., 06268. ($1.50)

White, J.W. and Aldrich, J.W. 1980. Greenhouse energy conservation-Penn State 1980. Ind. Res. Innov., 225 Pond Lab., University Park, Penn., 16802. ($2.50).

Periodicals:

Connecticut Greenhouse Newsletter. Conn. Coop. Ext. Serv., Univ. Conn., Storrs, Conn., 06268.

Colorado Greenhouse Growers Assoc. Bulletin. Colorado Greenhouse Growers Assoc. Inc., 2785 N. Speer Blvd., Suite 230, Denver, Colo., 80211.

Grower Talks. Geo. J. Ball Inc., P.O. Box P800, West Chicago, Ill., 60185.

Pennsylvania Flower Growers Bulletin. Pennsylvania Flower Growers, P.O. Box 384, Bloomsburg, Penn., 17815.

APPENDIX 3

Conversion Factors

Thermal resistance (R-value):
1 h ft^2 °F BTU^{-1} = 0.17611 m^2 $°C^{-1}W^{-1}$

Conductance (U-value = 1/R-value):
1 BTU h^{-1} ft^{-2} $°F^{-1}$ = 5.6783 W m^{-2} $°C^{-1}$

Energy:
1 $BTUh^{-1}$ = 0.2930W
1 BTU = 1.055 kJ

Electric:
1 KWh = 3,413 BTU
1 hp = 745.6 W

Boiler horsepower:
1 BHP = 33,742 BTU

Fuel:
1 gal = 4.546 L
1 gal no. 2 oil = 166,600 BTU at 100% efficiency.

Windpseed:
1 mph = 0.447 m s^{-1} = 1.609 km h^{-1}

Radiation:
1 BTU ft^{-2} = 0.01135 MJ m^{-2}

GREENHOUSE GLAZING MATERIALS: A COMPARISON

John Siemens'

Abstract.--This paper evaluates the most commonly used glazing materials for greenhouses, comparing their properties, performance characteristics, cost factors and heat loss.

Résumé.--Une évaluation des matériaux de vitrage les plus utilisés dans la construction de serres et une comparaison de leurs caractéristiques, leurs critères de qualité, des facteurs de coût et des pertes de chaleur sont présentées.

INTRODUCTION

A greenhouse, according to the World Book Dictionary, is "a building with a glass roof and glass sides, kept warm for growing plants". According to Webster's Third New International Dictionary, a greenhouse is "1) a glassed enclosure used for the cultivation or protection of tender plants; 2) a clear plastic shell covering a section of an airplane." At least Webster's definition alludes to a glazing product other than glass.

Today's greenhouses can be glazed with a variety of light-transmitting materials which fall into one of three categories: glass, flexible plastics and rigid plastics. The plastics can be further subdivided into generic materials such as polyvinyl chlorides, polyethylenes, polypropylenes, polycarbonates, acrylics and polyesters, to name a few. Research is continuing at the manufacturer's level in an effort to develop the "perfect" glazing material. Materials tested by independent laboratories, government agricultural agencies, and the greenhouse sector are usually compared with a standard which is "glass".

In this paper I shall attempt to compare the various glazing materials, discuss their pros and cons, and clear up some common misconceptions, particularly with regard to plastic glazing products.

The selection of a glazing material must be based on two important factors: performance and cost. These are detailed below.

Performance factors:
- transmission (photosynthetically active radiation, between .4 and .7 1-1) and infrared (IR) wave-lengths
- insulation values R or U
- fire resistance
- expected service life
- weatherability/surface stability
- aging

Cost factors:
- initial cost of material
- installation
- maintenance
- replacement
- structural considerations
- availability

Numerous reports have been published dealing with the above factors and the ways in which each may influence the greenhouse growing environment. Heating, cooling, ventilation, plant response, etc., are all affected by the characteristics of the glazing material used. This paper will expose only the tip of the iceberg in outlining the basic properties of the various glazing materials.

GLASS

In North America, glass panes used in the greenhouse industry have evolved from a

---

[1] Technical Manager, Chemacryl Plastics Limited, Rexdale, Ontario.

width of 16 in.[2] to the 20-in. width used in the late 1950s and early 1960s to the 24-in. width used today. Some 30-in.-wide glass is also being used, usually for institutional greenhouses.

A single-glazed glass greenhouse is generally used as the "control house" for comparison of the results of crop growth response, light levels at plant height, energy consumption, etc., in greenhouses with other than glass glazing.

Performance Characteristics of Glass Used in Greenhouse Construction

- transmits 90% of available solar energy
- transmits penetrating IR (infrared) radiation but becomes impervious to nonpenetrating IR radiation at about 2.8 p
- overall thermal conductivity - U value = 1.1 $BTU/hr/ft^2/^\circ F$
- heat transfer coefficient R = 0.88
- low impact resistance (Tempered glass has higher impact resistance than horticultural grade but is more costly.)
- noncombustible
- long life expectancy (dependent on local incidence of wind and hail)
- glazing bars required at approx. 61 cm centres
- requires yearly maintenance, resealing, caulking, etc. , to maintain air tightness
- can be sprayed with a shading solution to reduce heat between spring and fall

Cost

- ranges from $\$7/m^2$ for 24 oz. to $\$9.15/m^2$ for 32 oz. glass
- installed greenhouse cost ranges from about $\$75/m^2$ to $\$108/m^2$ of ground area, depending on whether the greenhouse is detached or gutter connected (These costs are based on an area of approx. 1800 m^2, and depend on the options installed.)

NOTE: All costs are quoted in Canadian dollars.

PLASTICS

Plastics became an alternative to glass in the mid-1950s. Clarification of the characteristics and limitations of the different plastics currently available may provide a better understanding of these materials. Factors such as initial cost, light transmission values, weatherability, installed costs and frequency of maintenance are major considerations when one is choosing a specific plastic.

There are two categories of plastics used in the greenhouse industry: flexible or film plastics and rigid plastics. The second category can be further divided into thermoset and thermoplastic groups.

Flexible (Film) Plastics

Flexible plastics include polyethylenes (PE) and polyvinyl-fluorides, among others. The most widely used film in the greenhouse industry is PE, which is known by tradenames such as Monsanto 602 or C.I.L. Dura-Film. PE is a flexible and inexpensive material, available in thicknesses of 2 mil to 8 mil. The greenhouse industry generally uses 4 or 6 mil polyethylene. The film is manufactured in widths of up to 12 m and lengths of up to 46 m.

Polyethylene is not a permanent cover. Even with ultraviolet (UV) inhibitors the material will deteriorate after a period of outdoor exposure. This breakdown is caused primarily by the radiation in the sun's rays. It is recommended that the outer polyethylene cover be replaced every year, although some growers have found that they can get 18 to 24 months of use out of this material.

Heat loss in single-glazed greenhouses can be reduced by covering the glazed areas with either a single or a double layer of PE. Continuous positive air pressure within the greenhouse will inflate the layer of PE, raising it above the glass and, in effect, providing double glazing.

A double layer of PE, either over existing glass or as the primary glazing, is much easier to inflate. A small blower (1/30 H.P. for every 900 m^2 is recommended by one film manufacturer) will inflate the layers of PE. Flexible 10 cm diameter plastic hoses connect the various bubbles so that a uniform air pressure is maintained between the layers throughout the greenhouse cover.

---

[2] Glass widths and thicknesses are given in English units because these are still in use in the industry.

Performance Characteristics of Double-layer UV-inhibited Polyethylene Used in Greenhouse Construction

- transmits 80% of available solar energy (88% for a single layer)
- quite permeable to the longer wavelengths of the thermal radiation spectra (This is one reason that PE houses cool off so quickly after sunset.)
- thermal conductivity: U value = 1.14 single, 0.7 double, R value = 1.43 double, 0.87 single
- the least durable covering material; has a maximum life expectancy of 18-24 months in our climate
- impact resistance twice as good as that of glass, although it is easily punctured by a sharp object (Small holes and cuts can be patched with a plastic-backed acrylic adhesive tape.)
- provides a more tightly sealed house than lapped glass
- minimum fire hazard
- can become brittle at low temperatures

Cost

- for UV-inhibited polyethylene film: 4 mil - \$.43 to \$.65/m^2, 6 mil - \$.65 to \$.86/m^2
- installed costs range from \$21.50 to \$32.00/m^2 for an 1800 m^2 complex, depending on options chosen
- reskinning of existing PE houses costs about \$.43 to \$.65/m^2 plus new film(s)
- PE-covered greenhouses are classified as high risk and underwriters are often reluctant to insure them.

Other flexible plastics such as polyvinyls and reinforced polyethylenes are not used extensively in North America. Life expectancy, size limitation and costs have prevented widespread acceptance of these plastics by the North American greenhouse industry.

Rigid Plastics

Both thermosetting (i.e., glass-reinforced polyesters - FRP or GRP) and thermoplastics (i.e., acrylic and polycarbonate) are available in rigid sheets.

Fibreglass-reinforced plastics: The use of FRP as greenhouse glazing material has declined in the last few years in southern Ontario. Corrugated or flat sheets are available in widths over 1.3 m and lengths up to 9 m. The sheets are made of fibreglass strands which are sandwiched between layers of polyester resin. The most common FRP panels used by the greenhouse industry are modified polyesters with 15% acrylic additives. These additives, along with a surface coating of polyvinyl-fluoride ("Tedlar"), have increased the life expectancy of the panels. Some manufacturers will guarantee replacement over a 15- to 20-year period. Some of the guarantees are prorated.

Performance Characteristics of FRP Used in Greenhouse Construction

- a single layer of FRP transmits 70% to 90% of available solar energy
- slightly higher IR transmission than with glass
- higher impact and sustained load-carrying capacity (two to four times that of glass)
- has a U value equal to that of single glass, U value = 1.1, R value = 1.00
- life expectancy of 10-20 years
- frequency of maintenance: a good cleaning yearly with a resurfacing recommended after 3-5 years
- a combustible material: insurance rates reflect replacment costs (2 1/2 to 3 times those of glass)
- special corrugated closure strips are required to seal at ridges, eaves, gutter, etc.
- structural support required at approx. 90-100 cm centres
- corrugated FRP sheets increase heat transfer surface area by 12% to 16% over that of flat sheets
- some tendency to discolor and erode on the surface after prolonged outdoor exposure

Cost

- 2.5 in. corrugated x 50.5 in. wide, 4 oz. about \$8.6/m^2, 5 oz. about \$9.7/m^2, flat fibreglass \$8.6 to \$9.7/m^2
- installed costs, for a greenhouse area of approx. 1800 m^2, depend on type of structure (gutter-connected or free-standing), options, etc., but range from \$59 to \$113/m^2.

Thermoplastic sheets: Although flat (monolithic) sheets of acrylic or polycarbonate formulation are available to the greenhouse operator they are rarely used because of their high cost, their deflection under load, and size restrictions. However, double-skinned (DSS) glazing panels extruded from either acrylic or polycarbonate molding powders have been developed in the last 10 years. They have all the physical properties of the monolithic sheets with the added benefits of double glazing, light weight and the ability to withstand greater live loads before deflection.

The acrylic DSS (tradenames Acrylite SDP or Exolite, etc.) used in the European greenhouse market is either 8 mm or 16 mm in overall thickness. The North American market uses primarily the 16 mm sheet.

The polycarbonate DSS (tradenames Cyro-Ion SDP, Exolite, Tuffak-Twinwall, Qualex, Cartoplast, etc.) is available in thicknesses of 4 mm to 8 mm, 10 mm and 16 mm.

Performance Characteristics of Acrylic DSS Used in Greenhouse Construction

- transmits 83% to 85% of available solar energy
- becomes impervious to nonpenetrating IR at about 2.2p
- high strength, stiffness and impact resistance
- thermal conductivity 16 mm (the thinner DSS will be less insulative): U value = .55, R value = 1.82
- reduces energy loss by 35% to 62% in comparison with single-glazed glass greenhouse
- most weatherable of all the light-transmitting plastics; will not discolor, become brittle, etc.
- diffusion of light similar to that by FRP
- minimal shading effect as glazing bars are on 122 cm centres
- available in lengths up to 7.6 m, sufficient to span from eave to ridge
- very lightweight, only 4.9 kg/m^2 (16 mm) and 3.5 kg/m^2 (8 mm)
- minimal maintenance
- life expectancy 20+ years
- combustible, flame spread comparable with that of red oak, insurance rates equal to those for FRP

Costs

- \$32 to \$43/m^2, depending on quantity, for 16 mm thickness
- installed greenhouse costs about \$32/m^2 more than a conventional glass house of the same dimensions
- if used as gable and sidewall glazing only, the additional cost over that of a comparable glass house would be about \$11/m^2

Performance Characteristics of Polycarbonate DSS Used in Greenhouse Construction

- not as weatherable as acrylics, slight discoloration with age
- combustible: flame spread half that of acrylic DSS
- highly resistant to impact
- less rigid than acrylic DSS; requires more support
- can be bent to a radius minimum 1.2 m (6 mm) or 4.6 m (16 mm)
- available in widths up to 2.1 m and lengths up to 9 m.

Cost

- less expensive than acrylic DSS in the thinner sheets, ranging from \$16/m^2 to \$27/m^2
- the 16 mm sheet costs about \$16/m^2 more than the 16 mm acrylic DSS

CONCLUSIONS

The primary use of a glazed enclosure is "for the cultivation or protection of tender plants". It sounds so simple. In reality, a greenhouse must not only protect plants but also provide an environment conducive to plant growth; therefore, a light-transmitting shell is required. The glazing material used directly affects that growing environment. The shell must also have insulative properties to reduce operating costs. A comparison of the performance characteristics and cost factors listed here should enable the prospective purchaser to make a choice between the glazing materials currently available.

CONTRASTING APPROACHES TO CONTAINERIZED SEEDLING PRODUCTION

1. BRITISH COLUMBIA

R.G. Matthews[1]

Abstract.--Container seedling production in British Columbia has expanded to 38 million seedlings annually in public nurseries and about 25 million annually in private nurseries with the BC/CFS styroblock serving as the principal container. Seedlings are grown in single crops during an extended normal growing season in facilities ranging from natural to climate-controlled environments.

Résumé.--En Colombie-Britannique, on produit maintenant 38 millions de semis en mottes emballées par année dans les pépinières publiques et 25 millions dans les pépinières privées; le principal contenant utilisé est le BC/CFS styroblock. Les semis sont produits individuellement au cours d'une saison de croissance prolongée, dans des installations où les conditions vont de naturelles à contrôlées.

INTRODUCTION

In 1981, production of container-grown seedlings for use on Crown lands in British Columbia totalled 58 million, of which 38 million were grown in Ministry of Forests nurseries and 20 million in commercial and industrial nurseries. Ministry nurseries are ultimately expected to produce at least 50 million container seedlings annually, while anticipated production by private nurseries is about 45 million container-grown seedlings by 1985-1986. The Ministry production totals represent seven nurseries, all located in the southern half of the province, with most of the production coming from southern coastal nurseries.

The present trend in nursery planning favors development of more northern nurseries to support the two largest and most northerly forest regions, Prince Rupert and Prince George. These regions currently account for most of the 23 million interior spruce (*Picea* spp.) trees produced annually. Lodgepole pine (*Pinus contorta* Dougl. var *latifolia* Engelm.) production totals 12.7 million trees, of which only a portion are for use in the boreal forest.

The name interior spruce is used locally to distinguish it from coastal Sitka spruce (*Picea sitchensis* [Bong.] Carr.). It encompasses white spruce (*P. glauca* [Moench] Voss), Engelmann spruce (*P. engelmannii* Parry) and their hybrids, and will be referred to in this paper as spruce. Spruce and lodgepole pine are two of approximately 15 commercially important species grown in British Columbia nurseries. This paper will discuss cultural methods common to all container crops, and specific requirements of spruce and pine.

Production methods for container crops in British Columbia have been reported elsewhere (Van Eerden 1974, Matthews 1979). Many of the basic cultural techniques have remained unchanged, and have become a matter of routine as a result of experience gained during the past 12 years. As more precise knowledge of the relationship between growing

---

[1] Container Culturist, Silviculture Branch, British Columbia Ministry of Forests, Victoria, British Columbia.

environments and quality of stock has become available, the degree of assurance of desired quality in routine production has improved. Nonetheless, to ensure improved reliability in attaining desired morphological and physiological characteristics, some techniques are still being modified and facilities are being upgraded as budgets permit. Accordingly, it is anticipated that nearly all shadeframes will ultimately be replaced by low cost plastic-covered greenhouses, because much of the stock produced in shadeframes has been too small (dry mass and root-collar diameter).

GENERAL METHODS IN CONTAINER CULTURE

Growing Medium

The growing medium should have a high water holding capacity, good aeration, high cation exchange capacity, appropriate pH, low natural fertility, low salinity, no weed seeds or pathogens, and good fibre length. Such a medium can be obtained only if the source and quality of peat are carefully evaluated. In Ministry nurseries, the supply of peat is limited to one or two local commercial peats which have proven acceptable and consistently reliable. Peat should be a low pH (4.0-4.5) sphagnum type with low calcium content.

The growing medium is comprised of three parts peat to one part (by volume) of #2 horticultural vermiculite. To this is added 3 kg/m^3 dolomite lime (12-mesh and finer) from a specific supplier. This is a relatively coarse lime which moderates pH slowly and does not increase salinity substantially. It is the basic source of calcium and magnesium for crop nutrition. The pH of the medium initially ranges from 4.0 to 4.2 but, under the influence of the lime and soluble fertilizers, pH rises slowly throughout the season to about 6.0 before declining to 5.2-5.5. Contrary to the pH/nutrient relationships in mineral soils, there is some evidence that the optimum pH for nutrient availability in media containing a high proportion of sphagnum peat is about one pH unit lower than previously thought optimum for conifers (Lucas and Davis 1961). In nurseries where the water contains substantial amounts of calcium and magnesium, the amount of lime incorporated into the growing medium may be reduced to 1 kg/m^3. Mixing of the medium is done with commercially available equipment. Water is added until a level of 400% above oven-dry weight is achieved, the point at which water can just be squeezed from the medium.

Styroblock Loading and Seeding

Experience with various methods of loading the growing medium into styroblocks and information generated by limited growth trials have resulted in guidelines for compaction or bulk density. On the basis of oven-dry weights and a usable volume of 33 ml in a styroblock 211 (2A) cavity, optimum compaction is thought to be 0.11 g/ml. Usable compactions may vary from 0.08 g/ml to 0.13 g/ml. Compaction above 0.14 g/ml will result in difficult extraction. Depending on species, variation on either side of the optimum may affect the dry weight of roots produced.

After loading, block cavities are tamped to an appropriate depth for sowing, after which the waste peat is washed from the block surfaces. The seed is sown with a vacuum-drum seeder, and receives a 5 mm covering of #2 granite grit or, more recently, a locally produced coarse industrial washed sand. The seeder was originally developed by the Agricultural Engineering Department of the University of British Columbia, under contract to the Canadian Forestry Service.

Water Quality

One of the most critical aspects of the culture of container-grown seedlings is the availability of adequate quantities of good-quality water. The trend away from coastal nurseries to those in the central and northern interior has necessitated the use of water of poorer quality. The pH of water should be on the acid side of neutral. However, pH in itself is not as important as other factors, such as salinity or total dissolved solids, and levels of sodium, calcium, magnesium, and bicarbonates. Excellent quality water is exemplified by the analysis for the Koksilah nursery on Vancouver Island given in Table 1. In the Ministry nurseries, poor quality water occurs in locations such as the Red Rock nursery in central British Columbia at Prince George. Even poorer quality water is being used in recently developed industrial and commercial nurseries. This may result in reduced overall growth and difficulty in controlling soil salinity levels because of the absence of a low salinity water source which may be used for leaching. Acidification of water sources has not proven necessary or advantageous in any Ministry nurseries to date.

Table 1. Comparative water analysis for two British Columbia nurseries.

		ppm											
Location	pH	TDS[a]	Bicarb alkalinity	Hardness $CaCO_3$	Ca	Mg	Na	K	Cl	SO_4	Fe[b]	Mn	Al
Koksilah[c]	6.7	42	25	26	8.6	1.0	2.0	0.2	1.4	1.0	.06	.01	.10
Red Rock[d]	7.5	264	241	280	66	28	5.2	.25	.88	57	.08	.19	.15

[a] Total dissolved solids
[b] Dissolved iron
[c] Koksilah-Vancouver Island-Municipal
[d] Red Rock-Prince George-Deep Well

Seedling Nutrition

Fertilization of crops is accomplished by using soluble fertilizers and/or by incorporating controlled-release fertilizers in the growing medium. Soluble fertilizers are injected into the irrigation system at almost every watering. A high phosphorus fertilizer (10-52-17) is used as a crop starter and finisher, and a balanced fertilizer (20-20-20) is used during the main growing season. All species are grown on this regimen, with variations in concentrations for individual species requirements. With 20-20-20, concentrations of 500-750 g/1000 L give N levels of 100-150 ppm. In addition, the heptahydrate form of ferrous sulphate is applied every 2 weeks to improve crop color and to prevent symptoms of iron chlorosis. Satisfactory results can be achieved with a predetermined nutrient schedule which specifies fertilizer applications two to four times weekly depending on expected evapotranspiration stresses. Ideally, crops should be watered and fertilized whenever necessary (e.g., for a styroblock 211, when approximately 2 kg of water has been lost from the saturated weight). As with other key elements, the source of soluble fertilizer is restricted to one supplier whose product has performed satisfactorily. Alternative proprietary fertilizers will be introduced slowly after initial test programs have determined their safety and acceptability.

Recently, controlled-release fertilizers have been incorporated into the growing medium with generally good results. This is particularly useful in outdoor facilities where rain often frustrates efforts to control nutrient levels with soluble fertilizers, and where sprinkler systems with poor distribution patterns make uniform application of nutrients difficult. A 3:1 peat: vermiculite growing medium would include:

3 kg/m^3 Green Valley dolomite lime (12-mesh and finer),
5.85 kg/m^3 Osmocote 18-6-12 (9 months),
0.13 kg/m^3 FTE 503 trace elements.

These nutrient rates are used for all species except the faster growing coastal Douglas-fir and Sitka spruce, for which Osmocote levels are reduced to 4 kg/m^3.

To incorporate Osmocote into the growing medium, mixing equipment must be capable of distributing the material uniformly without breaking or scarring the coating on the fertilizer prills. Because the release rate of Osmocote is temperature dependent, difficulties are sometimes experienced under cool growing conditions. Consequently, release rates are subject to annual variation. When Osmocote performs optimally, substantial increases in top and root dry weights over those of the present soluble fertilizer program can be achieved. The color of stock grown on Osmocote is excellent, and no difficulties have been experienced in achieving bud set and maturity. Soluble high phosphorus fertilizer is applied in conjunction with Osmocote as a starter and finisher, in preference to adding superphosphate to the growing medium.

It has been observed that when a low rate of Osmocote is incorporated into the soil medium, growth rates with conventional soluble fertilizer programs are improved. Therefore, all crops scheduled for soluble fertilization in 1981 had 1.3 kg/m^3 of Osmocote 18-6-12 incorporated into the growing medium.

Salinity of the Growing Medium

The experience with Osmocote demonstrated that past salinity levels were probably so conservative as to be limiting to growth. With soluble fertilizer programs, soil salinities often did not exceed 500 µmhos, with leaching recommended at about 600 µmhos. Use of Osmocote has resulted in salinity levels in the 1000-1250 range, with leaching occurring at levels approaching 2000 µmhos. Growth has been excellent in this range, and there is no known salinity damage. The appropriateness of these levels is confirmed by Boodley (1981), who contends that salinity levels in peat-vermiculite soil types can safely be higher than in mineral soils (Table 2). Boodley suggests that the medium range is best for continuous crop fertilization. In the low range, growth will probably be limited by lack of nutrients.

Table 2. Salinity levels in mineral soils and peat-lite mixes.[a]

Mineral soils	Peat-lite mix	Rating
µmhos (mhos x 10^{-6})		
Above 2000	Above 3500	Excessive
1750-2000	2250-3500	Very high
1250-1750	1750-2250	High
500-1250	1000-1750	Medium
0- 500	0-1000	Low

[a]Source: Boodley 1981.

Growing Facilities

Facilities for growing container crops range from outdoor compounds to climate-controlled greenhouses with fibreglass. Between these extremes are shadecloth-covered shadeframes and lower cost greenhouses covered with single or double polyethylene. The different types of facility accommodate the varying requirements of different species and allow for special requirements, such as producing crops for early fall planting. Almost all closed greenhouses have removable side walls and some also have roof vents. When summer temperatures rise to the point that fan systems must operate almost constantly, the side walls are removed and the fans are turned off. Natural ventilation is then utilized until it becomes desirable to close houses in late fall.

More expensive facilities are furnished with aluminum T-bar bench systems which support styroblocks and utilize a high percentage of floor area. Such houses are equipped with irrigation booms for greater efficiency and economy of operation. Simpler facilities generally use treated wood pallet supports, with conventional sprinkler heads on the perimeter of single houses or throughout shadeframe units.

Crop Scheduling

Most seedlings in British Columbia are spring planted, utilizing cold storage facilities between extraction at maximum hardiness in January, and planting from March to June. Container-grown stock is extracted, wrapped with PVC film in bundles of 25, put in poly-coated paper liners in waxed cartons and placed in cold storage at 2°C. Species susceptible to storage molds have been stored at -2°C. However, with frozen storage considerable difficulty has been experienced in ensuring that plug bundles are thawed prior to planting.

Most seeding is done in March and April, with some May sowing of pine in interior locations. Crop scheduling closely follows the natural growing season, requiring minimum input of fuel to moderate temperatures in spring and fall. Some double cropping has been attempted. This involved a February-sown crop which was moved from greenhouse to shadeframe after several weeks of initial growth. A second crop was then sown in the greenhouse, extending growing conditions into late fall. Because the quality of seedlings, especially in the second crop, was not entirely satisfactory, this procedure was discontinued. However, with improved growing schedules and a more judicious mix of species, multiple cropping may again be investigated.

SPRUCE AND PINE PRODUCTION

Seeding

Spruce seed is soaked for 24 hr and surface dried prior to a minimum stratification period of 3 weeks at 2°C. Surface drying prevents the spread of the cold fungus *Caboscypha fulgens* during stratification. Lodgepole pine seed is generally given the same treatment, although some seedlots germinate better without stratification. Germination levels have improved with better collection and seed sorting methods, but there are still many seedlots that have viabilities of 65-85%. To strike a balance between the efficient use of greenhouse space and thinning costs, the sowing rules given in Table 3 were utilized in 1981.

Table 3. Sowing rules for various germination rates, 1981.

Germination (%)	No. of seeds per cavity	Cavities to sow over request
96-100	1	1.25
86-95	1	1.35
76-85	2	1.25
66-75	2	1.35
56-65	3	1.45
46-55	4	1.45

Spruce is sown during the first half of April in interior nurseries and during the latter half of April in coastal nurseries (Fig. 1). The later sowing date on the coast reflects the use of simpler shadeframe facilities in this area. Pine is sown in the latter half of April on the coast and about a week later in interior locations.

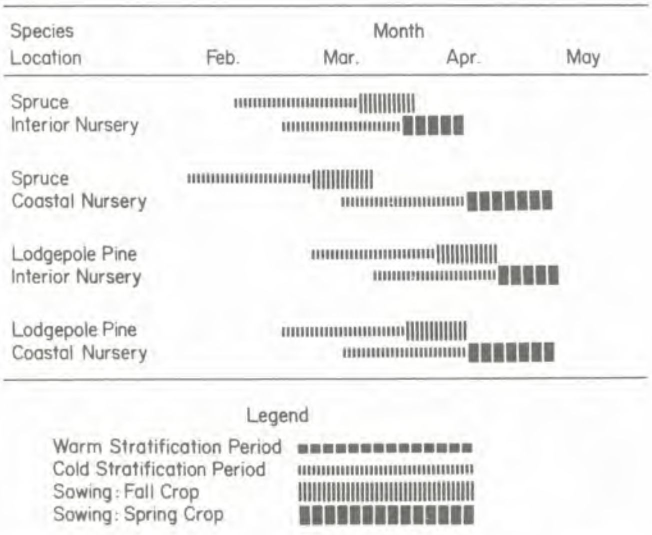


Figure 1. Optimum sowing dates and stratification periods for container stock in interior and coastal British Columbia nurseries.

Germination

Pine crops are usually germinated in open compounds. With spruce, and where facilities are available in pine nurseries, greenhouses may be used as germination facilities. Styroblocks are stacked 12 high on pallets and moved by forklift into germinators where they are left for approximately 7 days before being placed in their growing location. Greenhouses used as germinators are generally more efficiently heated, i.e., they may have double-poly roofs or an inner poly lining fitted for the purpose. Stationary misting nozzles or special misting booms maintain high moisture and humidity levels. Germinators tend to accelerate germination and give more uniform germination with some species; they may also reduce heating costs during the germination phase.

Misting of germinants continues until seed coats drop. When germination is complete, seedlings are thinned to one per cavity. Fertilization begins when the majority of seedlings show primary needle development.

Seedling Culture

At present, most of the spruce is grown in shadeframes in coastal nurseries. Shadecloth providing 46% shade has been used but 30% shade is now preferred. Double-poly houses also give satisfactory shade levels for spruce production. Because of deficiencies of stock grown in shadeframes, especially under unfavorable growing conditions, it is anticipated that all spruce production will ultimately be carried out in relatively inexpensive greenhouse structures. Some spruce is grown in fibreglass greenhouses but this is generally done only to accommodate requests for larger stock and for a small amount of fall planting.

Although a small percentage of lodgepole pine is grown in greenhouses, it is grown mostly in unshaded compounds, in both coastal and interior nurseries. Warmer locations are preferred for good growth. Pine can be greenhouse-grown, but it is important to maintain high light levels to prevent overgrowth of tops.

Because of the quality of stock produced in the past, and as a result of changing field requirements, it appears that spruce will increasingly be grown in styroblock 313s (4A) with a cavity volume of 60 ml and a seedling density of 936/m^2. Pine, on the other hand, will likely continue to be grown in styroblock 211s (2A) having a volume of 40 ml and a density of 1130/m^2.

Spruce originating in northern and/or high elevation locations and grown in southern nurseries are likely to initiate bud set at any time after germination. To avoid premature cessation of height growth, artificial light (5 foot-candles at crop level) is used to extend the natural photoperiod to 18 hr (Arnott 1974). In some cases, lights are mounted on irrigation booms to provide illumination at approximately half-hour intervals. Photoperiod extension is discontinued when it is necessary to initiate budset.

In facilities which permit some degree of control, day temperatures for spruce should be maintained at 20°C for optimum growth. The relative humidity should be kept low by adequate ventilation to enhance air root pruning, and to discourage growth of algae and disease. After germination is completed, wet-dry cycles should be established at the block surfaces. This can be accomplished with a watering schedule which relies on some measure of crop need for water (such as block weights or some measure of plant moisture stress) rather than on a fixed schedule. With soil compaction levels of approximately 0.1 g oven-dry weight per ml of cavity volume, a saturated styroblock 211 will weigh between 7 and 8.25 kg. A weight loss of 2 kg indicates the need for water. Approximately 10% of the nutrient solution applied should drain through the cavities at each irrigation to avoid excessive soil salinities.

The size of pine seedlings grown in outdoor units can vary widely according to location and annual weather conditions. Fortunately, pine plugs are generally adequate for planting through a wide range of top sizes. Pine plugs are no longer grown to the very heavy rooting standard of previous years because this predisposes the seedlings to root form problems after planting. A potential solution to this problem developed by Burdett (1978) utilizes a coating of copper carbonate in latex paint on cavity walls. Operational trials of this technique are under way in Ministry nurseries.

The majority of spruce crops currently being grown in shadeframes receive Osmocote as the basic source of nutrients, with supplementary 10-52-17 in spring and fall (Table 4). Spruce crops under cover will likely be grown on a soluble fertilizer schedule if an irrigation boom is available, or with Osmocote if a fixed irrigation system is used. Most pine crops are currently grown with soluble fertilizers, because growth increases with Osmocote have not been as great in the pines as in spruce.

Soluble 20-20-20, which also contains trace elements, may be increased to 750 g/1000 L to increase growth rates. In addition, daily fertilization may be utilized for brief periods to encourage growth. Finishing applications of 10-52-17 may be increased to 925 g/1000 L and Osmocote crops may receive supplemental applications of 20-20-20 for similar reasons. Ferrous sulphate (heptahydrate) at 150 g/1000 L is applied every 2 weeks during the main growing season for crops grown with soluble fertilizers, and may also be applied to crops grown on Osmocote to improve color. Nutrient concentrations for various fertilizer application rates are given in Table 5.

When desired height growth has been attained (generally by mid-August), the conditioning process begins. For spruce, photoperiod lights are turned off, fertilizer is changed to 10-52-17 for both species, and drought stressing is applied for 10-14 days. Drought stressing is quite moderate, when a 3 kg loss in block weights is used as a guide rather than the 2 kg water loss generally used as an indicator of water need. Stressing to the wilt point does not usually occur except in some edge cavities. A wetting agent may be necessary to re-wet plugs which have become too dry. Because removal of shadecloth in early September seems to negate efforts to initiate budset, current practice with spruce is to leave shadecloth in place until November in coastal locations. There are indications that higher seedling dry weights can be achieved by removal of shadecloth in midsummer. In interior loca-

Table 4. Typical fertilizer applications (625 g/1000 L)

	Fertilizer type	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
Pine Spruce	Soluble		◄10-52-17►		◄— 20-20-20 —►			◄——— 10-52-17 ———►	
Spruce	Osmocote		◄10-52-17►		◄— Water only —►			◄——— 10-52-17 ———►	

tions, pine crops are extracted and packaged for cold storage in October or November; spruce crops are cold stored mainly in January or February at their peak of dormancy.

Table 5. Concentrations of N, P, K in soluble fertilizers (ppm)

Fertilizer	Rate (g/1000 L)	N	P	K
10-52-17	625	62	142	88
10-52-17	925	92	210	130
20-20-20	625	125	55	104
20-20-20	750	150	65	125

Stock Specifications

Stock specifications for 1981 are presented in Table 6. The specifications for spruce are for crops grown in shadeframes; specifications for greenhouse—grown spruce would call for considerably larger seedlings. Representative growth curves for spruce and pine are presented in Figures 2 and 3, respectively.

In addition to morphological standards, container—grown stock is freezer tested to determine the level of frost hardiness prior to cold storage. The root growth capacity of container stock is generally very high and is not checked unless root damage is suspected.

CONCLUSION

Much has been learned about container stock production over the past 10 years. There is now a much better appreciation of the facilities and cultural techniques that are required to produce seedlings of specific morphological standards, consistently. Continuing expansion within Ministry nurseries and the recent development of industrial and commercial nurseries have created many problems associated with the handling of this greatly increased production, and in the provision of adequate facilities and equipment.

On many occasions, cultural principles have been compromised to compensate for other problems. These physical and organizational problems generally have one visible result: reduced quality of stock and/or numbers of seedlings produced.

Table 6. Container stock specifications for spruce and pine produced in British Columbia nurseries.

	Height (cm)	Root-collar diameter (mm)	Top dry weight (g)	Root dry weight (g)
Spruce				
211 Minimum acceptable	9.0	1.7	0.4	0.2
211 Optimum target	12.5	2.2	0.7	0.3
313 Minimum acceptable	10	1.8	0.5	0.25
313 Optimum target	17	2.5	0.9	0.4
Pine				
211 Minimum acceptable	7.0	2.2	0.45	0.25
211 Optimum target	12.5	2.6	0.7	0.4
313 Minimum acceptable	10	2.5	0.6	0.4
313 Optimum target	15	3.0	0.9	0.5

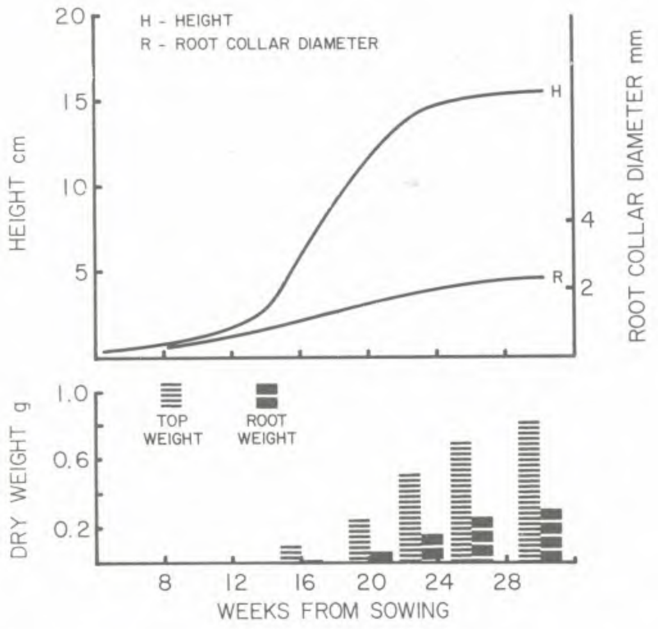


Figure 2. Typical growth curves for spruce grown in styroblock 211 (2A).

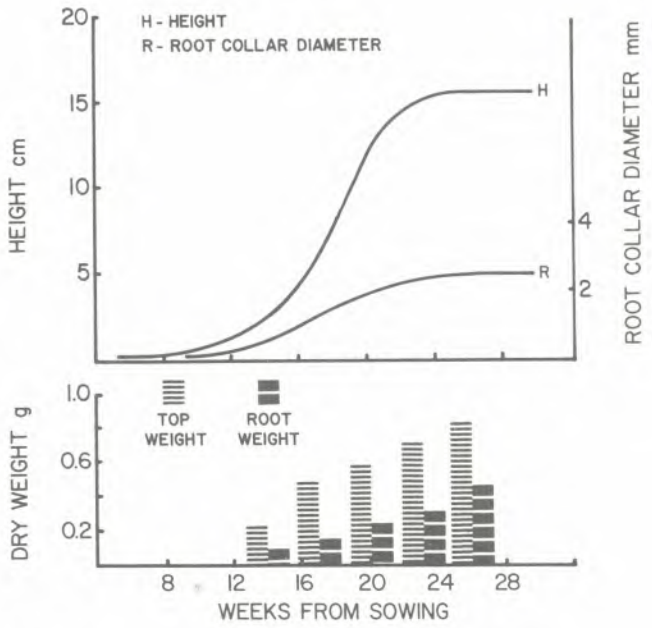


Figure 3. Typical growth curves for pine grown in styroblock 211 (2A).

If we are to produce high-quality stock consistently, there must be a continuing effort to adhere to known biological principles. The challenge in moving from a relatively small production to many millions annually is in organizing a smooth expansion of services and facilities, which will not jeopardize cultural principles and therefore seedling quality.

LITERATURE CITED

Arnott, J.T.
1974. Growth response of white-Engelmann spruce provenances to extended photoperiod using continuous and intermittent light. Can. J. For. Res. 4:69-75.

Boodley, J.W.
1981. Interpreting soluble salt levels. New York State Flower Ind. Bull., Apr.

Burdett, A.N.
1978. Root form and mechanical stability in planted Lodgepole pine in British Columbia. p. 162-165 in Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8.

Lucas, R.E. and Davis, J.F.
1961. Relationships between pH values of organic soils and availability of 12 plant nutrients. Soil Sci. 92:177-182.

Matthews, R.G.
1971. Container seedling production: a provisional manual. Dep. Environ., Can. For. Serv., Victoria, B.C. Inf. Rep. BC-X-58. 57 p.

Van Eerden, E.
1974. Growing season production of western conifers. p. 93-103 in R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. 68.

CONTRASTING APPROACHES TO CONTAINERIZED SEEDLING PRODUCTION

2. THE PRAIRIE PROVINCES

I.K. Edwards and R.F. Huber[1]

Abstract.-- Six containerized seedling facilities in the prairie provinces produce at least two crops annually for a total of 19 million conifer seedlings. Differences among facilities with respect to container type, growth medium, light intensity, photoperiod, temperature, and mineral nutrition during the growth and conditioning phases result in variable but acceptable planting stock for reforestation.

Résumé.--Six installations de production de semis en pot des Prairies produisent chaque année au moins deux récoltes représentant au total 19 millions de semis de conifères. Des différences entre les installations en ce qui concerne le type de pot, le milieu de culture, l'intensité de la lumière, la photopériode, la température et la disponibilité en substances minérales durant les périodes de croissance et de conditionnement font que leur matériel est variable mais acceptable pour le reboisement.

INTRODUCTION

In the prairie provinces (Alberta, Saskatchewan, and Manitoba) there are six nursery facilities producing containerized planting stock exclusively for reforestation purposes. These nurseries differ in their approach to containerized stock production chiefly because of the size and history of the particular operation. Production systems and cultural practices vary, and this variation is expressed in the quality of stock produced. This paper describes the growing facilities and their production systems, and highlights the significant features of containerized seedling production in the Canadian prairies.

GROWING FACILITIES

Three of the six growing facilities are located in Alberta--one at Hinton (St. Regis [Alberta] Ltd.), one at Whitecourt (operated jointly by Alberta government and Simpson Timber Co. [Alberta] Ltd.), and one at Smoky Lake (government-operated Pine Ridge Forest Nursery). In Saskatchewan there are two government-operated growing facilities--one at Big River (Big River Forest Nursery) and one at Prince Albert (Prince Albert Forest Nursery). The single Manitoba nursery (Pineland Forest Nursery) is government operated and located at Hadashville.

The growing facilities range in size from the 20-greenhouse operation at Pine Ridge to the single-greenhouse operations at Whitecourt and Big River. Approximately 19 million conifer seedlings are produced annually in the region (Table 1), with Alberta producing 80% of the total. Although species produced in the region include black spruce *(Picea mariana [Mill.]* B.S.P.) and red pine *(Pinus resinosa* Ait.), the principal species grown are white spruce *(Picea glauca* [Moench.] Voss), lodgepole pine *(Pinus contorta* Dougl.), and jack pine *(P. banksiana* Lamb.), which account for 62%, 25%, and 12%, respectively, of the regional total.

---

[1] Research Scientist and Nursery Practice Technician, respectively, Northern Forest Research Centre, Canadian Forestry Service, Edmonton, Alberta.

Table 1. Containerized seedlings shipped for reforestation in the prairie provinces (1980).

Species	Seedlings (000,000) Alberta	Saskatchewan	Manitoba
White spruce	10.515	0.840	0.180
Lodgepole pine	4.560	--	--
Jack pine	--	2.170	0.145
Black spruce	--	--	0.177
TOTAL	15.075	3.010	0.502

PRODUCTION SYSTEM

Container Type

Containers based on two distinct concepts are used, namely, Spencer-Lemaire "Rootrainers" and Japanese paperpots (Table 2). Choice of container type depends as much on sentiment as it does on practicality. Reasons for choosing the Spencer-Lemaire "Rootrainers", for example, vary from "we were involved with its development" and "it was developed in Alberta" to "it is good for root training", "it can be opened to check the root system", and "it is reusable". Paperpot users made their selection on the basis of lower cost (at the time the decision was made) and the manufacturer's claim of biodegradability. Other types of containers such as the styroblock and the RCA sausage have also been assessed. The styroblock was unacceptable because of root damage sustained during winter, and the 'sausage' was discarded because of the high density of the peat plug and poor wettability following drying. Regionally, optimum cavity size has been determined on the basis of the number of seedlings required to meet reforestation objectives without sacrificing stock quality.

Growth Medium

The most common growth medium is either commercial sphagnum peat or a mixture of peat and horticultural grade vermiculite in the ratio 2:1. In most cases, the peat is tested for pH and for electrical conductivity. Acceptable pH is in the range 4.5-6.0, and liming is recommended for supplies whose pH is below this range. High salinity is rarely a problem, although peat supplies have been rejected because of a high concentration of sodium sulfate. The maximum level for electrical conductivity in acceptable peat is 0.50 milli-siemens/cm. A coarse:fine ratio[2] of at least 0.5 is recommended (Carlson 1979); it is not determined on a routine basis, as experienced nurserymen can assess this characteristic by sight and touch. The growing medium is moistened (until water just appears when the growing medium is squeezed), then is fed mechanically into the containers that are vibrated as they pass beneath the feed hoppers.

Table 2. Container types used in the prairie provinces

Container type	Cavity volume (cm^3)	Cavities per tray
Spencer-Lemaire "Rootrainers":		
Ferdinand (Six)	40	102
Five	70	55
Japanese paperpots:		
FH 308	44	532
FH 315	88	532
FH 408	70	336

Sowing

Sowing is done mechanically with vacuum activated rotating drum seeders that deliver 3-5 seeds per cavity depending on the germination test for the seed lot. Thinning to one seedling per cavity is done 2 weeks after germination. The seeds are covered with No. 2 granite grit, after which the containers are moved to the greenhouse, saturated with water, and covered with burlap, 4-mil polyethylene sheets, or a combination of both materials until germination is complete (approximately 7 days for pine and 10 days for spruce).

---

[2] A given amount of peat is air-dried and sieved on a 2-mm sieve. The ratio of weight of material retained by the sieve and the weight of material not retained is the coarse:fine ratio.

CULTURAL ENVIRONMENT

Water

Throughout the growing phase water is applied as required. The need for watering is judged visually and by feel. Water is delivered through overhead sprinklers mounted on stationary or movable booms, but even coverage depends on strategic placement of the nozzles and consideration of their angle of spray.

Photoperiod

Beginning a week after germination, greenhouse lighting is regulated. All nurseries in the prairie provinces depend on natural daylight and, as production is restricted to spring and summer, the basic photoperiod is approximately 18 hr. Four of the six facilities also use intermittent light during the dark hours to prolong photoperiod and prevent dormancy. The intensity of this supplementary light can be a minimum of 400 lux (Tinus and McDonald 1979) and, at the various nurseries, ranges from incandescent or fluorescent light of 500 lux cycled on intermittently for 1 minute every 15 minutes to 4500 lux sodium arc lamps cycled on for 2 minutes every 30 minutes.

Temperature

At all nurseries, greenhouse temperatures during the day are generally in the 20-25°C range. The nurseries strive for 22°C for spruce and 25°C for pine, but two facilities operate in the 23-28°C range for pine. At night, greenhouse temperatures are reduced to the 16-20°C range for spruce and 14-19°C for pine. One nursery uses 20°C for both species.

Heating consists of forced air from a natural gas furnace in most cases. At one growing facility, a wood furnace is used. At one nursery, greenhouse benches are heated by electric cables during the germination phase, and at another, heated forced air is used. One nursery also has supplementary gas heaters mounted overhead. Cooling is done simply by means of fans and vents at some locations; at others, water-cooled aspen pads are used in conjunction with fans.

Fertilization

No fertilizers are added to the growing medium prior to filling of the containers. Seedlings are fertilized exclusively by nutrient solutions dispensed through the overhead irrigation system via automatic dilution equipment. Nutrient applications are carried out once a week, and in all cases enough solution is applied to saturate the entire plug of growing medium. Immediately after application of a nutrient solution, the foliage is rinsed with water. Throughout production, water is applied as required.

The commencement of nutrient applications depends on whether the nurseryman feels that such applications are required in the early phase (0-4 weeks) of growth. In some cases, nutrient applications begin 1 week after germination and continue for 3 weeks. While this early growth phase is believed to be critical for root development, nurserymen are undecided whether the level of food reserves in the seed is adequate for the seedling during this period. A nutrient solution consisting of low nitrogen (N), high phosphorus (P), and moderate to high potassium (K) is applied in the early phase of growth (Table 3). Beginning 4 weeks after germination and continuing for 8-10 weeks, a different solution (high N, low P, high K) is used; it is compatible with the rapid growth phase. Each solution also contains micronutrients: iron (5.5 mg/L), manganese (0.2 mg/L), copper (0.02 mg/L), zinc (0.05 mg/L), boron (0.35 mg/L), and molybdenum (0.03 mg/L).

When the required height growth is achieved, the seedling is hardened-off in preparation for planting in the same year or for overwintering. The nutrient solution used during this conditioning phase is characterized by low N, high P, and high K and, in some cases, is identical to that used in the early growth phase. The wide ranges in nutrient concentration of the solutions used during any phase of growth reflect not only personal preferences of individual nurserymen but also the wide tolerance of these species for nutrients under these growing conditions. Some of the formulations being used are those recommended for the region by Carlson (1979), and it is intended that these guidelines will be used in future operations.

Cropping Cycle

Five growers in the region produce two crops per year and one produces three crops. There is no production during the winter months although two producers begin their first crop in February. Most begin in March, and all greenhouse rearing terminates in mid-September. Where only two crops are produced annually, the first crop is usually grown in the greenhouse for 14-18 weeks and the second is grown for 14-19 weeks. However, three facilities use a 14-week greenhouse rearing period for both crops. Where three crops are produced annually, rearing times in the greenhouse are 8, 4, and 8 weeks for the first, second, and third crops, respectively. With one exception, all crops produced in one year are hardened-off and overwintered before planting the following year. At the nursery where three crops are produced annually, the first crop is conditioned in a cold frame before planting in the current year.

Hardening

Hardening or conditioning of the crop follows the rapid growth phase during which sufficient height growth has been achieved, and although it may be initiated in the greenhouse, it is usually completed in a cold frame.[3] The hardening process physiologically conditions both seedlings that will be planted out in the current year and those that will be held over winter for planting in the following year. Seedlings that will be planted in the current year undergo conditioning in the cold frame through partial shading and exposure to ambient air temperature. In preparation for overwintering, dormancy and associated budset must be induced. This is achieved by 1) reducing the photoperiod, 2) inducing moisture stress by witholding water, 3) reducing the nutrient applications to one a week (Table 3), and 4) reducing day and night temperatures gradually over a 2-week period to 10 °C and 3 °C, respectively. When the seedlings are being hardened in cold frames, the nutrient solution is applied once a week until freeze-up.

Proper hardening of seedlings in the prairies is not always achieved. Success of the procedure requires that the four steps be carried out sequentially (Tinus 1974), with the duration of each depending on the species and age of stock. Under operational conditions, however, temperature is sometimes reduced simultaneously with photoperiod. This might well be an area for further study to delineate the limits for manipulating these factors without jeopardizing the physiological quality of the seedling.

Overwintering

Seedlings are overwintered exclusively in cold frames, some of the containers being set on boards or pallets, some on a sand or gravel base, and still others on asphalt. Hardening-off solution is applied once a week or every two weeks until freeze-up. After thawing in the spring, the same nutrient solution is applied once a week or every two weeks until the seedlings are shipped. Success of overwintering containerized seedlings in the prairie provinces often depends on the availability of adequate snow cover, which provides insulation against the very low or fluctuating temperatures that characterize the region. Snow cover is also important in the few cases in which containers are being overwintered on pallets because of the mobility they afford. Without proper insulation, however, root damage is severe.

Crop Monitoring

At most nurseries, the stock is monitored for shoot height, stem diameter, shoot dry weight, and root dry weight throughout the growing season, starting as early as 4 weeks after germination. There is, however, great variation in the approach to monitoring. One nursery does not monitor consistently, although a visual check is made before the crop leaves the greenhouse. Another monitors root area, pH, electrical conductivity of the growing medium, and even N, P, and K analysis of the foliage, in addition to the four parameters mentioned previously. This nursery also monitors temperature in and around the container throughout the overwintering phase of production.

Only one nursery has morphological specifications for the seedlings produced: height = 10-18 cm, shoot:root ratio = 2-3, total dry weight = 500 mg for spruce and 700 mg for pine, and stem diameter = 2.0-2.5 mm. At other nurseries, the fitness of the crop for outplanting is checked visually (e.g., by opening 'books' and inspecting root systems) and a subjective judgment is made as to its suitability. Nurserymen in the region recognize the deficiencies in this area, and in future containerized stock will be monitored in a more systematic way. We ought to strive for improved stock quality, and therefore we should have clear standards against which to measure our progress. Closer monitoring of each aspect of the operation (especially growing medium, nutrient regime, and hardening-off) is required if nurseries are to capitalize on the technology that has made containerized seedling production a viable undertaking.

---

[3] This is a structure with open sides and a 4-m-high roof of shade cloth or snow fencing. One facility uses snow fencing supported 30 cm above the seedlings. The trays are set on sand, gravel, pallets, or wooden slats.

Table 3. Concentration (mg/L) of N, P, and K in nutrient solutions applied during different phases[a] of growth at different prairie nurseries[b]

Early growth			Rapid growth			Hardening-off		
N	P	K	N	P	K	N	P	K
100	228	83	200	88	166	78	170	250
33	103	150	125	61	156	33	103	150
	--		112	55	156	44	101	150
	--		300	38	201	44	101	150

[a] If germination is taken as week 0, the early growth, rapid growth, and hardening-off phases are 0-4, 4-16, and 16+ weeks, respectively.

[b] Each row describes the nursery regime used at one or more nurseries.

CONCLUSIONS

1. Containerized seedling production in the prairie provinces is still evolving. At present, cultural practices are based largely on the personal preferences of the nurserymen. More experimentation is needed to optimize growth factors at each location.

2. Controllable factors should be controlled. For example, uniform application of water and nutrient solution would help to reduce variation in stock size.

3. A greater degree of fine tuning of the conditioning process is required so that it can be achieved more precisely. Overwintering and frost damage would be minimized in consequence.

4. More nurseries need to develop standards for their own stock, based on planting requirements, and to monitor their operation closely to ensure that those standards are achieved.

LITERATURE CITED

Carlson, L.W.
1979. Guidelines for rearing containerized conifer seedlings in the prairie provinces. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-214. 62 p.

Tinus, R.W.
1974. Large trees for the Rockies and plains. p. 112-118 in R.W. Tinus, W.I. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. 68.

Tinus, R.W. and McDonald, S.E.
1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv., Rocky Mt. For. Range Exp. Stn. Gen. Tech. Rep. RM-60. 256 p.

CONTRASTING APPROACHES TO CONTAINERIZED SEEDLING PRODUCTION

3. THE MARITIME PROVINCES

R.D. Hallett'

Abstract.--Production facilities and cultural practices for producing containerized tree seedlings in Maritime greenhouses are described. Several systems are in use and some features are contrasted with those in other regions. New container facilities account for much of the expansion in nursery production. Further investigation of crop specifications, seedling hardiness and energy conservation are recommended.

Résumé.--On décrit les installations et les méthodes de culture employées dans les Maritimes pour produire en serre des plants en mottes emballées. Plusieurs systèmes sont employés, et on établit quelques points de comparaison avec d'autres régions. Les nouvelles installations de plants en mottes emballées comptent pour beaucoup dans l'augmentation de la production en pépinière. On recommande d'effectuer d'autres recherches sur les caractéristiques des cultures, la vigueur des plants et l'économie d'énergie.

INTRODUCTION

Containerized seedling production in the Maritime provinces has three main features: the operation of greenhouses in winter, the planting of actively growing seedlings, and the use of an extended planting season. In the early 1970s a two-crop system evolved: a "winter" crop of spruce *(Picea* spp.) is grown in heated greenhouses between December and February for late-spring and early-summer planting; following removal of the winter crop from the greenhouse, a "summer" crop of pine *(Pinus* spp.) is grown for late-summer planting.

More recently, additional summer crops have been grown with the later crops being held over .winter. These crops extend the container planting season because dormant seedlings can be planted in spring before the current winter crop is ready. Undersized crops can be grown for part of another season and summer planted after the winter crop, but before the current summer crop is ready.

Full-season planting is used by some agencies, except during extreme fire hazard. Actively growing black spruce *(Picea mariana* [Mill.] B.S.P.), red spruce *(P. rubens* Sarg.), jack pine *(Pines banksiana* Lamb.) and larch *(Larix* sp.), i.e., seedlings without fully lignified top growth or dormant terminal buds, are often outplanted. Other species such as white spruce *(Picea glauca* [Moench] Voss) or red pine *(Pinus resinosa* Ait.) usually have set bud at outplanting although seedling dry weight is still increasing rapidly in the nursery.

PRODUCTION FACILITIES

Greenhouses

Initially, free-standing metal-arch greenhouses with a double polyethylene cover were used. Recently, several large gutter-connected complexes with double-poly covers have been constructed. (One new heated complex covered with fibreglass is fitted with heat-shade curtains.) Bay widths vary from 4 to 11 m. The total greenhouse space available for forest tree seedling production in

---

[1] Forestry Officer, Maritimes Forest Research Centre, Canadian Forestry Service, Fredericton, New Brunswick.

the Maritimes is 5.8 ha, of which 60% is heated for winter production (Table 1). These greenhouses are serviced by headhouses that contain the boiler plant, loading equipment, and space for office, laboratory, and storage.

Greenhouse equipment

Heat is supplied from boiler plants to hot water unit heaters with adapters for duct-vent polytubing under benches or, for most gutter-connected complexes, through aerially mounted finned pipes for radiation heating to melt snow. In 1980, 27% of the 51 million seedlings grown were produced in heated greenhouses at a fuel cost of between $17 and $25 per thousand seedlings.

Most greenhouses are cooled by exhaust fans with motorized inlet shutters; pad cooling systems are used only in research greenhouses. Overhead, duct-vent polytubing with pressurizing fans and motorized inlet shutters provide recirculation of air when the greenhouses are closed, or fresh air for cooling or humidity control during the cold season. When the required cooling exceeds the mechanical capacity of the system, the polycovers are painted with a white latex paint. Some growers are reluctant to use paint on high-grade multiyear plastics, because it is then necessary to use new plastic for the following winter crop in order to provide sufficient natural light for growth. Curtains made from heat shield or shade fabrics have been installed in some gutter-connected complexes.

Greenhouse climate equipment is controlled mostly by programmable systems such as the Wadsworth (Arvada, Colorado) STEP (single total environmental programmer) system. Emergency generators provide electrical backup for winter heating and summer cooling.

The containers are generally placed on raised benches or, in most gutter-connected complexes, on raised pallets for transfer by forklift. Roller benches are also used. At some locations, crops are grown on the ground (total 1.4 ha).

Irrigation in most greenhouses is provided by irrigation carts mounted between benches or suspended from trusses. These are generally Spray-Rite Watering System (Waterford, Ontario) carts with TeeJet (Spraying Systems Co., Wheaton, Illinois) spray nozzles mounted on 31 cm centres, with the boom suspended 40-50 cm above the containers. Fertilization is usually done with liquid fertilizer injectors.

Shadehouses and holding areas

Most greenhouse nurseries use open holding areas, usually covered with crushed rock or gravel to a depth of 15 cm or more, for temporary holding, outdoor growing, or overwintering stock (Table 1). A gravel base provides good drainage and support for equipment. Some nurserymen cut narrow east-west strips in the forest to provide summer shade; these also provide a sheltered overwintering area because of the increased shade and snowcover. Irrigation of stock in such areas is accomplished by means of portable sprinkler irrigation systems with impact sprinklers mounted on risers.

Shadehouses are also used. They are constructed as pole-frame supports of wood or metal with a flat cover of lath snow fence or nylon shade cloth.

Wood frame shelterhouses constructed of 2.5 x 7.5 cm lath boards mounted on 15 cm centres have been used primarily for protection of overwintering stock at two locations which have unreliable snowcover. These shelterhouses are also used for frost protection of winter-grown stock that is moved out-

Table 1. Area of various container greenhouses in the Maritime provinces (m^2)

	Free-standing		Gutter-connected		Open holding area	Shade area
	Heated	Unheated	Heated	Unheated		
New Brunswick	12,000	6,800	10,700	6,000	70,000	10,000
Nova Scotia	3,100	9,500	7,400	Nil	47,500	930
Prince Edward Island	370	Nil	3,700	Nil	500	4,200
Total	15,470	16,300	21,800	6,000	118,000	15,130

side in spring, and as growing facilities during summer months. They are now covered year-round with a single poly cover and, consequently, are considered greenhouses.

Loading Equipment

High-capacity filling and seeding machines are in use at six nurseries. Seven of these machines were constructed by a New Brunswick firm. The machinery includes:

- an electrical control panel;
- a peat shredder and feeding screw; leading to
- a feeder-mixer bin with another feeding screw; leading to the top of
- the filling machine where flats are filled, compacted, and levelled;
- a return conveyor for surplus growing medium from the filler;
- a high-capacity sowing machine with self-cleaning attachment for the nozzles;
- a gritting machine to cover seed.

A dust-control system is available and is used at some locations. Two locations use other seeding machines: one uses a Vancouver Bio-Machine (Surrey, British Columbia), the other a Wendt seeder (Stockjo, Sweden).

Containers

Of the 51 million seedlings produced in 1981, 45% were in Japanese paperpots, 42% in Can-Am multipots, 11% in styroblocks, and 2% in Spencer-Lemaire "Rootrainers" (Table 2). Multipot production is increasing and new sizes are being developed at Can-Am Containers Ltd., Springhill, Nova Scotia. The total number of seedlings shipped from nurseries in 1981 was 73 million; container shipments accounted for 64%.

Growing Media

Most seedlings are grown in peat, although several nurseries use a 3:1 (v/v) peat and vermiculite growing medium. Osmocote (Sierra Chemical Co., Milpitas, California) slow-release fertilizer is used at some locations. Lime, granular fertilizer, and soil wetting agents are not added to the growing medium before it is loaded into the containers, nor is the medium premoistened. Operational problems include variations in medium density, difficulty in wetting the medium for germination, and lack of uniform mixing of the slow-release fertilizer. The peat is usually shredded at the time of loading and, if vermiculite or slow-release fertilizer is added, the mixing process is expected to be completed in the feeder-mixer bin.

The problems referred to above can be reduced by using a premix batch bin. Water is added to premoisten the peat or peat-vermiculite to a desired level. Then, if small volumes of high-density materials are to be added, they can be premixed with some other material which has also been premoistened and transferred to the batch bin for final mixing.

Although the availability of peat has presented some difficulties, the source used in the Maritimes is acceptable, and does not usually exhibit such problems as fineness, excessive debris, or high acidity.

Since the amount of peat used in forest nurseries is only a small portion of that used for horticulture, particularly in the United States, special demands for a quality best suited to containerized tree seedling production are left to the purchaser's discretion. Results of physical (cf. Carlson 1979) and chemical tests on some lots of peat and peat-vermiculite growing media analyzed at the Maritimes Forest Research Centre are given in Table 3.

STARTING THE CROP

Seeding

Usually, the species grown in the Maritimes, such as black spruce or jack pine, germinate acceptably without pretreatment for greenhouse sowing. However, the germination time of white spruce can be reduced by stratification, and the crop is subsequently more uniform. White spruce is stratified by placing layers of seed between layers of moist sand and storing for one or two months at 1-2 °C. White pine *(Pinus strobus* L.) and balsam fir *(Abies balsamea* [L.] Mill.) also germinate better if stratified, but only small quantities of these species are grown.

Seed coatings are not generally used and the use of fungicides at the time of seeding is discouraged unless specific fungi have been identified. Red lead or aluminum powder is sometimes used to make the seed more visible during the sowing operation. When prevention of damping-off is necessary, Captan is used most commonly (5 g/m^2 Captan 7.5D or 0.17 $kg/100\ m^2$ Captan 50W).

Multiple seeding (usually two or three seeds per cavity) is practised to obtain nearly complete stocking. The seed is

Table 2. Containerized tree seedling production in the Maritime provinces, 1981.

Container type	Crop shipped in 1981 from overwintered or current production: Held over winter from 1980 (000,000)	Current 1981 (000,000)	Crop held over winter for 1982 (000,000)
Multipot 1	8.1[a]	Nil	7.5
Multipot 2	6.6	1.9	11.7
Styroblock-2	1.4	0.5	1.0
Styroblock-4	Nil	1.8	1.7
Styroblock-8	0.9	0.2	0.2
Paperpot FH 408	4.0	20.2	3.0
Paperpot FH 608	Nil	0.4	Nil
"Rootrainers"	1.1	0.1	1.0
Total	22.1	25.1	26.1
Total crop shipped 1981	47.2		
Total crop produced 1981		51.2	

Table 3. Physical and chemical characteristics of peat and peat-vermiculite growing media.

Physical	Peat	Peat:vermiculite 2:1
Saturated weight (g/L)	630	650
Dry weight after saturation (g/L)	69	96
Ash content (%)	4.7	NA
Bulk density (g/ml)	0.069	0.096
Specific gravity (g/ml)	1.53	1.53
Pore volume (%)	95.5	94
Water capacity by volume (%)	56	55
Air capacity (%)	39.5	39
Coarse:fine ratio	0.48	NA
Drying time (hr at 60°C)	65	40
Chemical		
pH	3.6	5.2
Cation exchange capacity (meq/100 g)	121	160
Exchangeable sodium (meq/100 g)	1.78	NA
Conductivity (mhos x 10^{-5})	19	75
Total nitrogen (%)	0.9	NA

covered with a coarse, inert grit of silica or granite (or even limestone) ranging in particle size from 1 to 4 mm (60-80% in 1-2 mm range; 15-40% in 2 mm range or larger; few fines). The seeded trays or blocks are moved dry to benches in the greenhouse, then soaked to field capacity. They are not covered with plastic or other material.

Germination and Establishment

Temperature and relative humidity

Where heat is provided for germination, the temperature is raised to 24-26 °C with 80% relative humidity for 1 to 2 weeks. Light irrigation is carried out several times daily, as required to prevent drying of the seed or, in hot weather, to reduce surface temperatures.

Germination and establishment diseases

In the past, the fungicide Captan was applied at the time of sowing. Now, however, fungicide is not applied routinely during the period of germination and establishment. In fact, no fungicides are recommended unless a problem is specifically identified. Many times, losses blamed on fungal diseases are caused by other environmental factors such as excessive humidity, heat or sunlight, or the use of the fungicide Captan. Losses are reduced by controlling the growing conditions: high humidity and temperature are used only during germination, light irrigation is carried out to ensure complete emergence and to prevent seed caps from sticking, and fertilization is delayed until the third week following emergence. These measures reduce seedling etiolation and succulence.

Thinning

Thinning is done before there is significant root branching but after emergence is complete. Extra seedlings are pulled out by hand, although in some operations where emergence takes place over an extended period, scissors may be used. The crop is irrigated soon after the thinning operation to reduce stress. Thinning costs have varied from $2 to $4 per thousand seedlings.

GROWING THE CROP

Greenhouse Environment

Temperature

Greenhouse temperatures are generally kept between 21 and 24 °C on sunny days for spruce, and perhaps at 27 °C for pines. The set-point for heating may be only 18 °C; therefore, in overcast weather the greenhouse is cooler. Night temperatures vary from 10 to 16 °C. For warm weather cooling, shading is necessary, particularly in free-standing polyhouses, and white latex paint can be sprayed on the polyethylene to achieve the desired cooling effect. Where the greenhouse cover will be used more than one year, removable shades should be used rather than paint so that the next winter crop will receive as much sunlight as possible.

Relative humidity and soil moisture content

Relative humidities of 60-80% usually can be maintained year-round in the greenhouse. In hot summer weather, there is adequate humidity for growth at Maritime locations. However, excessive humidities in winter months prevent proper drying of soil and foliage and can result in soil saturation for extended periods, and consequently in reduced growth and root deterioration. This has been a particular problem with paperpot crops, and slow-release fertilizers are now being used to eliminate the need for water. Forced-air under-bench heating effectively warms the medium and evaporates moisture, but complexes with aerially mounted finned tube heating systems do not have this advantage.

Aeration within greenhouses is critical and, as noted earlier, growers are reluctant to reduce humidities to proper levels by using fresh-air systems supplemented by heating.

Lighting

Light requirements to prevent dormancy of black spruce are flexible. Other species like white spruce need supplemental lighting at all times when daylength is less than 14 hr (late August through early April at Fredericton).

Light is provided in several ways. Few nurseries use daylength extension. Rather, supplemental light is supplied by a 1-4 hr night break from strings of incandescent bulbs suspended over benches. Some use an intermittent night break from incandescent or fluorescent lighting mounted on irrigation carts. These travel over the crop taking 2.5 to 5 min to travel one way on a 23-m bench. As little as 5 fc of incandescent light can prevent dormancy of black spruce but dormancy of white spruce can occur with 15-20 fc of light in conjunction with other environmental stresses. Normal lighting intensities vary from 20 to 70 fc. Cart lighting often supplies light intensities of several hundred fc.

Water and Fertilizer Management

Irrigation

Watering carts are generally equipped with TeeJet 8003 nozzles, although some use coarser nozzles for older seedlings and summer watering. Usually, either a double or a coarse nozzle is mounted at the edges of all benches.

The weight of flats is used for water management. A few flats or blocks from different parts of the greenhouse are weighed because of variation due to the depth of grit mulch. For solid-wall containers, water is usually added to the point of drip or near field capacity. For winter crops, particularly paperpots, care must be taken to avoid long periods of saturation. The range of weights used for different containers is: paperpot FH 408, minimum 13.5 kg, maximum 14.5 kg; styroblock-4 and -8, minimum 5.8 kg, irrigate to point of drip.

Irrigation to the point of drip is carried out to reduce the danger of drying from the bottom up, or of individual cells drying in solid wall containers, particularly with underbench heating systems. Problems with such drying and with soil crusting, algae, fungus gnats, and soil salts have resulted from poor irrigation practices.

Fertilizing

In Maritime greenhouses, fertilizer is generally applied weekly as soluble fertilizer in concentrated solution which is watered in, often to the point of drip (ca. 1.1-1.3 kg/100 m^2 in 350 L of water followed by 550 L of rinse). Concentrated fertilizers must be rinsed off foliage to prevent burning. The types of fertilizer used and the rates of application are described in the cultural schedules in the Appendix and are divided according to the stages of seedling development. It should be noted that several growers are using constant fertilization techniques.

In general, the pH of irrigation waters has not been regulated in nurseries, although monitoring of soil pH is continuous. No specific problems have been identified except that certain commercial mixes of peat and vermiculite produce a pH exceeding 6, which causes chlorosis.

Soil fertility is monitored by analyses for pH, conductivity, and concentration of available nutrients (nitrate nitrogen, phosphorus, potassium, calcium, and magnesium). The balance and level of nutrients in foliage, indicators of the success of the fertilization program, are also checked. These factors are described elsewhere in these proceedings (Hallett 1982).

Hardening the Crop

Specific regimes are used to condition seedlings, depending on the next stage of production and whether the crop is in the greenhouse or outside. Supplemental light is shut off; the soil is leached to remove soil nutrients, then dried to develop stress; a high phosphorus and potassium fertilizer is applied; and both high and low temperature stresses are developed as permitted by weather conditions.

Temporary Holding

Shadehouses are used at some locations to acclimatize stock to outdoor conditions. At other locations, seedlings are moved, under favorable weather conditions, directly to holding areas where they are subsequently protected by irrigation from frost, wind, and sunlight. Most growers do not provide for air root-pruning of crops grown outside but place them on a base of coarse crushed rock. Roots penetrate this base, and consequently water loss from the containers is decreased. However, if the roots are left undisturbed too long, root egress from containers becomes significant and stock quality deteriorates. When the container is moved, the active roots below the container are broken, and those left in the container are largely inactive. The pallets used at some locations could be used for air pruning.

Both successful manipulation of the greenhouse environment and suitable weather are required before winter crops are moved outside in spring. Unless a degree of hardiness is achieved, moving seedlings into unpredictable spring weather can be very dangerous and heavy losses have frequently resulted from frost injury.

Overwintering

Stock must by cold hardy, as evidenced by woody stems and well formed buds. Although fertilization with high nitrogen fertilizers is discontinued by late summer, top dressings are needed to complete bud formation, maintain root growth, and prevent chlorosis. If containers are on pallets, they are moved onto the ground before it is frozen to avoid freezing injury to the roots. Edge protection is provided for all stock.

Overwinter protection from sun and wind is necessary to avoid winter drying, particularly in areas with unreliable snowcover. At some nurseries, sheltered openings are cut in a nearby forest. These openings are located so that direct sunlight reaching the crop is minimized. The surrounding trees reduce wind and increase the snowcover over the crop. Fungicides are applied to protect against mold damage, particularly on larger stock or at locations where snow molds have been a problem. Difolitan (captofol) is applied at 1 L per 500 to 1000 m^2. Shadehouses or sealed plastic enclosures may also be used for overwintering. Stock is moved into these structures in the fall, and those covered with plastic are left sealed against moisture loss until spring.

Seasonal and Species Differences in Crop Management

Seasonal

Seedlings grown in late winter often show excessive height with little branching, succulence, and poor root development. Growers attempt to reduce succulence and promote better root development by lowering the greenhouse temperature and relative humidity and by reducing available nitrogen. Currently, supplemental CO_2 is not being used to enhance growth and quality during these limiting conditions of winter.

In summer months, seedlings growing under greenhouse conditions require much water and, because nutrients are readily leached from organic soils, the principal problem is one of supplying adequate moisture while maintaining the necessary levels of soil nutrients.

Species

Black spruce and larch develop readily in the greenhouse but become very succulent under the combination of low light, high soil moisture, abundant nutrients, and elevated temperatures. Problems encountered in growing white spruce crops include the time and uniformity of germination and the prevention of dormancy when stresses are encountered. Jack pine grows rapidly in spring and summer but does not grow well in greenhouses during the low light conditions of winter. It is best grown as a spring-summer crop. Pine species are particularly sensitive to iron chlorosis on the peat or peat-vermiculite medium in combination with the types of fertilizer used in the Maritimes. This chlorosis is readily combatted by an application of chelated iron but not when the soil pH exceeds 6, as has occurred when insulation grades of vermiculite were used or when excessive lime was applied.

CROP SPECIFICATIONS

Stock standards for species raised in containers in the Maritime provinces are still under investigation by most agencies. A survey of specifications in the Maritimes indicates that two criteria are used: 1) the plug must be extractable, and 2) the seedling must be a minimum height--usually 15-25 cm for spruce and larch, and somewhat less for pine and some crops of white spruce. Height is the most commonly used parameter in the Maritimes. Suggested crop specifications for black spruce and jack pine in New Brunswick are given in greater detail elsewhere (Table 4).

A basic problem encountered in many programs is the difficulty in meeting the required crop specifications by the scheduled planting date. Failure to meet specifications generally means that the grower is faced with the dilemma of what to do with a substandard crop. An undersized crop may either be held for further growth or planted. When crops that are too small at the scheduled time of planting are held, the seedlings are often too large for the container and loss of quality is inevitable. Attempting to grow large seedlings in small containers has resulted in quality reduction, diseases of roots or shoots, and inferior shoot:root ratios at time of planting.

Hallett (1980) presented information on the growth of black spruce container crops in the Maritime provinces which suggested the need to develop standard curves for each nursery, species, and cropping method used. This is particularly important for scheduling the planting of winter or summer crops which are still actively growing. Nurserymen usually schedule for size but two other features are important: the plug must be extractable

Table 4. Suggested crop specifications for containerized black spruce and jack pine.

	Total seedling dry weight (mg)	Root-collar diameter (mm)	Height (cm)	Container size (cm^3)	Growing period (wk)
Black spruce					
Hallett[a]	650-850	1.6-2.0	15-20	55-75	16-20
Krause[b]	350-700	1.0-2.0	7.5-15	70	-
Kreiberg[c]	500-800	1.5-2.5	13-25	70	20-24
Jack pine					
Krause[b]	225-550	0.9-1.8	6-12	70	-
Krieberg[c]	400-600	1.0-2.0	10-20	70	-

[a] Hallett, R.D. 1980. Nursery practices for production of black spruce. Dep. Environ., Can. For. Serv., Fredericton, N.B. Tech. Note 13. 7 p.

[b] Krause, H.H. 1978. Appraisal of planting stock. N.B. Dep. Nat. Resour., Internal Rep., 23 p. (prepared by Dep. For. Resour., Univ. New Brunswick.)

[c] Krieberg, N.H. 1981. Personal communication, Fredericton, N.B.

and the shoot must be sufficiently hardy to withstand planting stress. By monitoring crop growth, the nurseryman can alert the planting supervisor if the crop is not ready. (This is better than being told the stock is inferior.)

CONCLUSION

Seedling production has expanded tremendously in the Maritime provinces--from 5 million in 1975 to more than 51 million in 1981. A variety of greenhouses and cultural practices are used to grow this stock, which varies in size and hardiness depending on the season of production and planting.

There are several development needs. Energy conservation techniques are being implemented in heated greenhouses as soon as is practical. Cultural refinements, such as the use of the slow-release fertilizers, are being investigated. The problem of conditioning seedlings for movement from greenhouses during periods of frost, for overwintering, or for outplanting is being studied. An operational method for assessing hardiness would have tremendous potential.

Crop specifications and quality are particularly important in the Maritimes, where an extended planting season is used. Differences in stock quality resulting from season or period of production require the development of crop specifications related to planting site and seasonal conditions. Crops planted in different seasons will require varying degrees of hardiness. Winter crops may be planted in late spring or during the dry, hot conditions of early summer, or they may be held until August when conditions are more moderate. Summer crops may be planted in late summer. Both winter and summer crops may be overwintered for planting as dormant stock in spring, or they may be held for further growth and planted in midsummer. They may even be overwintered a second time and planted as dormant stock in spring.

LITERATURE CITED

Carlson, L.W.
1979. Guidelines for rearing containerized conifer seedlings in the Prairie Provinces. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-214. 62 p.

Hallett, R.D.
1980. Seasonal patterns of growth for black spruce container seedlings raised in the greenhouse. Dep. Environ., Can. For. Serv., Fredericton, N.B. Tech. Note No. 20. 4 p.

Hallett, R.D.
1982. Monitoring crop development during the rearing of containerized seedlings. p. 245-253 in J.B. Scarratt, C. Glerum and C.A. Plexman, *Ed.* Proceedings of the Canadian Containerized Tree Seedling Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. O-P-10.

APPENDIX

REARING SCHEDULES FOR THE MARITIME PROVINCES

REARING SCHEDULE FOR WINTER CROPS

November to December

Seed Stratification and Greenhouse Sanitation

January (February) [a]

Seeding and Germination

Multiple sowing. Use no seed coating, fertilizers or fungicides. Cover with grit and soak containers to field capacity. Greenhouse temperatures of 24-27 °C (D/N) and relative humidity of 80%. Light irrigation as required to prevent drying of seed. Supplemental light to prevent the onset of dormancy (provided as night break).

Late January (late February)

Emergence (0 to 1 wk)

Reduce greenhouse temperature to 18-21 °C and relative humidity to less than 80% as soon as possible to prevent etiolation of seedlings and reduce risk of damping-off.

Seed Cap

Irrigate lightly to ensure complete germination and to prevent seed caps from sticking.

Cotyledon (2 to 3 wk)

Thin before significant root branching occurs but after emergence is complete.

Mid-February (mid-March)

Primary Needle (3 wk)

Apply fertilizers at beginning of third week (15 days) after emergence using 10-52-10 plus iron chelate.

March (April)

Active Height (6 to 15 wk)

Apply higher nitrogen fertilizers such as 20-20-20. Apply iron chelate at least once a month. Amend fertilizer formulation according to results of soil analysis.

April (May)

Hardening

Leach solid-wall containers (more difficult with paperpots). Use high day/low night temperatures and dry the soil periodically to induce hardiness by stress. Turn night lighting off. Change fertilizer to high phosphorus (10-52-10) (higher levels of potassium are held in the medium). Shade may become necessary in May; shade only to hold 24 °C for spruces, 27 °C for pines.

May (June) [b]

Outdoor Growing (15 to 18 wk)

Protect from frost, sun, or windburn. Fertilize with 20-20-20 (extra water and fertilizer required).

Late May to July

Shipping (18 to 21 wk)

Wet soil well before shipment. (Shipment continues over two to five weeks so that 18- to 23-wk-old seedlings are shipped).

REARING SCHEDULE FOR SUMMER CROPS

May (June) [c]

Seeding and Germination

Multiple sowing. Use no seed coatings, fertilizers, or fungicides. Cover with grit and water to field capacity. Greenhouse temperatures of 24-27 °C and relative humidity of 80%+. Frequent light irrigation to prevent seed drying and excessive heating of soil surface by sunlight. Night lighting not required.

Late May or June

Emergence (0 to 1 wk)

Reduce greenhouse temperature to 18-21 °C and relative humidity to less than 80% as soon as possible to prevent etiolation of seedlings and to reduce risk of damping-off.

Seed Cap

Irrigate lightly to ensure complete germination and to prevent seed caps from sticking (moderate humidity).

Cotyledon (1 to 2 wk)

Thin before significant root branching occurs.

Early June d

Primary Needle (3 wk)

Start fertilizing with high phosphorus (10-52-10) plus iron chelate at beginning of third week (15 days) following emergence.

Late June

Active Height (5 wk)

Start use of higher nitrogen fertilizer (20-20-20). Apply iron chelate once a month. Amend fertilizer formula according to results of soil analysis. Maintain temperatures between 18 and 27°C. Attempt 24°C maximum for spruce, and shade only when this temperature is exceeded. Crops may be left in the greenhouse or moved outdoors for the summer.

July

Outdoor Growing (6 wk)

Crops should be moved to raised pallets if they are not to be summer planted. Protect from sun and windburn by irrigating or sheltering. Extra water and fertilizer required.

Mid-August e

Shipping

Jack pine crops are shipped starting at 12 weeks.

Outdoor Growing

Crops left in greenhouse now moved out to raised pallets. Protect from sun and windburn. Leach (if no heavy rain) and withhold irrigation periodically to harden. Begin maintenance fertilizer with 10-52-10. Protect from early fall frosts with irrigation.

November

Overwintering

Place on ground to insulate roots. Protect as much as possible from drying winds and sunlight, particularly the edges. If snowmold is a problem, apply protective sprays.

May

Shipping or Growing-On

Ship for planting, or fertilize with 20-20-20.

Late June

Hardening

Leach (if no heavy rains); fertilize at a rate of 10-52-10.

July-August

Shipping

---

[a] Months within parentheses indicate that an operation or particular phase may occur at a later date.

[b] Some nurseries move stock to outdoor growing areas at an earlier date than others.

[c] Months within parentheses indicate that a third crop may be started at this time.

[d] If two summer crops are to be produced, this one should be set out as early as possible. It is essential to move the winter crop early, seed the first summer crop, grow to primary needle stage, and move outside. Even the third crop may be moved from the greenhouses in July to avoid severe heat.

[e] Crops can be held in greenhouses until October but extra care is required to ensure cold-hardiness induction before moving outdoors.

INFLUENCE OF EXTENDED PHOTOPERIOD ON GROWTH OF WHITE AND ENGELMANN SPRUCE SEEDLINGS IN COASTAL BRITISH COLUMBIA NURSERIES

J.T. Arnott and A. Mitchell[1]

Abstract.--Current knowledge of the effects of photoperiod on vegetative growth of northern hemisphere tree species is reviewed. The effects of extended daylength versus night interruption, minimum light intensity required and interaction with low night temperatures on growth of 1-0 white spruce *(Picea glauca* [Moench] Voss) and Engelmann spruce *(P. engelmannii* [Parry]) seedlings are discussed. Photoperiod regimes currently used for spruce in British Columbia nurseries are described.

Résumé.--On fait un survol des connaissances actuelles sur les effets de la durée d'éclairement sur la croissance végétative des arbres de l'hémisphère nord. On discute des effets de la prolongation de la durée du jour en regard de l'interruption de la nuit, de l'intensité lumineuse minimale requise et de son interaction avec les basses températures au cours de la nuit sur la croissance de semis 1-0 d'épinette blanche *(Picea glauca* [Moench] Voss) et d'épinette d'Engelmann *(P. engelmannii* [Parry]). On décrit les photopériodes couramment employées pour l'épinette dans les pépinières de la Colombie-Britannique.

I. PHOTOPERIODISM AND TREE SEEDLING GROWTH - A REVIEW

The effect of photoperiod on tree seedling growth has been known for a long time. The following section reviews the subject for participants in this symposium, and provides background information for the research done in British Columbia which is described in section II of this paper.

Daylength

The growth and development of many tree species is regulated by photoperiod. In general, continuous light and long days promote increased height growth, accompanied by increased diameter and dry weight. Bud determination, Lammas growth, and root development are also affected by long days in some species. Short days of 8-9 hours usually promote the cessation of height growth, and reduce leaf size and number, and root growth.

Dormancy may also be affected by photoperiod. Continuous light and/or long days may cause the breaking of dormancy. Short days generally induce the formation of buds and the onset of dormancy. More detailed information on the above, by species, is provided in Table 1.

Provenance and Altitude

Provenance and geographic (topographic) location modify the effect of photoperiod. Under similar conditions of temperature and photoperiod, southern provenances of a species grow better than northern ones (Jester and Kramer 1939; Vaartaja 1954, Magnesen 1969, 1971). Northern provenances have longer critical daylengths (Table 2).

---

[1] Research Scientist and Research Technician, respectively, Pacific Forest Research Centre, Canadian Forestry Service, Victoria, British Columbia.

Table 1. Effects of daylength on tree growth.

Common name	Scientific name	Day length[a]	Effects	Authority
European silver-fir	*Abies alba* Mill.	LD	increased height	Leibundgut and Heller (1960)
Sakhalin fir	*A. sachalinensis* Fr. Schm.	LD	increased height	Satoo (1961)
		LD	promoted lammas	Shibakusa and Kimata (1975)
		SD	fewer leaf primordia	Asakawa et al. (1974)
Gray birch	*Betula lutea* Michx.	SD	induced dormancy	Loveys et al. (1974)
Paper birch	*B. papyrifera* Marsh.	SD	stopped growth	Powell (1976)
European white birch	*B. pendula* Roth	SD	induced dormancy	Kelly and Mecklenburg (1978)
European larch	*Larix decidua* Mill.	LD	increased growth	Simak (1970)
Norway spruce	*Picea abies* (L.) Karst.	SD	induced dormancy	Robak (1962)
Engelmann spruce	*P. engelmannii* (Parry)	LD	increased height	Arnott (1974)
White spruce	*P. glauca* (Moench) Voss	CL	increased height	Fraser (1962)
		LD	no height increase	Vaartaja (1957)
		LD	increased height	Arnott (1974)
		SD	induced dormancy	Pollard (1974)
Black spruce	*P. mariana* (Mill.) B.S.P.	CL	increased height	Fraser (1962)
Sitka spruce	*P. sitchensis* (Bong.) Carr.	LD	increased root growth	Stahel (1972)
		SD	decreased height	Stahel (1972)
Jack pine	*Pinus banksiana* Lamb.	LD	no height increase	Vaartaja (1957)
Lodgepole pine	*P. contorta* var. *latifolia* Engelm.	CL	increased height, weight	Wheeler (1979)
Japanese red pine	*P. densiflora* Sieb. & Zucc.	CL	increased height	Ikemoto and Shidei (1963)
		SD	induced dormancy	Ikemoto and Shidei (1963)
Austrian pine	*P. nigra* Arnold	CL	increased height	Read and Bagley (1967)
		LD	increased height	Read and Bagley (1967)
Ponderosa pine	*P. ponderosa* Laws.	CL	increased height	Downs and Piringer (1958)
		CL	increased height	Read and Bagley (1967)
		LD	increased height	Read and Bagley (1967)
Eastern white pine	*P. strobus* L.	CL	increased root weight	Fowler (1961)
		LD	increased height	Fowler (1961)
Scots pine	*P. sylvestris* L.	CL	increased height	Jester and Kramer (1939)
		CL	increased height	Vaartaja (1951)
		CL	no height increase	Balut and Zelawski (1955)
		CL	broke dormancy	Wareing (1956)
		LD	increased height	Jester and Kramer (1939)
		LD	increased height	Downs and Borthwick (1956)
		LD	increased diameter	Wareing (1951)
		LD	induced dormancy	Wareing (1956)
		SD	reduced growth	Jester and Kramer (1939)
Loblolly pine	*P. taeda* L.	CL	increased height	Downs & Piringer (1958)
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco	LD	increased height	Lavender et al. (1968)
		SD	induced dormancy	Lavender et al. (1968)
Giant sequoia	*Sequoia gigantea* (Lindl.) Decne.	SD	reduced height	Skok (1961)
Eastern white cedar	*Thuja occidentalis* L.	LD	increased height	Bagley and Read (1960)
Western red cedar	*T. plicata* Donn	LD	no height increase	Vaartaja (1957)
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.	SD	induced dormancy	Cheung (1973)

[a] CL = Continuous light LD = Long days SD = Short days.

Table 2. Critical daylengths for northern and southern provenances of several species.

Species	Critical daylength (hr) Northern	Critical daylength (hr) Southern	Authority
Picea abies	20	14	Dormling et al. (1968) and Håbjørg (1978)
Picea sitchensis	14	10	Pollard et al. (1975)
Tsuga canadensis (L.) Carr. (Eastern hemlock)	16	15	Nienstaedt and Olson (1961)

As the critical daylength is approached, the variation within a provenance increases (Vaartaja 1959). The longer critical daylength observed for northern provenances indicates that initiation of budset in nature occurs at an earlier date and that the time required for the yearly vegetative growth cycle is shorter. In Norway spruce, southern European provenances have a 15-week cycle while northern ones set bud in 13 weeks (Dormling et al. 1968). It has been suggested (Simak 1975) and proven (Watt and McGregor 1963) that the use of supplementary illumination to meet the critical daylength requirement enables the growing of trees from northern latitudes in nurseries much farther to the south with good results.

The elevation at which the provenance is found also affects the response to photoperiod. High altitude provenances have longer critical daylengths for the cessation of apical growth and formation of terminal buds than do those from low altitudes (Holzer 1960, 1962; Simak 1970; Heide 1974; Habjorg 1978). A difference of 150 m in provenances of loblolly pine was enough to make a difference in growth under long days (McGregor and Kramer 1957).

Intermittent Light

One interruption

It has been known for a long time that 1 hr of low-intensity illumination in the middle of the dark period will delay the onset of dormancy in conifer seedlings. Wareing (1956) has described this for Scots pine, Vaartaja (1957) for jack pine and white spruce, Skok (1962) for giant sequoia and Irgens-Moller (1962) for Douglas-fir. An experiment comparing 10-hr days with 9.5-hr days plus 0.5-hr light at night showed that jack pine and lodgepole pine attained twice the height, total dry weight, leaf weight and root weight, and showed increased absorption and utilization of nitrogen when given the supplemental light at night (Giertych and Farrar 1961).

Repeated interruption

As a result of research it has been found that repeated short bursts of light *throughout* the dark phase are as effective as long days or a 1-hr night break for maintaining vegetative growth in conifer seedlings (McCreary et al. 1978). Tinus (1970) initially found that 323 lux of incandescent light given 3% of the time was sufficient to maintain growth of ponderosa pine and blue spruce *(Picea pungens* [Engelm.]), provided that no dark period exceeded 30 min. White spruce and Engelmann spruce given 1600 lux of incandescent light at different frequencies throughout the dark period responded best to a light break of 2 min for every 30 min of darkness (Arnott 1974) which was also found to delay the onset of terminal resting buds of mountain hemlock *(Tsuga mertensiana* [Bong.] Carr.), Noble fir *(Abies procera* [Rehd.]) and amabilis fir *(Abies amabilis* [Dougl.] Forbes) (Arnott 1976).

Quality and Intensity of Light

Quality of light

Many investigators have experimented with the quality and intensity of supplemental light required to extend the photoperiod for tree seedlings (Asakawa et al. 1974). Several experiments have compared the effectiveness of fluorescent versus incandescent supplemental light to extend the photoperiod for tree seedlings (Downs and Borthwick 1956, Downs 1957). While it has been demonstrated that fluorescent light does stimulate growth when used for supplemental photoperiodic lighting (Vaartaja 1957, 1959), incandescent light is generally more effective, as Downs and Piringer (1958) found for pines.

The spectral quality of the light supplement has a marked effect on seedling growth (Ceschi 1965). Using both red and far-red light to interrupt the dark period at various times, for various lengths of time, Dinus (1968) found that red light enhanced growth, leaf size, and leaf number of Douglas-fir, and the degree of response varied directly with the length of treatment. There was a small effect with a 2 min interruption, a better effect with 5 min and the best effect with a 30 min exposure. The effect also increased as the treatment approached the middle of the dark period. Far-red light also increased growth, but exposure of less than 15 min proved ineffective in preventing dormancy.

The use of alternative types of lights, other than fluorescent or incandescent, is not widely reported. Sodium vapor lamps have been used effectively to extend the photoperiod of Sitka spruce (Russell 1974, Johnstone and Brown 1976), mountain hemlock, amabilis fir, white and Engelmann spruce (Arnott 1979).

Intensity of light

There is a wide range in effective light intensities which will maintain vegetative growth in tree species (Table 3). There is also a strong interaction between the intensity of supplemental light used to extend daylength and the latitudinal source of the species. Three populations of European white birch (*Betula pubescens* Ehrh.) from latitudes 70°20', 63°20' and 56°20' had critical light intensities of 250-500, 100-250 and 15 lux, respectively. Thus, the northern populations required higher light intensities than the southern ones (Habjorg 1972).

Light intensity also interacts with night temperature (Habjorg 1972). The effect of light intensity is more pronounced at low than at high night temperatures. At a night temperature of 8°C, an increase in light intensity from 15 to 500 lux led to an increase in dry weight from 1.4 to 2.7 g per plant. The corresponding increase in dry weight at 13 and 18°C night temperatures was from 1.8 to 2.9 and from 2.0 to 2.7 g per plant, respectively. In Norway spruce, Magnesen (1969) found that short days overruled temperature in the induction of dormancy. Some species are sensitive to a very slight stimulus, and the effect of the light intensity is on the degree of elongation of the cotyledons and primary needles (Kozlowski and Borger 1971).

Mode of Action

Wareing (1949, 1950, 1951, 1956), in a series of experiments using Scots pine, laid

Table 3. Effective light intensities to extend photoperiod for several species.

Species	Intensity (lux)	Authority
Abies sachalinensis	1000	Satoo (1961)
A. amabilis	20	Arnott (1979)
Betula pubescens	15-500	Håbjørg (1972)
Larix laricina	40-110	Simak (1975)
Picea abies	1000	Simak (1975)
P. engelmannii	20-40	Arnott (1979)
P. glauca	80	Arnott (1979)
	400	Tinus and MacDonald (1979)
P. pungens	400	Tinus and MacDonald (1979)
P. sitchensis	7000	Johnstone and Brown (1976)
	6000	Russell (1974)
Pinus contorta	400	Tinus and MacDonald (1979)
P. densiflora	120	Ikemoto and Shidei (1963)
P. ponderosa	215-2150	Read and Bagley (1967)
	400	Tinus and MacDonald (1969)
P. strobus	270-4300	Fowler (1961)
P. sylvestris	40-1000	Simak (1975)
	220	Cathey and Campbell (1975)
Pseudotsuga menziesii	100	McCreary et al. (1978)
Tsuga heterophylla	400	Owston and Kozlowski (1976)
T. mertensiana	80	Arnott (1979)

the foundations of the currently accepted theory to explain the effects of photoperiod on growth and cambial activity. He attributed the effects to the production and availability of auxin, noting that low light intensities were enough to cause a response. A growth promoter, produced in the light, was balanced by some inhibitor produced in the dark, provided that the dark period was longer than 4 hr. Wareing's 1951 hypothesis was that "when the daily dark period exceeds 4 hr, there is a gradual accumulation of an inhibitor which promotes dormancy, and that when the duration of the dark period is less than 4 hr, there is a gradual reduction in the inhibitor and the suppression of dormancy."

The "Beltsville group" of the USDA Agriculture Research Service, including Hendricks, Borthwick, Parker, and others, did much of the basic research that led to the currently accepted explanation of the photoperiodic response of plants and the mechanism controlling it (Anon. 1961). These workers established that the part of the spectrum governing the inhibition of flowering in soybean *(Glycine sofa)* and cockelbur *(Xanthium* sp.) plants is from about 580 to 720 nm, i.e., the red light band. In further work on germination of lettuce seed the group found that germination was sensitive to the same wavelengths as those affecting flowering in the above plants. Red wavelengths promoted germination; far-red wavelengths inhibited it. They determined that a pigment, which they called phytochrome, was responsible for controlling these physiological responses. This light-sensitive protein converts to an active form, called Pfr, when exposed to red light (660 nm) and this prevents dormancy initiation. Far-red light (735 nm) reverses the effect of the red light and converts the phytochrome to the inactive form called Pr. It was discovered that phytochrome also reverts slowly to the inactive form in the dark. In addition to preventing dormancy, active phytochrome retards stem elongation as Meijer (1959) found when exposing certain plants to red light. Studies of the inhibitor-promoter mechanism in Douglas-fir by Dinus (1968) led him to conclude that• the active pigment Pfr was responsible for the prevention of dormancy in these tree seedlings. Plant growth responses were attributable to the levels of Pfr activity and not to their concentration. Dinus (1968) also found that responses of Douglas-fir to 30 and 55 min of far-red light resembled those of red light. Apparently, excessive far-red light reversed the normal photoreaction of phytochrome and caused the accumulation of the active form (Pfr) of the pigment.

As Tinus and MacDonald (1979) point out, "there are several important differences between light required for photosynthesis and that required for dormancy prevention. For the latter, wavelengths shorter than 550 nm are of no value, and wavelengths between 700 and 770 nm reverse the effect of red light. As red light intensity increases from zero, there is a threshold below which there is no growth response. Above the threshold, height growth increases rapidly and then tapers off at an upper limit above which there is no further response."

Cathey and Borthwick (1964) had shown that the conversion of the phytochrome from Pr to Pfr was influenced by the filtering action of chlorophyll and by anatomical differences in the leaves. Habjorg (1972) found that the northern sources of birch had a higher chlorophyll content than the southern ones, and as a result, less radiation would penetrate the interior of their thick, firm leaves. As the Pfr in these thick leaf cells would be far below that produced in the thinner leaves from the southern sources, Pfr would revert to its inactive form sooner, and this would lead to the induction of growth cessation. Habjorg (1972) concluded that this may be the reason for the higher light intensities required to maintain growth of the northern populations of birch.

Seedlings More Than One Year Old

Much of the research described above deals with the effects of photoperiod on seedlings during their first year of growth. The effects of extended photoperiod on older seedlings are varied. Scots pine given supplemental light in their second growing season showed an increase in leaf length and internode extension in response to long days, but there was no effect on leaf number (Wareing 1950). If a long day treatment is begun after leaf elongation has ceased in the second year, cambial activity is continued, but if the seedlings have below average vigor, there is no response (Wareing 1949). Japanese red pine given continuous light in August and September of the second year showed increased height and fresh weight in response to treatment (Ikemoto and Shidei 1966). Nagata (1967) noted that in second year Japanese red pine only internode extension was affected by photoperiod. Continuous light of 250 lux slowed early bud burst in the second year but enhanced bud development of this species (Nagata 1968).

Cold Hardiness

The induction of frost hardiness has often been linked to photoperiod. Alden and Hermann (1971) summarized research on the mechanism of the response.

The processes of dormancy and hardening seem related, in that apical bud development, a first sign of dormancy, must precede the low temperature treatment. Presumably, the conversion of amino acids and peptides to soluble proteins marks the hardy plants, and indeed some photosynthates may be required for this, as plants grown in the dark do not develop hardiness even though they are exposed to low temperatures. The hypothesis is, therefore, that some phytochrome-like compound reacts to promote hardiness. Furthermore, photoperiod must affect the development of hardiness because, if the dark period is broken, then hardiness may not develop, even though the trees were exposed to hardening temperatures of 5°C (McCreary et al. 1978), and long days may inhibit the hardening process even if temperatures are low (Christersson 1978). The process of dehardening may, however, be almost wholly controlled by temperature (Aronsson 1975). The above is not meant to be an exhaustive review of literature on cold hardiness as the subject will be covered in depth by others at this symposium.

II. PHOTOPERIOD EXPERIMENTS ON WHITE SPRUCE AND ENGELMANN SPRUCE SEEDLINGS IN BRITISH COLUMBIA

Continuous Versus Intermittent Light

When northern latitude and/or high-elevation provenances of the white/Engelmann spruce complex are grown in low-elevation nurseries in southern (coastal) British Columbia, the seedlings become dormant early in the growing season. The literature review above indicates that trees can be kept in a state of continuous growth by extending the daylength with low-intensity artificial light or by interrupting the dark period with light of low intensities. An experiment was undertaken to determine the minimum duration of dark period interruption required to maintain growth of four provenances of white/Engelmann spruce (Table 4), comparing such treatments with the growth response obtained using extended and natural daylengths in an outdoor container nursery at Victoria, British Columbia (Lat 48°28'N).

Details of the experiment have been described elsewhere (Arnott 1974) and are summarized as follows:

Five photoperiod treatments were evaluated, viz:

a) 2 min light every 30 min darkness
b) 1 min light every 10 min darkness
c) 15 sec light every 6 min darkness
d) An 18-hr photoperiod (natural daylength extended by supplemental light)
e) Control (natural daylength)

The supplemental incandescent light source consisted of two 300-watt incandescent reflector flood lamps suspended above the seedlings to provide a light intensity of 1600 lux. Seeds were sown on 10 March in BC/CFS styroblocks. The photoperiod experiment, which began on 20 April 1972, was conducted in an unheated shelterhouse.

Height growth of all four spruce provenances was significantly greater under the four supplemental light treatments than in the control, and interrupting the darkness with 2 min of light every 30 min was the most effective treatment. Within the interrupted dark treatments, a) produced significantly greater shoot weight but not root weight. All light treatments produced significantly greater shoot and root weights than the control.

Cessation of height growth and formation of terminal resting buds occurred as early as mid-May for control treatment e) of proven-

Table 4. Geographic origin of the four spruce provenances used in the 1972 experiment (Arnott 1974).

Provenance no.	B.C. Min. For. seedlot no.	Latitude	Longitude	Elevation (m)	Location
1	779	54°07'	122°03'	640	Aleza Lake
2	1548	53°36'	122°07'	1220	Jerry Cr.
3	905	51°36'	119°54'	430	Birch Island
4	1675	49°13'	117°41'	1770	China Cr.

ante 4, giving the trees a rosette appearance. Supplemental light delayed formation of these terminal buds, and maintained leaf production and internodal growth, thereby producing a 1-year-old seedling suitable for outplanting. Even within the light treatments, terminal buds appeared on some of the spruce provenances, particularly No. 4, before the end of the treatment period. Also, these terminal buds did not necessarily signify a continuous dormancy, as some flushed intermittently throughout the experiment. Height growth had practically ceased on all seedlings given supplemental light 14 days after the lights were turned off on 31 August.

In conclusion, the northern and high-elevation provenances (4, 2, and 1 - Table 4) grown at this southern, low-elevation nursery formed terminal resting buds very early in the growing season and ceased shoot growth unless given extended photoperiod treatments. At an intensity of 1600 lux, interrupting the darkness 2 min out of every 30 (i.e., 6.6% of the time) provided the best growth response for all provenances.

Minimum Light Intensities

The initial experiment above with white and Engelmann spruce used a supplemental light intensity of 1600 lux. However, the literature indicated that a wide range of light intensities was required for effective supplemental lighting. Therefore, an experiment was conducted in 1976 to determine the minimum light intensity required to maintain shoot growth of these species (Arnott 1979).

A 400-watt high-pressure sodium vapor lamp was used as the supplemental lighting source because, from an operational perspective, lights with higher luminous intensities are more desirable as they cover a greater nursery area. Spectral energy distribution of the sodium vapor source peaks in the 500-625 nm range which is considered to be close to the optimum for producing the effect of long photoperiod (Bickford and Dunn 1972).

The light experiment began on 24 May 1976 in the British Columbia Ministry of Forests shadehouse nursery at Duncan on southern Vancouver Island (Lat. 48°47'N). At 20 m above sea level, the nursery has a mild climate and long growing season (273 frost-free days) and is one place at which the Ministry grows white and Engelmann spruce seedlings for reforestation in the interior of the province.

The light source was positioned 2 m above the ground at one end of the shadehouse nursery. The light was tilted downward 3° toward the seedlings. The first seven light-treatment stations were positioned along the length of the shadehouse nursery at 6 m intervals in a direct line away from the light source. As a result of this linear distribution the light intensity at each station was progressively less with increasing distance from the lamp as shown below.

Treatment station	Distance from light source (m)	Light intensity (lux)
1	6	220
2	12	80
3	18	40
4	24	20
5	30	12
6	36	8
7	42	5
8 (control)	-	0

The control treatment was located in an adjacent corner of the same shadehouse where it received no supplemental light. The light itself was controlled by an automatic time clock to provide illumination throughout the dark period; i.e., a 24-hr photoperiod was used. It was turned off on 7 September 1976. On 24 May 1976, the four spruce seedlots (Table 5) were placed on a wooden pallet at each of the eight light-treatment stations. Throughout the experiment, they were grown under the standard operational container nursery regime used in shadehouses.

Table 5. Geographic origin of seed and seedlots used in the 1976 experiment (Arnott 1979).

Species	B.C. Min. For. seedlot no.	Latitude	Longitude	Elevation (m)	Location
Picea engelmannii (1)	1819	49°50'	120°45'	1130	Coquihalla
Picea engelmannii (2)	1379	51°50'	120°10'	1370	Moira Lake
Picea glauca (3)	1957	53°50'	126°45'	1040	Ootsa Lake
Picea glauca x *engelmannii* (4)	2507	49°10'	117°15'	1610	McIntyre Creek

The occurrence of terminal resting buds was noted and seedling height measurements were recorded biweekly throughout the experiment until 30 October 1976, when a destructive sample was taken for shoot and root dry weight.

Extending the photoperiod and increasing the light intensity had highly significant effects on seedling shoot growth of all four spruce seedlots. Shoot length and weight declined as the light intensity decreased. The effect of extended photoperiod and increasing light intensity on root weight was usually negative, although the differences were significant only in seedlots 2 and 3. The greatest shoot length response to light intensity was attained at the highest level (220 lux). The critical minimum intensity (the minimum level that yielded shoot lengths significantly different from the controls) varied by seedlot as follows:

Seedlot	Critical minimum (lux)
3	80
1,4	40
2	20

The trend in shoot weight was somewhat different. Minimum light intensity levels usually had to be one treatment level higher in order to produce a response which was significantly different from that of the controls. The smaller average shoot length and weight at the lower light intensities is a result of many of the seedlings forming terminal resting buds and ceasing shoot growth before the lights were turned off on 7 September. This effect was minimal on those seedlings growing with 220 lux. By 7 September seedlots receiving less than 40 lux of supplemental lighting were not significantly different from the controls in the proportion of terminal buds formed. Seedlings from all treatments were fully dormant by 7 October 1976.

From the experimental evidence, it can be generally concluded that northern-latitude and high-elevation populations of the white/Engelmann spruce complex can be successfully grown at southern, low-elevation container nurseries in coastal British Columbia by extending the photoperiod with a sodium vapor lamp that provides a minimum light intensity of 80 lux at seedling level.

Light Intensity and Provenance Interaction

The above evidence indicated that the minimum intensity required to maintain growth of the seedlings was in the range of 20-80 lux. However, the maximum intensity levels were not clearly defined. A series of experiments was conducted in 1980 to bracket this upper limit on a wide range of provenances grown under both greenhouse (heated) and shelterhouse (unheated) conditions. Experimental methods are summarized as follows.

Seedlings from seven seedlots from the white/Engelmann spruce complex, covering a range of 10 degrees of latitude, were selected from operational sowings in the B.C. Ministry of Forests' container nurseries and shipped to Victoria. They were held in a heated greenhouse (min temp 18°C) with a 19-hr photoperiod until the initiation of the experiment.

The seven seedlots were randomly assigned to four light intensity treatments (0, 100, 200, and 400 lux) in both a heated greenhouse and an unheated shelterhouse on 13 June 1980. These light intensities were provided to extend the photoperiod to a constant 19 hr throughout the experiment. Incandescent lightbulbs were suspended above the seedlings and the bulb height and number were adjusted to provide the treatment intensities of 100, 200 and 400 lux. Time clocks activated the lights 1 1/2 hr before sunset. Standard cultural practices of seedling fertilization and irrigation as described by Van Eerden (1974) for container nurseries were employed throughout the experiment.

The treatment replicates were measured every 2 weeks to record a) frequency of terminal resting buds and b) shoot length of the seedlings. The supplemental photoperiod lights were shut off on 15 September 1980 and measurements continued until seedlings in all treatments had formed a terminal resting bud, after which a destructive sample was taken for a) seedling height, b) root collar diameter and c) seedling dry weight.

In summary, the results were as follows (Arnott, unpublished data):

1. Height growth of all provenances grown under extended daylength was significantly different from that of the controls.

2. There were no significant differences in seedling height among all three extended daylength treatments. The trend, however, was for a reduction in seedling height at the 400 lux light level, and this substantiates claims made by Tinus and MacDonald (1979) that too much supplemental light is detrimental to seedling height growth.

3. The more northerly populations of white spruce and the high elevation population of Engelmann spruce did not require higher intensities of light than the southern/low elevation populations to maintain shoot growth. A light intensity of 100 lux was sufficient to provide significantly larger seedlings for all populations. As noted above, intensities of 400 lux provided no significant increase in growth response and generally (over 71% of the time) created a negative trend in height growth.

4. Seedling height growth was significantly greater in the greenhouse than in the shadehouse for all treatments (including the control). Normal daylight intensities were similar in these two growing areas but temperatures were not. The differences in mean minimum and mean maximum temperatures between the two units are shown in Table 6. Clearly, warmer conditions in the greenhouse accounted for the significantly larger seedlings.

Table 6. Temperature differences between greenhouse and shadehouse (°C).

	Mean maximum			Mean minimum		
Month	G.H.[a]	S.H.[b]	Diff.	G.H.	S.H.	Diff.
June	26	20	6	19	11	8
July	27	24	3	18	14	4
August	26	25	1	18	14	4
Sept.	25	23	2	19	15	6

[a] G.H. = Greenhouse
[b] S.H. = Shadehouse

Low Night Temperature Effects

As low night temperature is known to have a significant interaction with extended photoperiod treatments in birch (Habjorg 1972) and spruce (Brix 1972), further experiments with the same seven spruce provenances were conducted the same year in controlled environment chambers to define the effects of low night temperature on the growth response of spruce under an extended photoperiod with a light intensity of 200 lux. (The effects of low night temperature could not be clearly separated from the results of the greenhouse/shadehouse comparison owing to the confounding effect of higher mean maximum day temperatures.) Growing conditions in the growth rooms are summarized as follows:

Growth chamber/ treatment	Day temp. (°C)	Night temp. (°C)	Extended photoperiod light intensity (lux)
A-control	21	18	0
B-warm nights	21	18	200
C-cold nights	21	7	200

The experiment was initiated simultaneously with the aforementioned greenhouse/shadehouse trial and the same seedling measurement schedule was followed.

Results are summarized as follows (Arnott, unpublished data):

1. Extending the daylength to 19 hr with 200 lux produced significantly larger seedlings.

2. Cool 'nights' of 7°C produced smaller seedlings than those grown under 18°C nights.

3. Seedlings grown under cool night temperatures did not set terminal resting buds any sooner than those grown under warm night temperatures. In other words, 200 lux of extended daylight prevented terminal budset on seedlings growing under both night temperature regimes. On the basis of the work of others (Habjorg 1972), it had been anticipated that those seedlings grown under cooler night temperatures would have set a terminal resting bud sooner. If anything, the cooler night regime tended to delay the formation of terminal buds in spruce.

CURRENT OPERATIONAL PROCEDURES

The findings from the above research have been used as guidelines by the B.C. Ministry of Forests for operational production of containerized interior spruce seedlings in their southern nurseries. Although specific details vary according to nursery location, the main features are common to all and are as follows:

All nurseries use the 400-watt high-pressure sodium vapor lamp in a 'Power Flood' reflector as the source of light for extending

2. There were no significant differences in seedling height among all three extended daylength treatments. The trend, however, was for a reduction in seedling height at the 400 lux light level, and this substantiates claims made by Tinus and MacDonald (1979) that too much supplemental light is detrimental to seedling height growth.

3. The more northerly populations of white spruce and the high elevation population of Engelmann spruce did not require higher intensities of light than the southern/low elevation populations to maintain shoot growth. A light intensity of 100 lux was sufficient to provide significantly larger seedlings for all populations. As noted above, intensities of 400 lux provided no significant increase in growth response and generally (over 71% of the time) created a negative trend in height growth.

4. Seedling height growth was significantly greater in the greenhouse than in the shadehouse for all treatments (including the control). Normal daylight intensities were similar in these two growing areas but temperatures were not. The differences in mean minimum and mean maximum temperatures between the two units are shown in Table 6. Clearly, warmer conditions in the greenhouse accounted for the significantly larger seedlings.

Table 6. Temperature differences between greenhouse and shadehouse (°C).

	Mean maximum			Mean minimum		
Month	G.H.[a]	S.H.[b]	Diff.	G.H.	S.H.	Diff.
June	26	20	6	19	11	8
July	27	24	3	18	14	4
August	26	25	1	18	14	4
Sept.	25	23	2	19	15	6

[a] G.H. = Greenhouse
[b] S.H. = Shadehouse

Low Night Temperature Effects

As low night temperature is known to have a significant interaction with extended photoperiod treatments in birch (Habjorg 1972) and spruce (Brix 1972), further experiments with the same seven spruce provenances were conducted the same year in controlled environment chambers to define the effects of low night temperature on the growth response of spruce under an extended photoperiod with a light intensity of 200 lux. (The effects of low night temperature could not be clearly separated from the results of the greenhouse/shadehouse comparison owing to the confounding effect of higher mean maximum day temperatures.) Growing conditions in the growth rooms are summarized as follows:

Growth chamber/ treatment	Day temp. (°C)	Night temp. (°C)	Extended photoperiod light intensity (lux)
A-control	21	18	0
B-warm nights	21	18	200
C-cold nights	21	7	200

The experiment was initiated simultaneously with the aforementioned greenhouse/shadehouse trial and the same seedling measurement schedule was followed.

Results are summarized as follows (Arnott, unpublished data):

1. Extending the daylength to 19 hr with 200 lux produced significantly larger seedlings.

2. Cool 'nights' of 7°C produced smaller seedlings than those grown under 18°C nights.

3. Seedlings grown under cool night temperatures did not set terminal resting buds any sooner than those grown under warm night temperatures. In other words, 200 lux of extended daylight prevented terminal budset on seedlings growing under both night temperature regimes. On the basis of the work of others (Habjorg 1972), it had been anticipated that those seedlings grown under cooler night temperatures would have set a terminal resting bud sooner. If anything, the cooler night regime tended to delay the formation of terminal buds in spruce.

CURRENT OPERATIONAL PROCEDURES

The findings from the above research have been used as guidelines by the B.C. Ministry of Forests for operational production of containerized interior spruce seedlings in their southern nurseries. Although specific details vary according to nursery location, the main features are common to all and are as follows:

All nurseries use the 400-watt high-pressure sodium vapor lamp in a 'Power Flood' reflector as the source of light for extending the photoperiod. The lamps are positioned to provide as uniform coverage as is possible within the physical limitation of each type of production facility (which ranges from greenhouses to unheated outdoor shadeframes). They are mounted on the shadeframe walls or, more usually, on the greenhouse irrigation booms. The Koksilah shadeframe, measuring 48 m x 30 m, which holds approximately 1 million seedlings in styroblocks, uses four lamps fixed to the shadeframe supports to provide a minimum light intensity of 20 lux at seedling level. Cross-fit houses, which do not have irrigation booms, and are 60 m long, have one lamp at either end plus a third one mounted towards the centre.

Most nurseries use a fixed lighting system programmed to extend the photoperiod to a constant 18- or 19-hr from the time of seed germination to early August. Minimum light intensities at seedling level are usually 40 to 120 lux although some nurseries provide as little as 20 lux. Those nurseries using an 18- or 19-hr photoperiod provided by lamps mounted on irrigation booms simply move the boom to the centre point of the greenhouse for the night. Two lamps on the top of the boom, directed to opposite ends of the unit, provide adequate light (>20 lux) for half the length of the house.

Only two nurseries--Surrey and Green Timbers--use night interruption on spruce. Unlike many horticultural nurseries which use a fixed series of lights programmed to light the unit sequentially throughout the night, the B.C. seedling nurseries move the light source. The sodium vapor lamps are stationed on the irrigation booms which travel back and forth throughout the darkness. The boom passes over the seedlings every 25-30 min and seedlings are never subjected to total darkness for periods exceeding 30 min. The travelling light system is more economical than the fixed system as it requires fewer numbers of sodium vapor lamps. However, it does depend on 100% reliability of the moving boom which, through mechanical failure, could result in a nursery unit being in total darkness for an entire night. The effect of such a system failure on growth of white and Engelmann spruce is not known. However, failure of the intermittent light source for two nights has resulted in formation of terminal resting buds on other tree species (R.W. Tinus, personal communication).

The sodium vapor lamps are usually turned off in early August to allow the seedlings sufficient time to form terminal buds, grow sufficient roots and develop winter hardiness throughout the latter part of the year. Prolonged use of lights beyond early August delays budset and has detrimental effects on the above-mentioned seedling characteristics. Sodium vapor lamps, for extended photoperiod or night interruption, have been used since 1974 by the B.C. Ministry of Forests to grow white and Engelmann spruce from northern and high elevation sources at southern B.C. nurseries where the long growing season and favorable temperatures can be used to advantage in seedling production.

LITERATURE CITED

Anon.
1961. Plant and light-growth discoveries. USDA Spec. Rep. 22-64.

Alden, J. and Hermann, R.K.
1971. Aspects of the cold hardiness mechanism in plants. Bot. Rev. 37:37-142.

Arnott, J.T.
1974. Growth response of white-Engelmann spruce to extended photoperiod using continuous and intermittent light. Can. J. For. Res. 4:69-75.

Arnott, J.T.
1976. Container production of high elevation species. Proc. Joint meeting of Western Forest Nursery Council and Intermountain Nurserymen's Assoc. Aug. 10-12, Richmond, B.C.

Arnott, J.T.
1979. Effect of light intensity during extended photoperiod on growth of amabilis fir, mountain hemlock and white and Engelmann spruce seedlings. Can. J. For. Res. 9:82-89.

Aronsson, A.
1975. Influence of photo- and thermoperiod on the initial stages of frost hardening and dehardening of phytotron-grown seedlings of Scots pine *(Pines sylvestris* L.) and Norway spruce *(Picea abies* [L.] Karst.). Stud. For. Suec. 128:1-20.

Asakawa, S., Sasaki, S. and Morikawa, Y.
1974. Growth of tree seedlings under lights of different spectral compositions. J. Jap. For. Soc. 56:441-447.

Bagley, W.T. and Read, R.A.
1960. Some temperature and photoperiod effects on growth of Eastern Redcedar seedlings. Iowa State Coll. J. Sci. 34: 595-602.

Balut, S. and Zelawski, W.
1955. [The annual growth cycle of *Pinus sylvestris* and *Picea abies* seedlings under continuous illumination.] Sylwan 99:501-504.

Bickford, E.D. and Dunn, S.
1972. Lighting for plant growth. Kent State Univ. Press. 221 p.

Brix, H.
1972. Growth response of Sitka spruce and white spruce seedlings to temperature and light intensity. Dep. Environ., Can. For. Serv., Victoria, B.C. Inf. Rep. BC-X-74.17 p.

Cathey, H.M. and Borthwick, H.A.
1964. Significance of dark reversion of phytochrome in flowering of *Chrysanthemum morifolium.* Bot. Gaz. 125:232-236.

Cathey, H. and Campbell, L.E.
1975. Effectiveness of five vision-light sources on photo-regulation of 22 species of ornamental plants. J. Am. Hort. Soc. 100:65-71.

Ceschi, I.
1965. [The variability of some characters of Douglas-fir under different light regimes.] Schweiz. Z. Forstw. 116:46-59.

Cheung, K.-W.
1973. Induction of dormancy in container-grown western hemlock *(Tsuga heterophylla* [Raf.] Sarg.). B.C. For. Serv. Res. Notes No. 59.

Christersson, L.
1978. The influence of photoperiod and temperature on the development of frost hardiness in seedlings of *Pinus sylvestris* and *Picea abies.* Physiol. Plant., Copenhagen. 44:288-294.

Dinus, R.J.
1968. Effect of red and far-red light upon growth of Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) seedlings. Dis. Abstr. 29B:6-7.

Dormling, I., Gustafsson, A. and Von Wettstein, D.
1968. The experimental control of the life cycle in *Picea abies* [L.] Karst. I. Some basic experiments on the vegetative cycle. Silv. Genet. 17:44-64.

Downs, R.J.
1957. Photoperiod control of growth and dormancy in woody plants. p. 529-537 *in* Thimann, K.V., *Ed.* Physiology of forest trees. Ronald Press Co., N.Y.

Downs, R.J. and Borthwick, H.A.
1956. Effects of photoperiod on growth of trees. Bot. Gaz. 117:310-326.

Downs, R.J. and Piringer, A.A., Jr.
1958. Effects of photoperiod and kind of supplemental light on vegetative growth of pines. For. Sci. 4:185-195.

Fraser, D.A.
1962. Growth of spruce seedlings under long photoperiods. Can. Dep. For., Tech. Note No. 114.

Fowler, D.P.
1961. Effect of photoperiod on white pine seedling growth. For. Chron. 37:133-143.

Giertych, M.M. and Farrar, J.L.
1961. The effect of photoperiod and nitrogen on the growth and development of seedlings of jack pine. Can. J. Bot. 39:1247-1254.

Habjorg, A.
1972. Effects of light quality, light intensity and night temperature on growth and development of three latitudinal populations of *Betula pubescens* Ehrh. Inst. Den. and Nursery Manage., Agric. Univ. Norway, Rep. No. 47.

Habjorg, A.
1978. Photoperiodic ecotypes in Scandinavian trees and shrubs. Meld. Nor. Landbrukshoegskole 57:33.

Heide, O.M.
1974. Growth and dormancy in Norway spruce ecotypes *(Picea abies).* I. Interaction of photoperiod and temperature. Physiol. Plant., Copenhagen 30:1-12.

Holzer, K.
1960. [Results of tests on spruce seedlings in culture chambers]. Silv. Genet. 9:137-138.

Holzer, K.
1962. [Genetically determined photoperiodic reactions of spruce seedlings.] Proc. 13th Congr. Internatl. Union For. Res. Orgn., Vienna 1961 Pt. 2(1), Sect. 22/7, 1962.

Ikemoto, A. and Shidei, T.
1963. Studies on the photoperiodism in woody plants. Effect of photoperiodic treatment of different duration given at different growth periods on the development of one-year-old seedlings of *Pinus densiflora.* J. Jap. For. Soc. 45:174-180.

Ikemoto, A. and Shidei, T.
1966. Studies on the photoperiodism of woody plants. Utilization of photoperiodic treatment to shorten the nursery bed period of *Pinus densiflora.* Memoirs of the College of Agric., Kyoto Univ., Kyoto. 88:49-64.

Irgens-Moller, H.
1962. Genotypic variation in photoperiodic response of Douglas-fir seedlings. For. Sci. 8:360-362.

Jester, J.R. and Kramer, P.J.
1939. The effect of length of day on height growth of certain forest tree seedlings. J. For. 37:796-803.

Johnstone, R.C.D. and Brown, W.
1976. Low pressure sodium (SOX) tube lights as a source of supplementary lighting for improved growth of Sitka spruce seedlings. U.K. For. Comm. Res. and Dev. Pap. No. 111.

Kelley, R.J. and Mecklenburg, R.A.
1978. The effect of photoperiod on root growth of European birch *(Betula pendula)* seedlings. HortScience 13:369.

Kozlowski, T.T. and Borger, G.A.
1971. Effect of temperature and light intensity early in ontogeny on growth of *Pinus resinosa* seedlings. Can. J. For. Res. 1:57-65.

Lavender, D.P., Ching, K.K. and Hermann, R.K.
1968. Effect of environment on the development of dormancy and growth of Douglas-fir seedlings. Bot. Gaz. 129:70-83.

Leibundgut, H. and Heller, H.
1960. [Photoperiodic reaction, light requirements and shoot development of young Silver fir plants.] Beih. Z. Schweiz. Forstver. 30:185-198.

Loveys, R., Leopold, A.C. and Kriedmann, P.E.
1974. Abscisic acid metabolism and stomatal physiology in *Betula Zutea* following alteration in photoperiod. Ann. Bot. 38:85-92.

Magnesen, S.
1969. [Experimental ecological studies on the termination of growth in *Picea abies* seedlings. 1. The effect of day-length and temperature relationships during the growing season.] Medd. Vestland. Forstl. Forsokssta. 14(48):1-50.

Magnesen, S.
1971. [Experimental ecological studies on the termination of growth in *Picea abies* seedlings. 2. The effect of different autumn temperatures and periods of low night temperature.] Medd. Vestland Forstl. Forsokssta. 14(51):229-269.

McCreary, D.D., Tanaka, Y. and Lavender, D.P.
1978. Regulation of Douglas-fir seedling growth and hardiness by controlling photoperiod. For. Sci. 24:142-152.

McGregor, W.H.D. and Kramer, P.S.
1957. The effect of photoperiod on photosynthesis respiration and growth of Loblolly pine seedlings from two sources. Abstr. in Plant Physiol. 32 (Suppl.):x-xi.

Meijer, G.
1959. Photomorphogenesis in different spectral regions. p. 101-109 in Proc. Conf. Photoperiodism and Related Phenomena in Plants and Animals, Gatlinburg, Tenn., 1957.

Nagata, H.
1967. Studies on the photoperiodism in the dormant bud of *Pinus densiflora* Sieb. et Zucc. I. Effects of photoperiod on the growth of first- and second-year seedlings of *P. densiflora.* J. Jap. For. Soc. 49:279-285.

Nagata, H.
1968. Studies on the photoperiodism in the dormant bud of *Pinus densiflora.* III. Photoperiodism in the terminal buds of second-year seedlings. J. Jap. For. Soc. 50:174-180.

Nienstaedt, H. and Olson, J.S.
1961. Effects of photoperiod and source on seedling growth of eastern hemlock. For. Sci. 7:81-96.

Owston, P.W. and Kozlowski, T.T.
1976. Effects of temperature and photoperiod on growth of western hemlock. p. 108-117 in Atkinson, W.A. and Zasoski, R.J., *Ed.* Proceedings of the Western Hemlock Management Conference. Coll. of For. Resour., Univ. Wash., Contrib. No. 34.

Pollard, D.F.W.
1974. Bud morphogenesis of white spruce *Picea glauca* seedlings in a uniform environment. Can. J. Bot. 52:1569-1571.

Pollard, D.F.W., Teich, A.H. and Logan, K.T.
1975. Seedling shoot and bud development in provenances of Sitka spruce, *Picea sitchensis* (Bong.) Carr. Can. J. For. Res. 5:18-25.

Powell, L.E.
1976. Effect of photoperiod on endogenous abscisic acid in *Mahus* and *Betula.* HortScience 11:498-499.

Read, R.A. and Bagley, W.T.
1967. Response of tree seedlings to extended photoperiods. USDA For. Serv., Rocky Mt. For. Range Exp. Stn., Res. Pap. No. RM-30.

Robak, H.
1962. [New nursery studies on the relation between summer daylength and termination on the first year's growth in Norway spruce and Douglas-fir.] Medd. Vestland. Forstl. Forsokssta. 11(36):199-246.

Russell, K.W.
1974. Growing container Sitka spruce under high pressure sodium lights. Dep. Nat. Resour., Washington. DNR Notes No. 9.

Satoo, S.
1961. [Effect of long-day treatment under various nutritional conditions on the growth of *Abies sachalinensis* seedlings.] J. Jap. For. Soc. 43:320-324.

Shibakusa, R. and Kimata, M.
1975. [Studies on the dormancy of *Abies sachalinensis* Masters. I. Effect of long-day treatment on the formation of lammas shoots and the breaking of initial dormant buds.] J. Jap. For. Soc. 57:224-227.

Skok, J.
1961. Photoperiodic responses of *Sequoia gigantea* seedlings. Bot. Gaz. 123:63-70.

Skok, J.
1962. Further aspects of the photoperiodic responses of *Sequoia gigantea.* Bot. Gaz. 124:17-19.

Simak, M.
1970. Photo and thermo periodic responses of different larch provenances (*Larix decidua* Mill.) Stud. For. Suec. Skogshogsk. No. 86.

Simak, M.
1975. [Intermittent light treatment of forest plants in a plastic greenhouse produces better plant material.] Sver. Skogs. Tidsk. 73:373-381.

Stahel, J.B.
1972. The effect of daylength on root growth of Sitka spruce. For. Sci. 18:27-31.

Tinus, R.W.
1970. Response of *Pinus ponderosa* Laws. and *Picea pungens* Engelm. to extension of photoperiod with continuous and intermittent light. Abstr. in Plant Physiol. 46 (Suppl.):25.

Tinus, R.W. and MacDonald, S.E.
1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv., Rocky Mt. For. Range Exp. Stn., Gen. Tech. Rep. RM-60. p. 96-99.

Vaartaja, O.
1951. [Photoperiodism in Finnish trees.] Metst. Aikak 4:105-107.

Vaartaja, O.
1954. Photoperiodic ecotypes of trees. Can. J. Bot. 32:392-399.

Vaartaja, O.
1957. Photoperiodic responses in seedlings of northern tree species. Can. J. Bot. 35:133-138.

Vaartaja, O.
1959. Evidence of photoperiodic ecotypes in trees. Ecol. Monogr. 29:91-111.

Van Eerden, E.
1974. Growing season production of western conifers. p. 93-103 in R.W. Tinus, W.I. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Wareing, P.F.
1949. Photoperiodic control of leaf growth and cambial activity in *Pinus sylvestris.* Nature 163:770-771.

Wareing, P.F.
1950. Growth studies in woody species. I. Photoperiodism in first-year seedlings of *Pinus sylvestris.* II. Effect of daylength on shoot-growth in *Pinus sylvestris* after the first year. Physiol. Plant., Copenhagen 3:258-276, 300-314.

Wareing, P.F.
1951. Growth studies in woody species. III. Further photoperiodic effects in *Pinus sylvestris.* Physiol. Plant., Copenhagen 4:41-56.

Wareing, P.F.
1956. Photoperiodism in woody plants. Ann. Rev. Plant Physiol. 7:191-214.

Watt, R.F. and McGregor, W.H.
1963. Growth of four northern conifers under long and natural photoperiods in Florida and Wisconsin. For. Sci. 9:115-128.

Wheeler, N.
1979. Effect of continuous photoperiod on growth and development of lodgepole pine seedlings and grafts. Can. J. For. Res. 9:276-283.

THE EFFECT OF DORMANCY INDUCTION, LOW TEMPERATURES AND MOISTURE STRESS ON COLD HARDENING OF CONTAINERIZED BLACK SPRUCE SEEDLINGS

A.L. D'Aoust[1] and S.I. Cameron[2]

Abstract.--Cold hardening and acclimatization of coniferous seedlings are discussed and reviewed in relation to plantation success. A reduction in temperature and photoperiod at the end of the production period is the best acclimatization treatment for cold stress. Moisture stress, deprivation of nitrogen and low temperature in the dark did not improve hardening of black spruce (*Picea mariana* [Mill] B.S.P.) material. Preliminary field observations indicate that acclimatized seedlings have a superior survival rate.

Résumé.--Cette communication traite de l'endurcissement au froid comme facteur du succès de la plantation et de l'acclimatation de semis de conifères. La réduction de la température et de la photopériode au terme de la période de production constitue le meilleur traitement d'endurcissement au froid. La contrainte hydrique, la privation d'azote et le froid dans l'obscurité n'ont pas amélioré l'endurcissement de nos semis d'épinette noire (*Picea mariana* [Mill.] B.S.P.). Des observations préliminaires faites sur le terrain indiquent que les semis acclimatés ont un meilleur taux de survie.

INTRODUCTION

The degree of cold hardiness of a crop is an important consideration for the container nurseryman faced with moving a crop out of a greenhouse in spring or late summer for outplanting or overwintering.

Interest in cold hardiness is not new in Canada. Early work by Scarth (1936), Siminovitch and Briggs (1949) and more recently Glerum (1976) has indicated some fundamental changes in the plant during its annual cycle. Winter hardiness is a characteristic of temperate climate perennial species. The cold acclimatization process to obtain hardiness is the result of interactions between the plant genome and the environment. For example, the sensitivity of red spruce (*Picea rubens* Sarg.) to winter desiccation, as compared with black spruce (*P. mariana* [Mill.] B.S.P.), is well recognized (Roche 1969). However, winter hardiness is a very broad term and is defined as the capacity to avoid or tolerate the stresses imposed by winter conditions (low temperature, dry air, frozen ground, frost heaving, sunscald, etc.). The cold hardiness component is of major importance and is defined as the ability to withstand freezing temperatures. In this paper, discussion is restricted to cold hardiness and the acclimatization process, termed cold hardening.

PRACTICAL LIMITATIONS

Ideally, the field forester or nursery manager would like to specify, as part of a quality index, the cold hardiness of his stock. Aside from the obvious technical difficulties, the precision of such an estimate in a production facility with a variety of

---

[1] Research Scientist, Laurentian Forest Research Centre, Canadian Forestry Service, Ste-Foy, Quebec.

[2] Research Scientist, Maritimes Forest Research Centre, Canadian Forestry Service, Fredericton, New Brunswick.

seed sources will be limited by a number of factors.

The genetic variation of eastern boreal conifers is well recognized. The work of Holst and Yeatman (1961), Roche (1969), Morgenstern (1978) and others has indicated a clinal within-species variation and, in some cases, a variation with latitude and an attitudinal interaction as well. A further complication arises from hybridization among spruces (Manley 1972). It is therefore important that seed and seedling movement be confined within defined seed zones (Fowler and MacGillivray 1967). For stand improvement, superior material from remote locations can be introduced following proper testing (Corriveau and Boudoux 1971, Neinstaedt and Teich 1971, Fowler and Mullin 1977, Morgenstern 1978).

Large geographical areas have historically been subdivided into zones or regions according to major climatic and ecological factors (Fowler and MacGillivray 1967, Ouellet and Sherk 1967, Rowe 1972). A critical factor limiting plant distribution is mean minimum temperature of the coldest month of the year. However, within these divisions there are year-to-year variations and no one can accurately forecast meteorological conditions in any given winter. Therefore, depending on location, the probability of frost occurrence and severity is variable. Such uncertainty requires that biological material be prepared for the most severe seasonal condition in the field.

In practice, then, despite excellent work on agricultural crops and some field and nursery measurements with forestry material, both intrinsic factors and current lack of data preclude the use of a precise prescription for hardening off[3] of each boreal species.

AVOIDING THE REQUIREMENT

Avoidance of those months when the risk of frost is high is impractical because of cultural restraints other than cold hardiness, notably drought, cold soils, and effect of planting date on post-outplanting survival and performance. With bare-root stock, emphasis is on spring and fall planting (Bonner 1960, Ackerman and Johnson 1962). However, bare-root stock in Ontario has given unreliable results with fall planting (Anon. 1977). Seedling root regeneration potential and rooting of cuttings show a bi-modal pattern of activity, with maximum rooting generally recorded in the spring (Girouard 1975, Day et al. 1977). Arnott (1972) and Van Eerden (1972) have also indicated a tendency towards a bi-modal curve for survival and growth with container stock on the west coast, while Scarratt (1972) in the east has reported that all summer planting of tubed seedlings was feasible with the Ontario tube. Undoubtedly, the use of container stock extends the possible planting period, but until better performance data are available, the consensus is that the best season for planting is the spring, and that results are variable in the fall.

Aside from the obvious application of cold hardening to overwintered stock, the seasonality of outplanting requires the use of cold-stored material to optimize use of the planting periods. The physiology of the association between survival and particularly regrowth is unclear in relation to a) a certain minimum number of degree-hardening days[4] before lifting in fall (Mullin and Hutchison 1978), or to b) lifting of bare-root stock for cold storage in spring, which is limited by degree-days above 0°C (Mullin 1978). There appears to be a low temperature interaction with the seedling which induces a state of readiness for cold storage and eventual re-growth. Cold storage is essentially a mild freezing condition, and cold acclimatization for this storage process has some similarities with the conditioning of seedlings (containerized or otherwise) to withstand low temperatures (Hocking and Nyland 1971).

INDUCTIVE FACTORS

The literature on cold hardiness indicates that a number of factors influence its induction. Cessation of rapid vegetative growth appears to be a prerequisite (van den Driessche 1970, Weiser 1970, Levitt 1972, Aronsson 1975, Sandvik 1976, Christersson 1978). A minimum light intensity, provided in a short-day regime, is essential (van den Driessche 1970, Timmis and Worrall 1975, Sandvik 1976). Cold temperature, in some cases, can replace the short-day requirement (van den Driessche 1970, Sandvik 1976, Christersson 1978). Light frost can also increase the degree of cold hardening (Weiser 1970, Levitt 1972, Timmis and Worral 1975). Finally, moisture and nutrient regimes have occasionally had some influence on hardening off (Levitt, 1972, Christersson 1973, Tanaka

---

[3] Hardening off: the process of adaptation by plants so as to tolerate cold, heat and drought.

[4] Degree-hardening days: the cumulative daily minimum difference between 10°C and the temperature at root level (15 cm depth).

and Timmis 1974, Timmis 1974). Species differ in their response to acclimatization factors. Norway spruce (Picea abies [L.] Karst.) is less sensitive than Scots pine (Pinus sylvestris L.) to lowering of temperature during hardening off (Aronsson 1975), and with some conifers, the photoperiodic control seems to be a less dominant factor than the amount of light (McGuire and Flint 1962).

It is evident that actively growing seedlings have to be acclimatized properly before outplanting or storage. In an effort to assess the importance of the various inductive factors, the first author has been carrying out preliminary experiments on black spruce. Details of cultural methods are reported elsewhere (D'Aoust 1978, 1980). Black spruce is important to reforestation in eastern Canada, as it accounts for approximately 59% of container stock raised east of the Ontario-Manitoba border (Smyth 1980).

CESSATION OF VEGETATIVE GROWTH

Although true dormancy may not be an absolute necessity, growth cessation appears to be a prerequisite for primary stage cold acclimatization. One way to modify the growth pattern of black spruce seedlings is to reduce the photoperiod so as to slow down the rate of dry matter accumulation. Seedlings under long-day (LD) and short-day (SD) regimes respond differently in height growth (Fig. 1). Cessation of height growth is evident soon after the imposition of a SD treatment, but height growth recovers as soon as daylength is again increased. Cessation of height growth is not the only effect of short days, as the development of axillary buds and branches also ceased under these conditions (Fig. 2).

TEMPERATURE-PHOTOPERIOD INTERACTION

In fall, both temperature and photoperiod decline. Growth chamber simulation of the autumn environment (with the exception of temperatures lower than 4 °C which were beyond the capacity of the chamber) in the Quebec region (Table 1) indicates that 2 to 3 weeks are sufficient to stop height growth in black spruce at different ages (Fig. 3).

When the two factors are separated and seedlings are compared with an actively growing (LD) control, it can be seen that a short photoperiod, with little effect from temperature regime, stops height growth. Shortening the daylength also reduces dry weight accumulation of the shoot (Fig. 4A), but the daylength effect is less pronounced on the root system (Fig. 4B).

The effect of temperature/photoperiod on cold hardiness (as opposed to vegetative growth rate) can be seen from the combination of four inductive treatments: LD-warm (control), SD-warm, LD-cool, and SD-cool (Fig. 5).

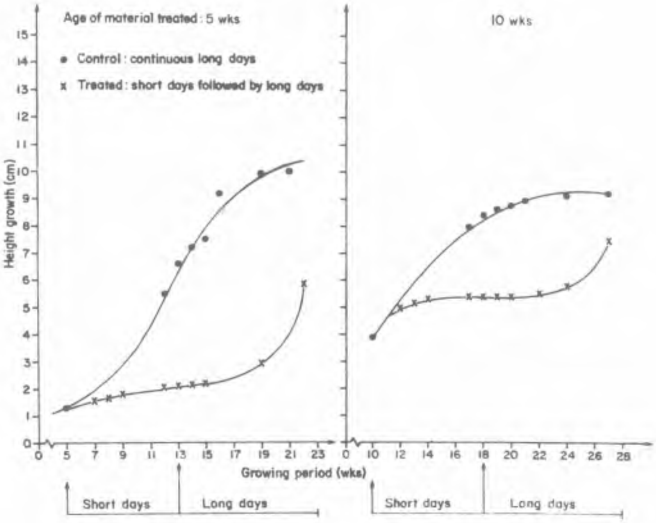


Figure 1. Effect of changing the photoperiod on growth of black spruce seedlings.

Table 1. Meteorological data for 1943 to 1971, at Quebec airport, and the artificial climate prescribed to imitate autumn conditions.

	Natural conditions[a]			Artificial conditions[b]		
	min. (°C)	max. (°C)	photoperiod[c] (h)	min. (°C)	max. (°C)	photoperiod[d] (h)
August	11.9	23.4	13.4	16	21	13.3
September	7.7	18.6	11.8	12	17	11.6
October	2.6	11.8	10.2	8	13	9.8
November	−3.2	3.5	9.0	4	9	8.0

[a] Climatic data from the Atmospheric Environment Service.

[b] Artificial conditions were programmed by using one week for each month to be reproduced.

[c] Minimum monthly hours of sunlight.

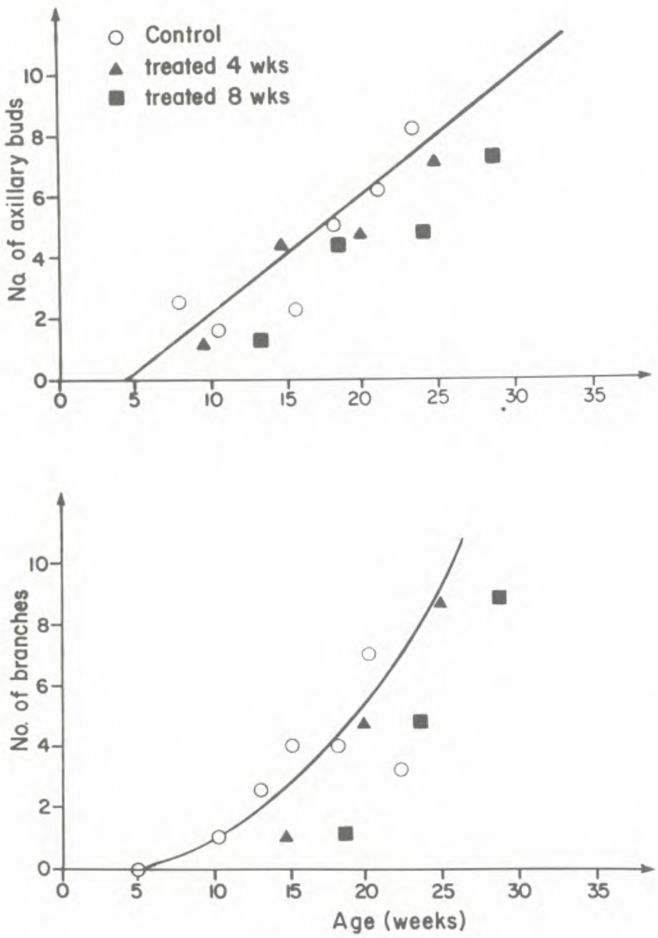


Figure 2. Effect of shortening the photoperiod on morphological development of black spruce seedlings.

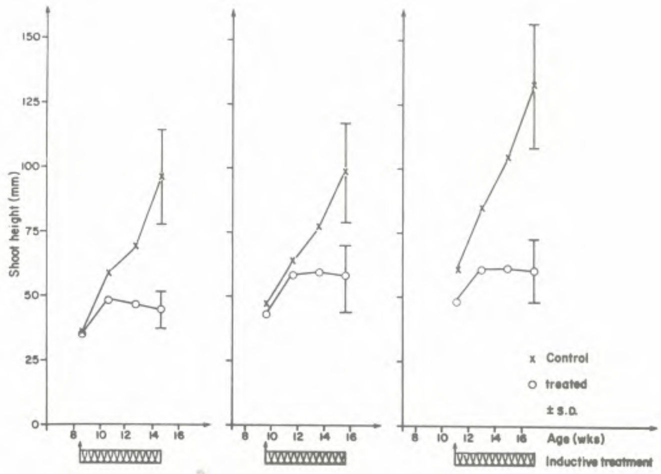


Figure 3. Effect of a gradual decline in temperature and photoperiod on the growth of black spruce seedlings.

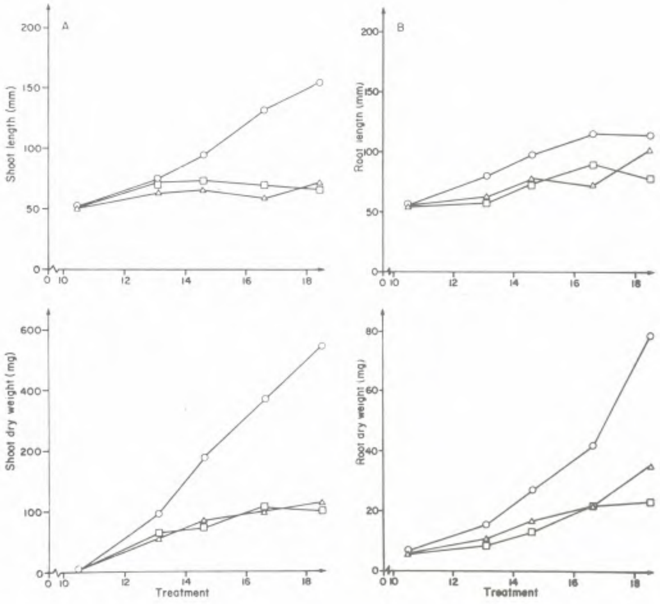


Figure 4. Effect of a gradual decline in temperature and/or photoperiod on the growth of black spruce seedlings. Shoot (A) and root (B) measurements; control (○) with constant long days and day-night temperatures (15 hr 25°/20°), a second treatment with a declining photoperiod (□), and a third with a weekly decline in both photoperiod and temperature (△).

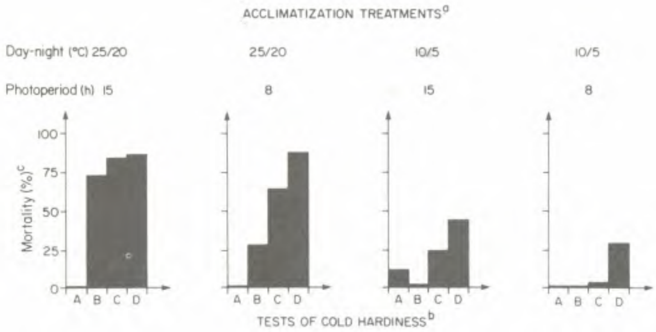


Figure 5. Effects of different cold acclimatization treatments on cold hardiness of 14-wk-old black spruce seedlings.[5]

Each regime results in a different degree of cold hardening after similar induction times, as judged by regrowth and mortality after periods of controlled freezing at -4°C, which, when prolonged, are increasingly lethal.[6]

Low temperatures induce a strong cold hardiness effect. The effect of short days is not as important as that of low temperature, but short days still affect the cold hardening of black spruce seedlings significantly. The seedling root systems exhibited a mortality pattern identical to that of the shoot for the different conditions (data not shown).

DROUGHT AND FERTILIZATION

The effect of drought during cold hardening was assessed by periodically imposing moisture stress until a visible wilting occurred. When the same freezing tests and the four temperature/photoperiod combinations described above were used, moisture stress did not markedly improve the cold hardiness of cold acclimatized seedlings (Fig. 6).

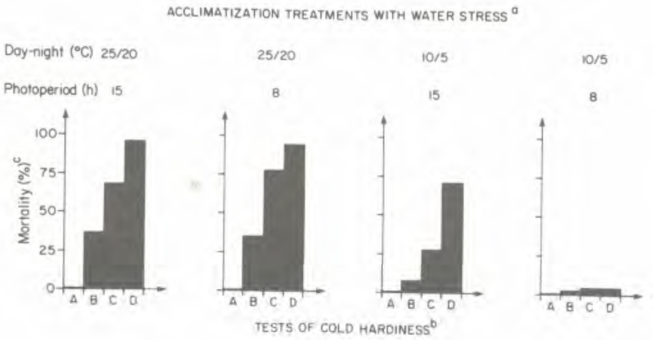


Figure 6. Effects of different acclimatization treatments with water stress on the cold hardiness of 14-week-old black spruce seedlings.?

The only exception was the actively growing control material which acquired a mild cold tolerance (compare Fig. 5 and 6 for treatment at 25°/20°C and 15 hr).

Seedlings were also treated with PK or NPK at the end of the production period, and submitted to cold stress. Seedlings deprived of nitrogen (PK treatment) did not appear to

---

[5] a) Seedlings were treated at high or low temperatures under short- or long-day conditions for 4 to 6 weeks.

b) A cold hardiness test was carried out in cold rooms; 24 hr at 4°C (A); 24 hr at 4°C and 4 hr at -4°C (B); 24 hr at 4°C and 8 hr at -4°C (C); 24 hr at 4°C and 24 hr at -4°C (D). For each interaction (acclimatization x cold period) 10 seedlings were sampled and transferred to a growth chamber for evaluation of their cold tolerance.

c) After 2 weeks of normal care, the seed lings were evaluated visually as either tolerant or severely damaged and dead. The histograms represent average values for five replicates.

[6] Ice formation in the rooting medium was noticed after 4 hr at -4°C and a solid ice block was present after 8 hr at -4°C.

[7] a) Seedlings were treated at low or high temperatures under short- or long-day conditions for 4 to 6 weeks and watering was withheld until wilting was evident.

b) Cold hardiness was induced in cold rooms; 24 hr at 4°C (A); 24 hr at 4°C and 4 hr at -4°C (B); 24 hr at 4°C and 8 hr at -4°C (C); 24 hr at 4°C and 24 hr at -4°C (D). For each interaction (acclimatization x cold period) 10 seedlings were sampled and transferred to a growth chamber to evaluate their cold tolerance.

c) After 2 weeks of normal care, the seedlings were evaluated visually as either tolerant or severely damaged and dead. The histograms represent average values for three replicates.

b hardier than those fertilized with NPK during the entire rearing period (data not shown).

FIELD SURVIVAL

Preliminary field tests with limited numbers of seedlings have yielded promising results. Survival has been assessed after one year on seedlings subjected to four cold acclimatization regimes prior to outplanting in spring and fall (Table 2).

Table 2. Mortality rates of transplanted seedlings after one year in the field.

	Acclimatization conditions			
Day/night temp. (°C):	25°/20°	25°/20°	10°/5°	10°/5°
Photoperiod (hr):	15	8	15	8
Spring planting	18%	5%	9%	1%
Fall planting	48%	21%	5%	15%

Mortality after one year in the field indicates that spring planting is superior to fall planting and that seedlings subjected to short-day or cold treatments survived better than did untreated seedlings.

CULTURAL APPLICATION

The similarity in response of black spruce to various inductive factors suggests that the same general prescriptions proposed for other species (Tinus and McDonald 1979) may be used in container nurseries. More precise recommendations concerning treatment manipulation to optimize the rate and/or depth of cold hardening are unavailable.

Indeed, it is necessary to be cautious with our conclusions since the material used originated from a single provenance and was treated under strict environmental control. Furthermore, the cold hardiness assays have used only mild cold stresses (-4°C), and subsequent evaluation was carried out under artificial conditions. However, evaluation of correlations between cold acclimatization conditions and field performance on the basis of so few experiments requires care. Field conditions may have been atypical, and the variation in results observed in the initial trial is sufficiently great that we must be cautious. Even so, some guidelines specific to this species seem applicable.

Bud formation as a morphological indicator of cold hardening may be inappropriate, since long days at low temperatures do not produce visible buds, but freezing tolerance similar to that observed by Timmis and Worral (1975) for Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) has been recorded (Fig. 5 and 6).

The short-day/low temperature combination induces the greatest cold hardiness (Fig. 5 and 6) although it is not always easily achieved operationally. Short days in the greenhouse can be obtained by opaque shade covering, and low temperature by proper ventilation. However, in late spring or early fall ventilation may not be sufficient, because of warm outdoor temperatures. Presumably, during such conditions only the short-day component would be effective. Active short-day imposition using shading with black spruce (as opposed to simply discontinuing supplementary lighting) is not practised, to our knowledge, although the inductive effects on growth cessation have been well documented (Vaartaja 1959, Morgenstern 1969, D'Aoust 1981). In addition to accelerating the rate of growth cessation, short days can decrease the shoot:root ratio at the end of the production period (Fig. 4), a modification generally regarded as being beneficial to the survival of transplanted seedlings.

Cold hardiness induction is possible with a shadehouse. If the seedlings are moved out of the greenhouse in spring or fall, low outdoor temperatures will induce hardening off, although frost damage may be prevented by irrigation or supplemental heat. The risk of frost in both seasons and the lengthening photoperiod in spring may require that initiation of dormancy induction be done in the greenhouse before transfer to a shadehouse for further hardening. It was once thought that, since seedlings needed short days and low temperatures for maximum cold hardiness, the two processes could be culturally separated by beginning with the short-day treatment followed by cold storage. However, our results indicate that this method does not work and therefore, like Weiser (1970), we believe that the low temperature treatment, to be effective, must be carried out concurrently with short-day treatment.

As with other species (Tanaka and Timmis 1974, Timmis 1974) neither moisture stress nor nitrogen deprivation at the end of the production period appear to affect the cold hardening process in black spruce. However, leaching followed by moderate water stress cannot be discounted as a potential preliminary treatment applied prior to dormancy induction. Aside from the shock-stress value in growth cessation (Tinus and McDonald 1979), some evidence (compare Fig. 5 and 6) indicates that slight cold hardiness can be induced by moisture stress during the active growth phase (Tanaka and Timmis 1974, Blake *et* al. 1979).

CONCLUSIONS

It is possible to modify growth behavior of containerized black spruce substantially so as to affect the cold hardiness of seedlings. A reduction of photoperiod with low temperatures, at the end of the production period, is the best acclimatization treatment, but short days or low temperatures alone can also stimulate cold hardening. Such flexibility must be considered a cultural advantage. Cold hardening influences survival, but additional factors, such as bud size and response to other types of stress, determine subsequent field performance. Detailed outplanting performance assessments may show that a regime tailored to produce maximal cold hardening may have to be modified to optimize other quality indices (Tinus 1974, Christersson 1978). Obviously, extensive, carefully planned field trials will be required to define a precise prescription. However, one positive aspect of cold hardiness induction is that, as far as environmental stresses are concerned, it appears that the plant does not have many ways of surviving adverse conditions. Tolerance of stresses other than cold--namely, heat, drought and salt--can be induced by the same acclimatization process (Levitt 1972, Christersson 1976, Vieira da Silva 1978). The container nurseryman should be aware that the processes involved in hardening crops to withstand various stresses are related, and therefore inducing tolerance of one may affect response to others beneficially.

LITERATURE CITED

Ackerman, R.F., and Johnson, H.J.
1962. Continuous planting of white spruce throughout the frost-free period. Can. Dep. For., For. Res. Br. Tech. Note 17. 13 p.

Anon.
1977. Plantation establishment symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Symp. Proc. O-P-5. 123 p.

Arnott, J.T.
1972. Influences affecting container seedling performance on Vancouver Island, British Columbia. p. 84-91 in Waldron, R.M., *Ed.* Proceedings of a Workshop on Container Planting in Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. DPC-X-2.

Aronsson, A.
1975. Influence of photo and thermo period on the initial stages of frost hardening and dehardening of phytotron-grown seedlings of Scots pine (*Pinus sylvestris* L.) and Norway pine (*Picea abies* L. Karst.). Stud. For. Suec. 128. 20 p.

Blake, J., Zaerr, J. and Hee, S.
1979. Controlled moisture stress to improve cold hardiness and morphology of Douglas-fir seedlings. For. Sci. 4:576-582.

Bonner, E.
1960. Reforestation problems in eastern spruce forest. For. Chron. 36:153-155.

Christersson, L.
1973. The effect of inorganic nutrients on water economy and hardiness of conifers I. The effect of varying potassium, calcium and magnesium levels on water content, transpiration rate and the initial phase of development of frost hardiness of *Pinus sylvestris* L. seedlings. Stud. For. Suec. 103. 26 p.

Christersson, L.
1976. The effect of inorganic nutrients on water economy and hardiness of conifers II. The effect of varying potassium and calcium content on water status and drought hardiness in pot-grown *Pinus sylvestris* Karst. seedlings. Stud. For. Suec. 136. 23 p.

Christersson, L.
1978. The influence of photoperiod and temperature on the development of frost hardiness in seedlings of *Pinus sylvestris* and *Picea abies.* Physiol. Plant 44: 288-294.

Corriveau, A., and Boudoux, M.
1971. Le developpement des provenances d'epinette blanche de la region forestière des Grands-Lacs et du Saint-Laurent. Dep. Environn., Serv. can. for., Ste-Foy, Que. Rapp. Inf. Q-F-X-15. 38 p.

D'Aoust, A.L.
1978. Influence de l'irradiation sur la croissance de plants d'epinette noire en contenants places dans deux enceintes de culture. Can. J. For. Res. 8:316-321.

D'Aoust, A.L.
1980. Influence de la concentration d'un engrais chimique sur la croissance et les echanges gazeux de semis d'epinette noire en conteneurs. Nat. Can. 197:125-133.

D'Aoust, A.L.
1981. The induction of dormancy by short-day treatment of container-grown black spruce seedlings. Dep. Environn., Serv. can. for., Ste-Foy, Que. Rapp. Inf. LAU-X-47. 16 p.

Day, R.M., Stependick, J.T., and Butler, J.M.
1977. Root periodicity and root regeneration potential are keys to successful plantation establishment. p.19-21 *in* Anon., Plantation Establishment Symposium Proceedings. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Symp. Proc. 0-P-5.

van den Driessche, R.
1970. Influence of light intensity and photoperiod on frost hardiness development in Douglas-fir seedlings. Can. J. Bot. 48. 2129-2134.

Fowler, D.P., and MacGillivray, H.G.
1967. Seed zones for the Maritime provinces. Dep. Environ., Can. For. Serv., Fredericton, N.B. Inf. Rep. M-X-12: 23 p.

Fowler, D.P. and Mullin, R.E.
1977. Upland-lowland ecotypes not well developed in black spruce in northern Ontario. Can. J. For. Res. 7: 35-40.

Glerum, C.
1976. Frost hardiness of forest trees. p. 403-418 *in* M.G.R. Cannell and F.J. Last, *Ed.* Tree Physiology and Field Improvement. Academic Press, New York, N.Y.

Girouard, R.M.
1975. Seasonal rooting response of Norway spruce stem cuttings. Plant Prop. 23:9-10.

Hocking, D., and Nyland, R.D.
1971. Cold storage of coniferous seedlings. A review. Appl. For. Res. Inst., State Univ. Coll. For., Syrcuse, N.Y. Res. Rep. 6. 70 p.

Hoist, M.J., and Yeatman, C.W.
1961. A provenance study in *Pinus banksiana* Lamb. Recent Adv. Bot. Sec. 14:1612-1616.

Levitt, J. *Ed.*
1972. Response of plants to environmental stresses. Academic Press, New York, N.Y.

Manley, S.A.M.
1972. The occurrence of hybrid swarms of red and black spruces in central New Brunswick. Can. J. For. Res. 2:381-391.

McGuire, J.J., and Flint, H.L.
1962. Effects of temperature and light on frost hardiness of conifers. Proc. Am. Soc. Hort. Sci. 80:630-635.

Morgenstern, E.K.
1969. Genetic variation in seedlings of *Picea mariana* (Mill.) B.S.P. I. Correlation with ecological factors. Silv. Genet. 18:151-160.

Morgenstern, E.K.
1978. Range-wide genetic variation of black spruce. Can. J. For. Res. 8:463-473.

Mullin, R.E.
1978. Test of frozen spring storage for white spruce and red pine planting stock. Tree Plant. Notes 29:26-29.

Mullin, R.E., and Hutchison, R.E.
1978. Fall lifting dates, overwintering storage, and white pine seedling performance. For. Chron. 54:261-264.

Nienstaedt, H., and Teich, A.
1971. The genetics of white spruce. USDA For. Serv. Res. Rep. W0-15. 24 p.

Ouellet, C.E. and Sherk, L.C.
1967. Woody ornamental plant zonation I. Indices of winter hardiness. Can. J. Plant Sci. 47:231-238.

Roche, L.
1969. Variation in growth behavior of fifteen red spruce *(Picea rubens* Sarg.) provenances at three sites in Quebec. Dep. Environ., Can. For. Serv., Ste-Foy, Que. Inf. Rep. Q-X-15. 13 p.

Rowe, J.S.
1972. Forest regions of Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Publ. 1300. 172 p.

Sandvik, M.
1976. Studies on growth rhythm and development of hardiness in seedlings of Norway spruce. XVI IUFRO Congress, Norway.

Scarratt, J.B.
1972. Tubed seedling research in northern Ontario. p. 129-141 in Waldron, R.M., *Ed.* Proceedings of a Workshop on Container Planting in Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. DPC-X-2.

Scarth, G.W.
1936. The yearly cycle in the physiology of trees. Trans. Roy Soc. Can. Sect. 5. 30:1-10.

Siminovitch, D., and Briggs, D.R.
1949. The chemistry of living bark of black locust tree in relation to frost hardiness I. Seasonal variation in protein content. Arch. Biochem. Biophys.23: 8-17.

Smyth, J.H.
1980. A directory of forest tree nurseries in Canada. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. 0-X-305. 51 p.

Tanaka, Y. and Timmis, R.
1974. Effects of container density on growth and cold hardiness of Douglas-fir seedlings. p. 181-186 in R.W. Tinus, W.I. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Timmis, R.
1974. Effect of nutrient stress on growth, bud set and hardiness in Douglas-fir seedlings. p. 187-193 in R.W. Tinus, W.I. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Timmis, R., and Worrall, J.
1975. Environmental control of cold acclimation in Douglas-fir during germination, active growth and rest. Can. J. For. Res. 5:464-477.

Tinus, R.W.
1974. Characteristics of seedlings with high survival potential. p. 276-282 in R.W. Tinus, W.E. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Tinus, R.W. and McDonald, S.E.
1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv., Gen. Tech. Rep. RM-60. 256 p.

Vaartaja, D.
1959. Evidence of photoperiodic ecotypes in trees.. Ecol. Monogr. 29:91-111.

Van Eerden, E.
1972. Influences affecting container seedling performance near Prince George, British Columbia. p. 92-100 in Waldron, R.M., *Ed.* Proceedings of a Workshop on Container Planting in Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. DPC-X-2.

Vieira Da Silva, J.
1978. Quelques similitudes entre les agressions, par la salinite et celles causees par la secheresse et par le gel. Soc. bot. Fr. Arch. Bot. 125 (3-4): 275-284.

Weiser, C.J.
1970. Cold resistance and injury in woody plants. Science 169:1269-1278.

PRACTICAL APPLICATION OF DORMANCY INDUCTION TECHNIQUES TO GREENHOUSE-GROWN CONIFERS IN SWEDEN

Gunnel Rosvall-Ahnebrink[1]

Abstract.--Experiments to determine the effects of different hardening treatments in the nursery on 1-year-old Scots pine *(Pinus sylvestris* L.) and Norway spruce *(Picea abies* [L.] Karst.) seedlings are described. Seedling performance after early autumn planting and early lifting for overwinter cold storage were better if long night treatments were used. Long night treatments are used in several Swedish nurseries.

Résumé.--Description d'expériences visant à déterminer les effets de différents traitements d'endurcissement en pépinière sur les semis de pin sylvestre *(Pinus sylvestris* L.) et d'épinette de Norvège *(Picea abies* (L.) Karst.) âgés d'un an. Après plantage au début de l'automne et arrachage précoce en vue de leur entreposage à froid pour l'hiver, ces semis présentaient une meilleure performance s'ils étaient soumis à des traitements nyctipériodiques. De tels traitements sont en usage dans les pépinières suédoises.

INTRODUCTION

Planting in the autumn often fails (e.g., Hulten and Jansson 1974). One probable reason for this is that planting stock is not physiologically adapted to the relatively harsh conditions at the planting site. Also, seedlings growing outdoors in the nursery sometimes suffer from autumn frost damage, and this leads to reduced seedling quality. To avoid damage to stock overwintering in cold storage, seedlings must be fully dormant when lifted (Hocking and Nyland 1971, Venn 1980). However, sometimes as early as mid-October in northern Sweden, snow or frozen ground make lifting difficult or impossible.

To adapt planting stock to the conditions it will be exposed to in autumn it is desirable that the development of cold hardiness be regulated in the nursery during summer and autumn. Photoperiod, light intensity, and temperature are probably the most important external factors that regulate the development of cold hardiness. However, their influence varies at different stages of the development process (Weiser 1970).

For Norway spruce *(Picea abies [L.]* Karst.) and Scots pine *(Pinus sylvestris* L.), the most common species in Sweden, it has been demonstrated that short days, or more correctly, long nights (LN), are the most important factor inducing dormancy (e.g., Dormling et al. 1968, Heide 1974, Aronsson 1975, Christersson 1978). Recommendations for the practical application of LN-treatment in nurseries have been made by Sandvik (1975, 1980) for Norway spruce and by Rosvall-Ahnebrink (1977, 1980) for Norway spruce and Scots pine.

The results presented in this paper are derived from a number of nursery experiments with one-year-old containerized Norway spruce, Scots pine and lodgepole pine *(Pinus contorta* Dougl.) seedlings. One aim of the experiments was to determine suitable growing schedules for nursery stock during the final period in the nursery. Emphasis was placed

---

[1] Forest Officer, Department of Silviculture, Swedish University of Agricultural Sciences, Umeå, Sweden

on investigating how the development of cold hardiness can be regulated by LN treatments in the greenhouse, and these treatments have been compared with the growing schedules normally used. Some results of these experiments have been published (Rosvall-Ahnebrink 1977, 1980), but more detailed reports are in preparation.

MATERIALS AND METHODS

Seedlings

Scots pine and Norway spruce seeds from mid-Sweden (about 60° N) were sown in paperpot containers in the spring of 1977 and 1978 (Table 1) at the Nassja nursery (60° N).

Low humified peat, containing 1 kg dolomite lime per m^3, was used as the growing medium and the seeds were covered with a thin layer of styrofoam pellets.

The seedlings were kept in a production-size plastic-covered greenhouse for three months or more, depending on the hardening treatments applied. The greenhouse was heated to prevent temperatures from dropping to less than 15°C, and was ventilated when the temperature exceeded 25°C. During hot days, maximum temperatures were sometimes 40°C.

Fertilization was started two to three weeks after sowing. Each week, 2-4 g N per m^2 were applied in the form of a complete liquid fertilizer with N:K:P in the proportions of 100:65:13 (Ingestad 1967). Pine seedlings for the autumn planting trial were fertilized until late July when LN treatment began, or else they were moved outdoors. All other seedlings were fertilized until mid-August.

Hardening treatments

Three different hardening treatments were used in various sequences from mid-July (1978) or late July (1977), when seedlings were still in active growth. The conditions were (1) LN-treatment in greenhouse, (2) natural night length in greenhouse, and (3) natural night length outside (seedlings moved outdoors).

During the LN-treatment seedlings were daily covered with black curtains from 4 p.m. to 8 a.m. (16-hr night). Natural night length, defined as time between sunset and sunrise, is approximately 6 hr at 60°N in mid-July.

The different hardening treatments are presented in the lower portions of Figures 1-3 (pine, planted in autumn 1977), Figures 4-6 (spruce, planted in autumn 1978), Figure 7 (pine, cold stored during winter 1978-1979) and Figure 8 (spruce, cold stored during winter 1978-1979).

During the hardening period in 1977, daily maximum temperatures in the greenhouse varied between 20°C and 40°C, and daily minimum temperatures in the greenhouse varied between 10°C and 20°C. Seedlings growing outside were not exposed to temperatures below 0°C before they were outplanted.

In 1978, daily maximum temperatures in the greenhouse varied between 25°C and 45°C. Daily minimum temperatures were about 20°C to mid-September, and thereafter about 15°C.

Table 1. Data for Scots pine and Norway spruce seedlings used in autumn planting and overwinter cold storage experiments.

Experiment	Seed origin	Container	Sowing	Hardening treatments started
Pine, autumn planting in 1977	Seed orchard at Sör Amsberg (61°N), grafts from 61°N	Paperpot FH 408, 850 containers per m^2	4 May, 1977	25 July, 1977
Pine, cold storage during winter 1978-1979	Seed orchard at Hedesunda (60°N), grafts from 60°N	Paperpot FH 508 585 containers per m^2	14 April, 1978	17 July, 1978
Spruce, autumn planting in 1978 and cold storage during winter 1978-1979	Seed orchard at Sollerön (61°N), mother trees from 59°N	Paperpot FH 408, 980 containers per m^2	18 April, 1978	17 July, 1978

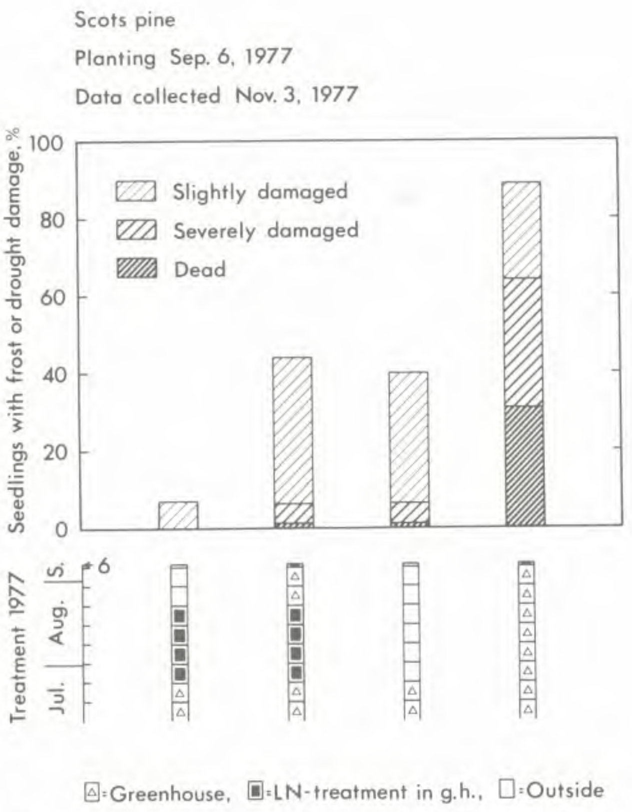


Figure 1. Scots pine (61°N) seedlings with frost or drought damage 2 months after autumn planting, at a site near Bredmossen (60°N). During the final 6 weeks in the nursery (60°N), the 1-year-old seedlings were given different hardening treatments, under natural night length or long night (LN) conditions.

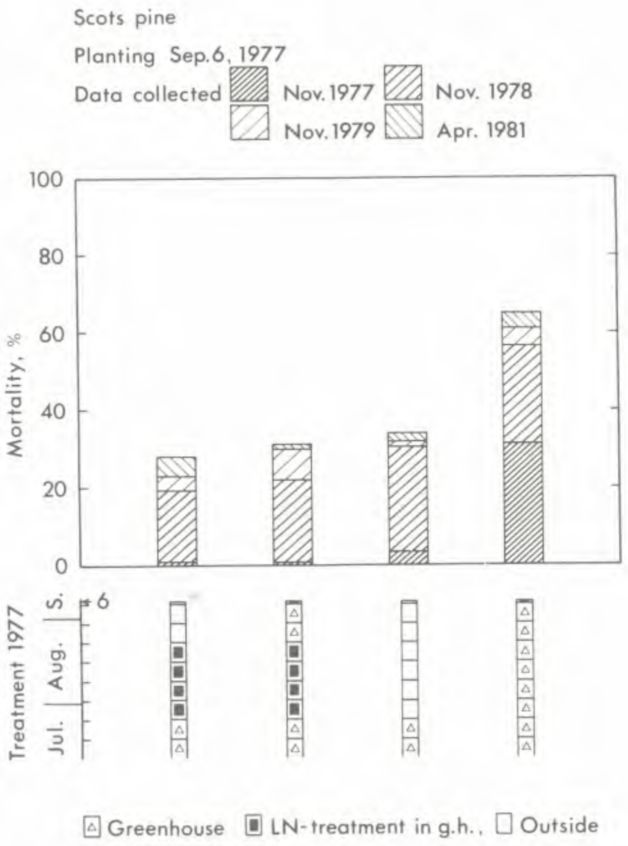


Figure 2. Accumulated mortality of Scots pine (61°N) seedlings after autumn planting, at a site near Bredmossen (60°N). During the final 6 weeks in the nursery (60°N), the 1-year-old seedlings were given different hardening treatments, under natural night length or long night (LN) conditions.

Outdoor daily maximum temperatures were about 15°C lower than in the greenhouse, and daily minimum temperatures were about 10°C lower than in the greenhouse. Seedlings growing outdoors were exposed to temperatures below 0°C on 20, 21 and 25 September.

Autumn planting

Field trials were established to evaluate the effects of the treatments on seedling performance after early autumn planting.

On 6 September 1977, six weeks after hardening treatments started, the pine seedlings were planted on a harsh site (Bredmossen, 60°N) that had been difficult to regenerate. Twenty-five seedlings of each treatment were randomly assigned to rows within each of six blocks. Height, condition class (0-5; 0 = not damaged, 1-2 = slightly damaged, 3-4 = severely damaged, 5 = dead) and cause of damage were recorded in early November 1977, November 1978, November 1979 and April 1981.

On 30 August 1978, six weeks after hardening treatments began, the spruce seedlings were planted at a site (Stjärnsund, 60°N) less harsh than that where the pine seedlings were planted. The planting design was similar to that used on the pine seedlings, except that only 20 seedlings were planted in each row. Seedling performance was recorded as described above in late October 1978, October 1979 and April 1981.

Cold storage

A cold storage experiment was begun in 1978 to evaluate the effects of the treat-

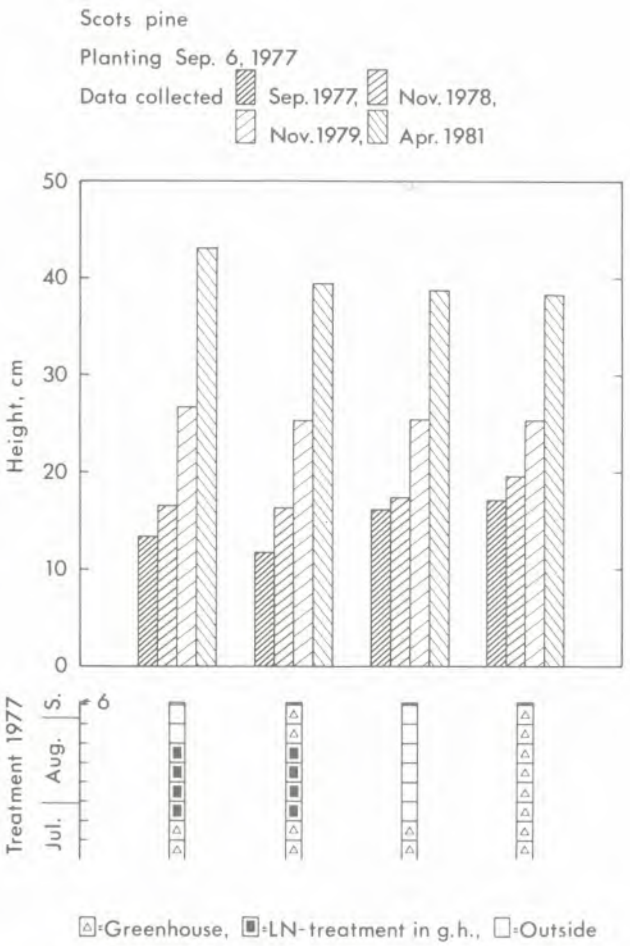


Figure 3. Height of Scots pine (61°N) seedlings after autumn planting, at a site near Bredmossen (60°N). During the final 6 weeks in the nursery (60°N), the 1-year-old seedlings were given different hardening treatments, under natural night length or long night (LN) conditions.

ments on overwinter storage. Pine and spruce seedlings were lifted earlier than normal, on 13 and 27 September, eight or ten weeks after hardening treatments began. Three replicates, each of 11-15 seedlings per treatment and date, were placed in waxed cardboard boxes and stored at -5 °C until 11 May 1979. After a week of thawing the seedlings were planted on nursery land and their condition records were assessed on 23 May 1979, in the same way as in the autumn planting trials.

RESULTS

Autumn planting

The hardening treatment at the nursery during the last six weeks before early autumn planting was of great importance for plantation performance (Fig. 1-6).

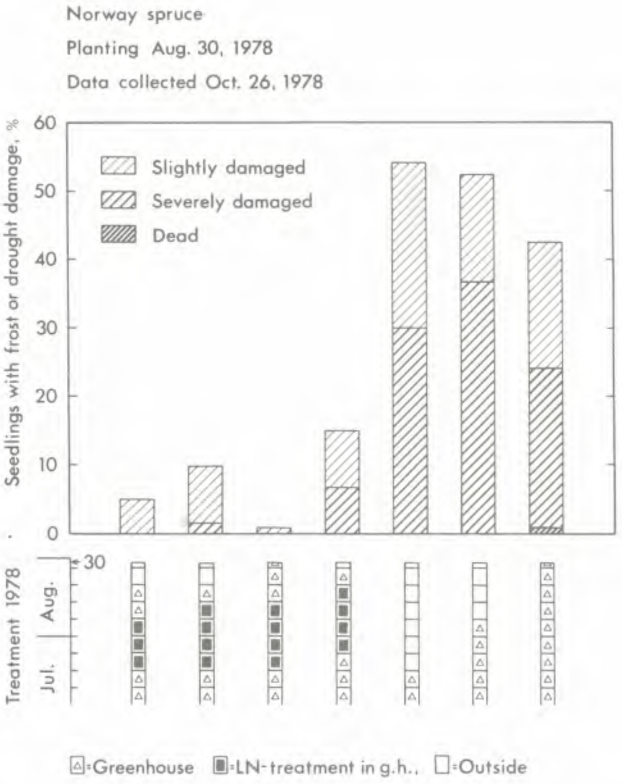


Figure 4. Norway spruce (59°N) seedlings with frost or drought damage 2 months after autumn planting, at a site near Stjärnsund (60°N). During the final 6 weeks in the nursery (60°N), the 1-year-old seedlings were given different hardening treatments, under natural night length or long night (LN) conditions.

On both sites, frost and drought were the most important causes of damage within two months of planting. Seedlings in hardening treatments which prevented severe damage by frost or drought during this period also had the lowest mortality two or three growing seasons after planting.

The pine seedlings (Fig. 1-3) were probably exposed to frost almost immediately after planting, and this resulted in dramatic differences among the treatments. The most favorable was the LN-treatment followed by outdoor conditions. For pine seedlings grown exclusively under natural night lengths, hardiness was significantly improved by an outdoor period of 6 weeks.

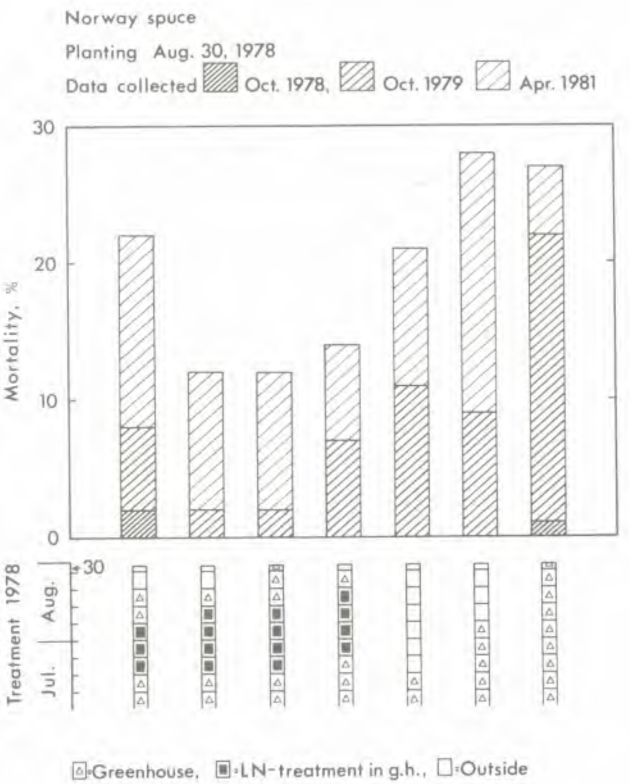


Figure 5. Accumulated mortality of Norway spruce (59°N) seedlings after autumn planting, at a site near Stjärnsund (60°N). During the final 6 weeks in the nursery (60°N), the 1-year-old seedlings were given different hardening treatments, under natural night length or long night (LN) conditions.

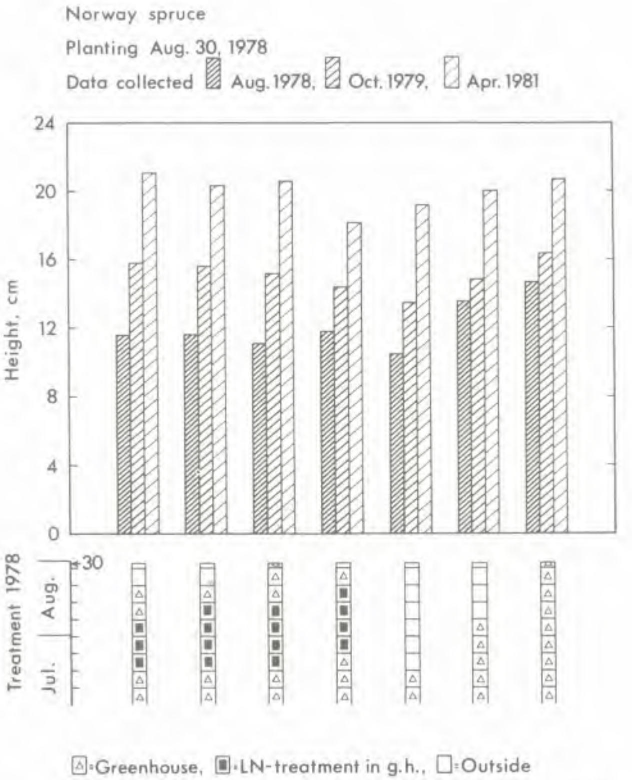


Figure 6. Height of Norway spruce (59°N) seedlings after autumn planting, at a site near Stjärnsund (60°N). During the final 6 weeks in the nursery (60°N) the 1-year-old seedlings were given different hardening treatments, under natural night length or long night (LN) conditions.

The spruce seedlings (Fig. 4-6) were probably exposed to frost for two weeks after planting. Seedling performance was considerably improved by LN treatment, and the date when LN treatment began was important. Unlike the results with pine, hardiness of spruce was not improved by an outdoor period for seedlings grown in only natural night length conditions.

Cold storage

Lifting pine seedlings on 13 September (Fig. 7), 8 weeks after the hardening treatments began, was fatal irrespective of previous treatment. When lifted 2 weeks later (Fig. 7), seedlings grown outdoors had been exposed to frost, and their tolerance of storage was improved. Pine seedlings exposed to LN treatment followed by outdoor conditions showed the best performance. The storage tolerance of pine seedlings grown under natural night length conditions was better if they were grown outdoors from mid-July instead of from early August. Storage was fatal if the seedlings were moved directly from the greenhouse to cold storage, irrespective of previous night length treatment. Pine seedlings exposed to LN treatment began to grow again if they were kept in the greenhouse after the LN-treatment (data not shown).

In the case of spruce it was not possible to store seedlings from 13 September (Fig. 8), eight weeks after hardening treatments began, although LN-treatment followed by outdoor conditions improved storage tolerance to a limited extent.

When the seedlings were lifted two weeks later (Fig. 8) storage tolerance in these treatments was further improved. Although

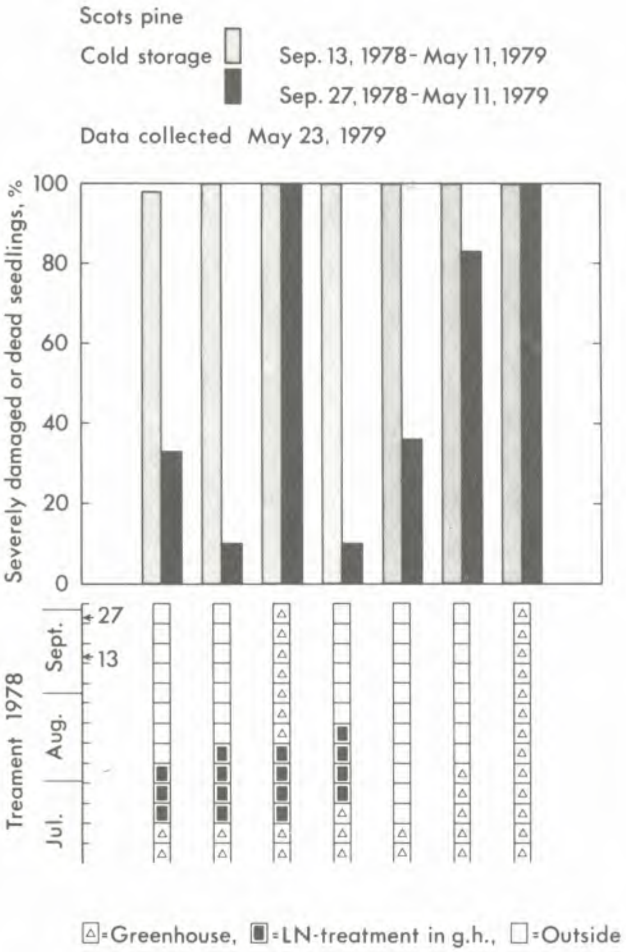


Figure 7. Severely damaged or dead Scots pine (60°N) seedlings after cold storage at -5°C over winter and planting on nursery land (60°N). During the final 8 or 10 weeks in the nursery (60°N) before storage, the 1-year-old seedlings were given different hardening treatments, under natural night length or long night (LN) conditions.

leaving spruce seedlings in greenhouse conditions after LN-treatment did not cause bud break (data not shown), it was nevertheless detrimental to the hardening process. If spruce seedlings were grown under natural night length conditions from mid-July, outdoor conditions during at least four weeks before storing favored hardiness development. However, moving seedlings to outdoor conditions in mid-July was no better than moving them out in mid-August.

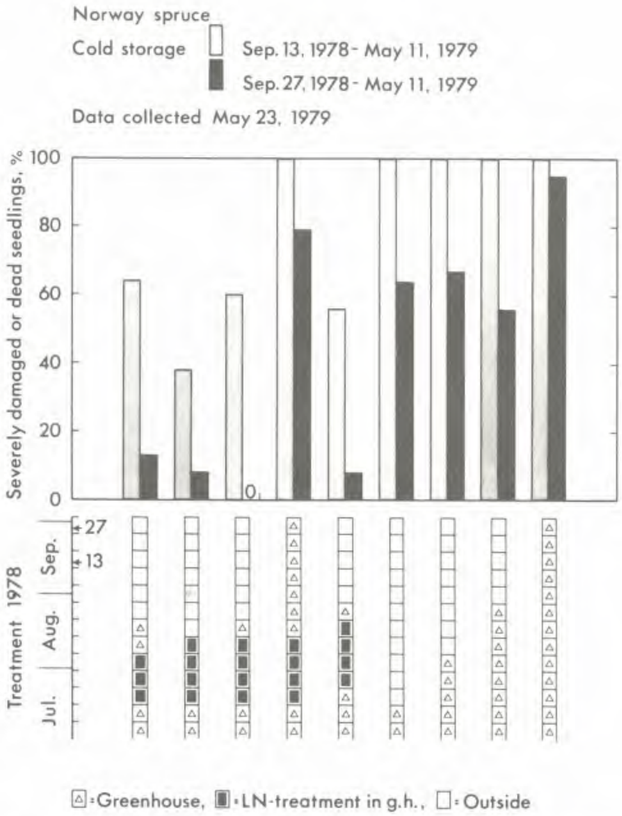


Figure 8. Severely damaged or dead Norway spruce (59°N) seedlings after cold storage at -5°C over winter and planting on nursery land (60°N). During the final 8 or 10 weeks in the nursery (60°N) before storage, the 1-year-old seedlings were given different hardening treatments, under natural night length or long night (LN) conditions.

CONCLUSIONS

The environmental conditions to which seedlings are exposed in the nursery, from mid- or late July, are very important to seedling performance after early autumn planting and early lifting for overwinter cold storage.

Hardiness development can be initiated earlier than normal by starting LN-treatment in the greenhouse in mid-July. A period of about four weeks with long nights is sufficient. Pine seedlings should be moved outdoors directly after that period, to allow hardiness development to continue. Spruce seedlings can be kept in the greenhouse for an additional week to favor lignification and bud maturation (data not presented). About six weeks after the hardening process is initiated, seedlings are tolerant to light frosts.

If seedlings are to be kept over winter in cold storage, hardiness development must continue during at least four more weeks. Temperatures below 0 °C during this period will probably improve hardiness.

Under natural night length conditions, the development of cold hardiness in pine is favored by outdoor conditions, and outdoor conditions from an earlier date are better than those from a later date. For spruce as well, the development of cold hardiness is favored by outdoor conditions, but the date on which the seedlings are moved outdoors is not as important as for pine.

Practical application of LN treatment

Today, LN treatment to regulate the development of cold hardiness during the final portion of the growing season is used in several Swedish nurseries. The Sör Amsberg nursery, owned by Stora Kopparberg-Bergvik, began using the method on a small scale as early as 1974. At that time they covered the seedlings in the greenhouse manually. Today they use the LN treatment on a large scale, and their black-out systems, which are now automatic, are placed inside the greenhouses.

In recent years several other nurseries have started using the method on a smaller scale. In these nurseries the black-out systems are placed outside, and in two of them seedlings can be covered automatically.

Early summer

Nursery experiments have been conducted to investigate whether LN treatment can be used for purposes other than that of regulating the development of cold hardiness during the final portion of the growing season (Rosvall-Ahnebrink, in prep.).

After sowing in a heated greenhouse early in the year, seedlings are very susceptible to damage if they are planted out in June or July without pretreatment. To improve the hardiness of this crop, experiments have been conducted with LN treatment. Norway spruce and Scots pine seedlings have been exposed to long nights in the greenhouse, starting in May or June, for a period of three to seven weeks. In some cases the period with LN treatment has been followed by one to two weeks in darkness at about 5 °C.

Results of tests for frost and drought hardiness demonstrate that hardiness during summer can be considerably increased by using some of the above treatments. However, further experiments are required before recommendations can be made to the nurseries.

Pine seedlings sown in a heated greenhouse early in the year, to be planted in the autumn or following spring, often differ greatly in height and shoot morphology, even if they are grown outdoors from June.

Experiments with Scots pine have been conducted to produce seedlings that appear to be two years old, with secondary needles and lateral buds, although they are produced in one season. If early-sown pine seedlings are given the LN treatment during a short period in spring or early summer, and then are grown in natural night length conditions, they will look like two-year-old seedlings in the autumn. The experiments have demonstrated that two weeks of LN treatment are sufficient to produce this effect.

Field trials have been established to determine whether these pine seedlings will perform better than those produced in the usual manner. In the meantime, the method is being used on a large scale in one Swedish nursery (Sor Amsberg), and several other nurseries show a keen interest in it.

LITERATURE CITED

Aronsson, A.
1975. Influence of photo- and thermoperiod on initial stages of frost hardening and dehardening of phytotron-grown seedlings of Scots pine *(Pinus silvestris* L.) and Norway spruce *(Picea abies* [L.] Karst.). Stud. For. Suec. 128:1-20.

Christersson, L.
1978. The influence of photoperiod and temperature on the development of frost hardiness on seedlings of *Pinus silvestris* and *Picea abies.* Physiol. Plant. 44:288-294.

Dormling, I., Gustafsson, A. and von Wettstein, D.
1968. The experimental control of the life cycle in *Picea abies* (L.) Karst. Silv. Genet. 17:44-63.

Heide, O.
1974. Growth and dormancy in Norway spruce ecotypes *(Picea abies)*. I. Interaction of photoperiod and temperature. Physiol. Plant. 30:1-12.

Hocking, D. and Nyland, R.
1971. Cold storage of coniferous seedlings. A review. App. For. Res. Inst., State Univ. Coll. For., Syracuse, New York, Res. Rep. No. 6. 70 p

Hulten, H. and Jansson, K-A.
1974. Biologisk uppföljning av rotade plantor vid praktisk skogsodling planteringsär 1972. [Biological follow up of rooted plants at practical artificical regeneration. Planting year 1972.] R. Coll. For., Dep. Refor. Stockholm, Sweden, Res. Notes 56. 42 p.

Ingestad, T.
1967. Methods for uniform optimum fertilization of forest tree plants. 14th IUFRO Congress, Section 22. p. 265-269.

Rosvall-Ahnebrink, G.
1977. Artificiell invintring av skogsplantor i plastväxthus. [Artificial hardening of spruce and pine seedlings in plastic greenhouses.] Exp. genek. R. Coll. For., Dep. For. Genet., Res. Notes 27. p. 153-161.

Rosvall-Ahnebrink, G.
1980. Kan vi varaktigt förändra en plantas invintringsförlopp? [Is it possible to permanently change the hardening process for Norway spruce and Scots pine seedlings?] Sveriges Skogsvardsforbunds Tidskrift. Specialnummer Skogsgenetik och skogstradsforadling 1980. (1-2):170 178.

Sandvik, M.
1975. Kontroll av innvintringstempoet hos granplanter i praktiske produksjonsanlegg. Arsskr. norske skogpl.sk. 1974:49-56.

Sandvik, M.
1980. Environmental control of winter stress tolerance and growth potential in seedlings of *Picea abies* (L.) Karst. N. Z. J. For. Sci. 10:97-104.

Venn, K.
1980. Winter vigour in *Picea abies* (L.) Karst. VII. Development of injury to seedlings during overwinter cold storage. A literature review. [Vinterstyrke hos gran. VII. Utvikling av skader pa planter under kjolelagring over vintern. En litteraturoversikt.] Rep. Norwegian For. Res. Inst. 35:483-530.

Weiser, C.J.
1970. Cold resistance and injury in woody plants. Science 169:1269-1278.

COLD HARDINESS AND BUD DEVELOPMENT UNDER SHORT DAYS IN BLACK SPRUCE AND WHITE SPRUCE SEEDLINGS

S.J. Colombo[1], D.P. Webb[2], and C. Glerum[1]

Abstract.--Cold hardiness of first-year seedlings of black spruce *(Picea mariana* B.S.P.) and white spruce *(P. glauca* [Moench] Voss) was increased by exposure to 8-hr photoperiod at 20°C. After five weeks of short days, a temperature of -9°C did not cause damage in either species. Shoot elongation ceased and bud development began after exposure to short days. The development of cold hardiness was strongly correlated with the decreasing rate of shoot elongation and the increasing number of needle primordia in the terminal buds. After eight weeks of short days, bud development in both species was virtually complete.

Résumé.--On a augmenté la résistance au froid de semis d'épinette noire *(Picea mariana* [Mill.] B.S.P.) et d'épinette blanche *(Picea glauca* [Moench] Voss) de moins d'un an en les soumettant à une photopériode de huit heures à 20°C. Après cinq semaines dans ces conditions, une température de -9°C n'a causé aucun dommage aux deux espèces. L'allongement des pousses a cessé et les bourgeons ont commencé à se développer après l'exposition à la courte photopériode. L'augmentation de la résistance au froid était fortement corrélée avec la réduction de l'allongement des pousses et l'augmentation du nombre de primordiums foliaires dans les bourgeons terminaux. Après huit semaines de photopériode courte, le développement des bourgeons était pratiquement complet chez les deux espèces.

INTRODUCTION

In Ontario, winter damage to container-grown spruce seedlings is currently a serious problem limiting the availability of vigorous stock for outplanting. A principal cause of winter damage is that container seedlings are hardened outside, under prevailing weather conditions. Seedlings are then susceptible to freezing damage until sufficient cold hardiness has developed in response to shortening daylengths and cool temperatures. One way to reduce these losses is to ensure adequate cold hardiness by exposure to short days before moving the trees outside.

During cold hardening in tree seedlings, a series of changes takes place in shoot elongation and bud formation. However, the interrelationships of these processes have not been thoroughly investigated for eastern boreal coniferous species such as black spruce *(Picea mariana* [Mill.] B.S.P.) and white spruce *(P. glauca* [Moench] Voss).

It was decided, therefore, to test the effects of 8-hr days at 20°C on cold hardiness, shoot growth and bud development of black spruce and white spruce seedlings.

MATERIALS AND METHODS

Black spruce and white spruce seed from single-tree collections made in the vicinity of the Petawawa National Forestry Institute (Lat. N. 46° 00', Long. W. 77° 26') was germinated and grown in a glasshouse for 12 weeks at temperatures of 17-25°C, under natural

---

[1] Research Scientists, Ontario Tree Improvement and Forest Biomass Institute, Ontario Ministry of Natural Resources, Maple, Ontario.

[2] Research Scientist, Great Lakes Forest Research Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario.

daylength supplemented to 16 hr with high-intensity sodium vapor lamps providing 175 $uE.m^{-2}.s^{-1}$ of photosynthetically active radiation (PAR).

Seedlings were grown in 350 cm^3 Styrofoam pots (four seedlings per pot) filled with a peat moss:vermiculite mixture (2:1 v/v). Twice a week, beginning 29 days after sowing, 70 ml of nutrient solution (Hocking 1971) were applied to each pot. After 12 weeks, pots were placed for eight weeks in growth chambers under an 8-hr short-day treatment with a PAR of 246 and a constant day-night temperature of 20 °C. Fertilization was continued on a weekly basis with half-strength Hocking's solution.

The effect of 8-hr days was assessed by measuring cold hardiness, bud development and shoot elongation at weekly intervals for the eight weeks of short-day treatment.

Cold hardiness was tested by exposing the seedlings to freezing temperatures (-9 °C). The freezing test consisted of preconditioning 16 seedlings (four pots) of each species at 5 °C for 12 hr. Eight seedlings served as controls and were left at 5 °C. The remaining eight seedlings were placed in a Styrofoam chest, with vermiculite insulation around the pots to protect the roots from freezing. The chest was sealed and placed in a freezer for 6 hr, during which time air temperature in the chest decreased approximately 10 °C in the first hour and $0.8\,^{\circ}C \cdot hr^{-1}$ over the next 5 hr down to -9 °C. The chest was post-conditioned for 12 hr at 5 °C before opening.

The degree of cold hardiness was determined after freezing both by measuring the leakage of electrolytes from damaged shoots and by assessing the development of visible symptoms of damage.

Electrolyte leakage was measured by means of a modified version of the methods described by Aronsson and Eliasson (1970) and Green and Warrington (1978) and as developed by Dexter et al. (1932). Two seedlings from each pot in the controls and in the -9 °C treatment were decapitated 8 cm below the shoot tip and placed in test-tubes containing 25 ml of distilled water. After 24 hr at room temperature (approximately 24 °C) the test-tubes were vigorously shaken and electrical conductivity of the solution was measured with a Radiometer model CDM3 conductivity meter. The test-tubes were then placed in boiling water for 10 min and, after a further 24 hr at room temperature, the tubes were shaken and electrical conductivity was remeasured. Relative conductivity was calculated as the percentage of electrical conductivity measured before over that measured after boiling. A lower percentage of relative conductivity indicates a greater hardiness.

Visible symptoms of freezing damage (Table 1) were assessed on the four seedlings (two pots) of each species remaining from both the freezing test and its control, after they had been placed in the glasshouse for 30 days.

Table 1. Scale of visible freezing damage for white spruce and black spruce.

Rating	Symptom
0	No damage
1	Terminal alive, some needles red
2	Terminal killed, fewer than 50% of needles red
3	Terminal killed, more than 50% of needles red
4	Main stem and lateral shoots killed, just a few needles near base of epicotyl alive
5	Seedling completely dead

Shoot elongation was measured on a permanent sample of 20 trees of each species every week for the eight weeks of short-day treatment. Bud development was assessed on eight shoot apices per species at weekly intervals, from week 0 to week 8. Budscales were counted and removed to permit examination of needle primordia on the apical meristem. The total number of needle primordia was estimated by counting primordia in spirally arranged parastichies (rows) on the apical meristem and multiplying by the total number of parastichies, as described by Pollard (1973). The shoot apices from the eighth week of the short-day treatment were prepared for scanning electron micrography, according to standard procedures (Gregory 1980). Buds from production-run container stock were similarly examined for comparison.

RESULTS

The cold hardiness of both species increased with time of exposure to short days. From the first to the fourth week, relative conductivities in black spruce and white spruce exposed to the -9°C freezing treatment fell from 95.1 to 14.8% and from 39.5 to 13.1%, respectively (Fig. 1). At the same time, visible damage decreased from 4.5 to 2.0 and from 5.0 to 0.75 (Fig. 2), which also indicated a marked increase in cold hardiness.

From the fifth week on, the -9°C freezing treatment did not damage either black spruce or white spruce, as measured by the relative conductivity method, although some visible damage occurred up to the fifth week after short-day treatment began. These two assessment methods were strongly correlated (r = 0.935, P <0.01) (Fig. 3).

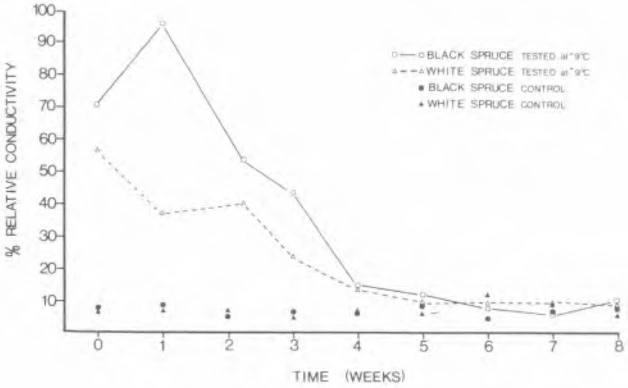


Figure 1. Development of cold hardiness as measured by relative conductivity in black spruce and white spruce under short-day (8-hr) treatment.

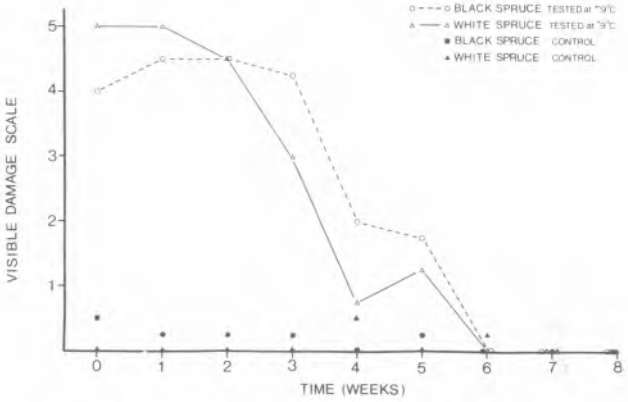


Figure 2. Development of cold hardiness as measured by visible damage in black spruce and white spruce under short-day (8-hr) treatment.

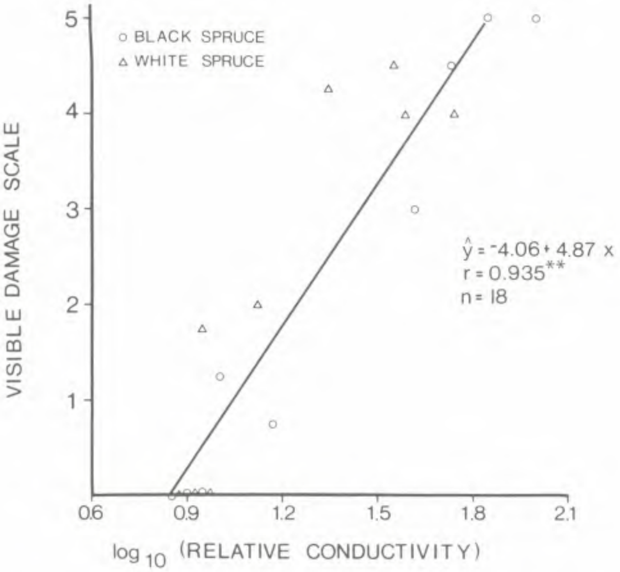


Figure 3. Relationship between relative conductivity and visual assessments of freezing damage in black spruce and white spruce.

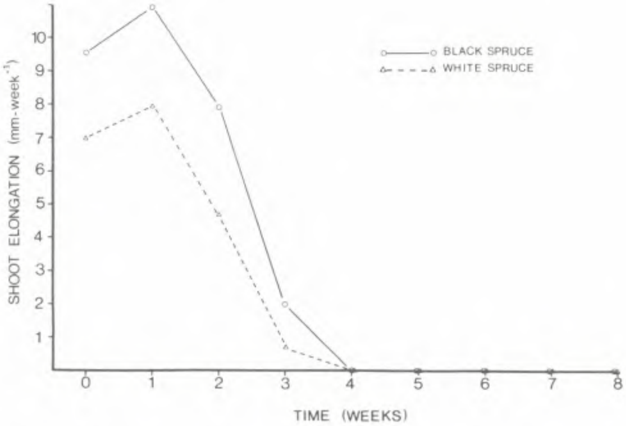


Figure 4. Shoot elongation in black spruce and white spruce under short-day (8-hr) treatment.

The pattern of shoot elongation in most cases resembled that of relative conductivity (r = 0.938, P <0.01) (Fig. 4 and 5). Shoot elongation decreased after week 1 and, by week 4, had ceased in both black spruce and white spruce.

Bud development in both species was initiated in the first week of short-day exposure. Budscale formation was complete within two weeks, by which time 33 needle primordia (16% of the final number) had formed in black spruce, and 40 primordia (22%) had formed in white spruce (Fig. 6). Needle primordia were rapidly initiated between weeks 2 and 5. By week 5, 173 primordia (83% of the final primordia complement) had formed in black spruce and 165 primordia (90%) had formed in white spruce. After week 5, primordia were produced more slowly so that by the end of the

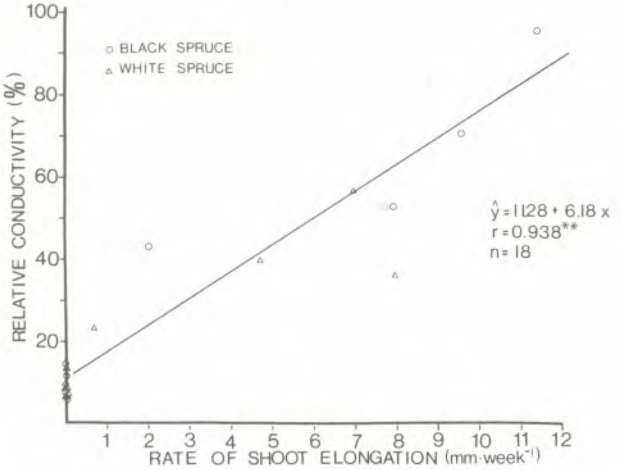


Figure 5. Correlation between relative conductivity and rate of shoot elongation in black spruce and white spruce under short-day (8-hr) treatment.

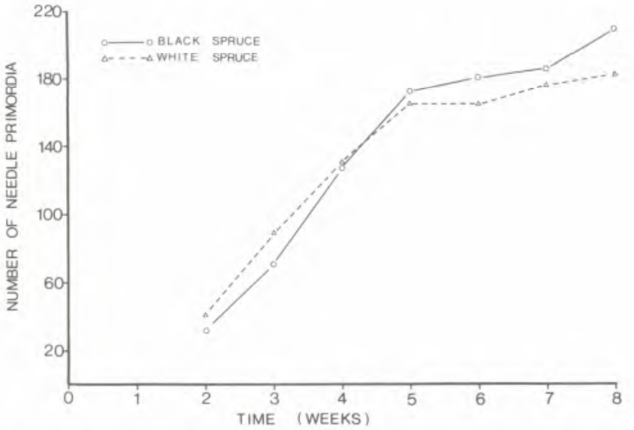


Figure 6. Needle primordia initiation in black spruce and white spruce under short-day (8-hr) treatment.

eighth week the complement of needle primordia was 209 in black spruce and 182 in white spruce. Development of needle primordia in both species was negatively correlated ($r = -0.937$, $P < 0.01$) with relative conductivity (Fig. 7).

Seedlings of both species exposed to eight weeks of short days in growth cabinets produced large apical meristems with many needle primordia (Fig. 8a). In comparison, the apical meristems of production-run black spruce container seedlings were small and, on average, produced only 95 needle primordia (Fig. 8b) (Colombo and Glerum 1982).

DISCUSSION

Photoperiod and temperature are two major environmental factors influencing cold hardiness development in conifers (Aronsson 1975, Glerum 1976, Christersson 1978). In the present experiment, cold hardiness increased in both species after two weeks of exposure to 8-hr days. After six weeks all seedlings were hardy to at least -9 C, the limit of the present test. Christersson (1978) found that, in Norway spruce *(Picea abies* [L.] Karst.), six weeks of short days and warm temperatures (20 C) induced cold hardiness to -16 C without visible damage. Since damage in the present test was not observed in either black spruce or white spruce exposed to -9 C after six weeks of short days, the seedlings may well have been hardy to a temperature similar to that found by Christersson.

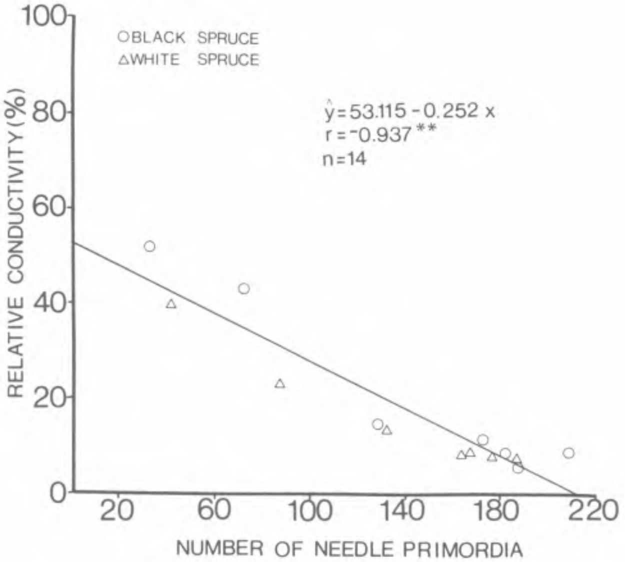


Figure 7. Correlation between relative conductivity and number of needle primordia in black spruce and white spruce under short-day (8-hr) treatment.

The electrical conductivity method could be a useful tool of the container nurseryman for making operational decisions concerning the cold hardiness of his stock, since the state of cold hardiness was obtained as reliably ($r = 0.934$) using conductivity measurements as with visible damage assessments. Similar correlations between the electrical conductivity and visible damage assessment methods have been shown for Scots pine *(Pines sylvestris* L.) (Aronsson and Eliasson 1970) and radiata pine *(Pinus radiata* D. Don) (Green and Warrington 1978). Conductivity has also been used as a measure of cold hardiness in Norway spruce (Aronsson 1975) and Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) (van den Driessche 1969, 1976).

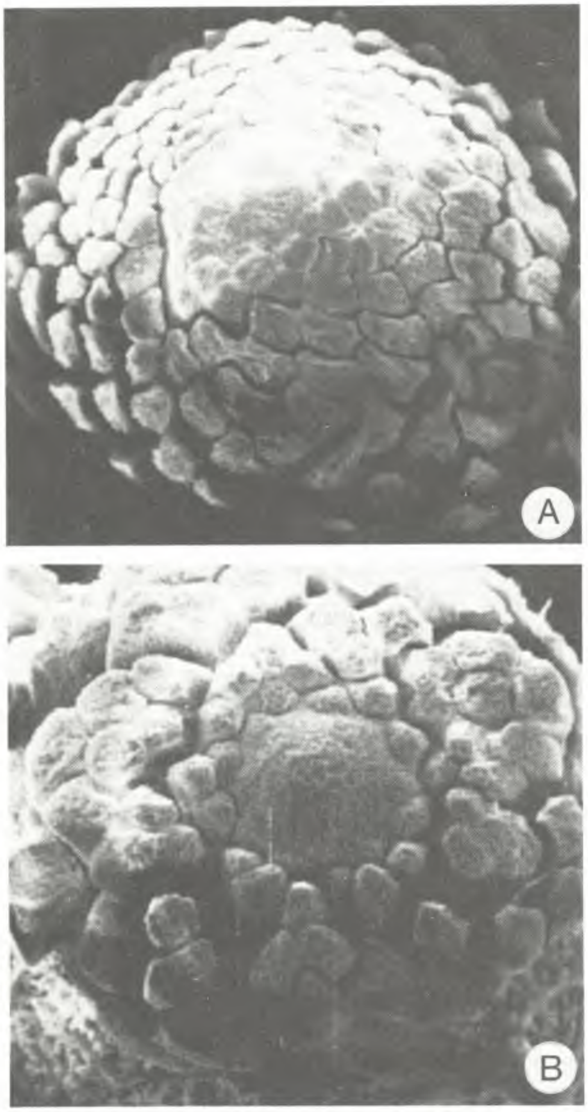


Figure 8. Representative bud development in black spruce seedlings: (A) after eight weeks of short day (8 hr) treatment (72x) and (B) from a production-run overwintering bed (98x).

Shoot elongation and bud development were equally good indicators of the state of cold hardiness (r = 0,938 and 0.937), and may be useful for predicting the initial development of cold hardiness in black spruce and white spruce seedlings in the container nursery. Shoot elongation measurements are simple to perform, but provide information for only the first few weeks of cold hardiness development. Bud development gives an indication of cold hardiness beyond the time when shoot elongation ceases, but is less easily determined. The relationship of cold hardiness to shoot elongation and bud development is now being investigated under operational conditions, to determine whether under different environmental and nutritional regimes these correlations remain strong.

Although not examined in this experiment, short-day pretreatment followed by periods of low temperature and frost is one method of achieving maximal cold hardiness (Timmis and Worrall 1975). While low temperature exposure preceding or during short-day treatment can likewise result in maximal cold hardiness (Timmis and Worrall 1975, Christersson 1978), this treatment will inhibit bud development (Heide 1974, Pollard and Logan 1977, 1979). In Ontario, container seedlings are placed outside for overwintering without the benefit of short-day treatment. In this instance, not only are seedlings susceptible to damage by freezing temperatures which commonly occur in late summer in northern Ontario, but bud development may be reduced by temperatures below the optimum. In the experiment reported in this paper, production-run black spruce seedlings formed less than half as many needle primordia as were formed in controlled environmental conditions, apparently because bud development was reduced by low outdoor temperatures.

It is recommended that seedlings grown in greenhouses be exposed to short, warm days before being put outside in the fall. This would allow buds to develop large numbers of needle primordia, while cold hardiness could increase without the risk of freezing damage.

Short, warm days can be achieved artificially, when natural daylengths would otherwise allow continued shoot elongation, by shading seedlings in the greenhouse for a period of four to six weeks, after which the seedlings can be moved outside. Alternatively, cold hardiness and bud development can be promoted without shading, by leaving seedlings in a heated greenhouse later in the fall (Sandvik 1980), under naturally declining daylengths. In northern Ontario bud development in extended greenhouse culture is largely completed between late September and early October (Colombo, unpublished data), at which time temperatures in the greenhouse can be gradually lowered to promote greater levels of cold hardiness, before seedlings are put outside.

ACKNOWLEDGMENTS

Dr. J. Percy and Dr. A. Retnakaran of the Forest Pest Management Institute, Canadian Forestry Service, assisted with sample preparation for electron microscopy. Electron photomicrographs were made by Dr. P. Roberts of the Ontario Ministry of the Environment. Technical assistance was provided by D. Marles and R.M. Siltanen of the Great Lakes Forest Research Centre.

LITERATURE CITED

Aronsson, A.
1975. Influence of photo- and thermoperiod on the initial stages of frost hardening and dehardening of phytotron-grown seedlings of Scots pine *(Pinus silvestris* L.) and Norway spruce *(Picea abies* [L.] Karst.). Stud. For. Suec. 128. 20 p.

Aronsson, A. and Eliasson, L.
1970. Frost hardiness in Scots pine *(Pinus silvestris* L.). I. Conditions for test on hardy plant tissues and for evaluation of injuries by conductivity measurements. Stud. For. Suec. 77. 30 p.

Aronsson, A., Ingestad, T. and Goran Loof, L.
1976. Carbohydrate metabolism and frost hardiness in pine and spruce seedlings grown at different photoperiods and thermoperiods. Physiol. Plant. 36:127-132.

Christersson, L.
1978. The influence of photoperiod and temperature on the development of frost hardiness in seedlings of *Pinus* silvestris and Picea abies.Physiol. Plant. 44:288-294.

Colombo, S.J. and Glerum, C.
1982. Bud development in black spruce container stock. Ont. Min. Nat. Resour., For. Res. Note. (In press).

Dexter, S.T., Tottingham, W.E. and Graber, L.F.
1932. Investigations of the hardiness of plants by measurement of electrical conductivity. Plant Physiol. 7:63-78.

Glerum, C.
1976. Frost hardiness of forest trees. p. 403-420 *in* M.G.R. Cannell and F.T. Last, *Ed.* Tree Physiology and Yield Improvement. Academic Press, New York.

Green, L.M. and Warrington, I.J.
1978. Assessment of frost damage in radiata pine seedlings using the diffusate electroconductivity technique. N. Z. J. For. Sci. 8:344-350.

Gregory, R.A.
1980. Annual cycle of shoot development in sugar maple. Can. J. For. Res. 10:316-326.

Heide, O.M.
1974. Growth and dormancy in Norway spruce ecotypes. II. After effects of photoperiod and temperature on growth and development in subsequent years. Physiol. Plant. 31:131-139.

Hocking, D.
1971. Preparation and use of a nutrient solution for culturing seedlings of lodgepole pine and white spruce. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-1.

Pollard, D.F.W.
1973. Provenance variation in phenology of needle initiation in white spruce. Can. J. For. Res. 3:589-593.

Pollard, D.F.W.
1974. Bud morphogenesis of white spruce *Picea glauca* seedlings in a uniform environment. Can. J. Bot. 52:1569-1571.

Pollard, D.F.W. and Logan, K.T.
1977. The effects of light intensity, photoperiod, soil moisture potential, and temperature on bud morphogenesis in *Picea* species. Can. J. For. Res. 7:415-421.

Pollard, D.F.W. and Logan, K.T.
1979. The response of bud morphogenesis in black spruce and white spruce provenances to environmental variables. Can. J. For. Res. 9:211-217.

Sandvik, M.
1980. Environmental control of winter stress tolerance and growth potential in seedlings of *Picea abies* [L.] Karst. N. Z. J. For. Sci. 10:97-104.

Timmis, R. and Worrall, J.
1975. Environmental control of cold acclimation in Douglas fir during germination, active growth, and rest. Can. J. For. Res. 5:464-477.

Timmis, R.
1976. Methods of screening tree seedlings for cold hardiness. p. 421-435 in M.G.R. Cannell and F.T. Last, *Ed.* Tree Physiology and Yield Improvement. Academic Press, New York.

van den Driessche, R.
1969. Measurement of frost hardiness in two-year-old Douglas fir seedlings. Can. J. Plant. Sci. 49:159-172.

van den Driessche, R.
1976. Prediction of cold hardiness in Douglas fir seedlings by index of injury and conductivity methods. Can. J. For. Res. 6:511-515.

ENVIRONMENTAL CONTROL OVER THE SHOOT GROWTH OF PINE SEEDLINGS

S. Thompson[1]

Abstract.--In 1-0 Scots pine (*Pinus sylvestris* L.), shoot morphology and second season shoot growth potential are predetermined largely by date of budset and cessation of shoot elongation. They can be manipulated by photoperiod and temperature to produce seedlings of saleable size, uniform morphology and good potential for growth during their second season.

Résumé.--Chez le pin sylvestre (*Pinus sylvestris* L.) 1-0, la morphologie de la pousse et le potentiel de croissance de la pousse lors de sa deuxième année sont fortement prédéterminés par la date de la formation des bourgeons et de la cessation de la croissance des pousses. On peut influer sur eux en faisant varier la photopériode et la température pour produire des semis commercialisables, une morphologie uniforme et un bon potentiel de croissance pendant la deuxième année.

Through the use of containerized seedlings we can look forward to the day when planting survival is 100% and transplant shock no longer reminds us of how badly we have performed the transfer of the seedling from nursery to forest. Then it will be prudent to raise pine seedlings which, because of the high number of stem units (primordia) they hold at their apex, are predisposed to make good height growth during their first season in the forest.

The first season in the life of a north temperate pine is unique for it is the only time when the shoot growth of two seasons is determined by a single period of activity at the apical meristem. Consequently, the nurseryman has the ability to control 1-0 seedling height as well as the potential (based on the number of stem units held at the apex) for shoot growth during the seedling's first season in the forest.

The shoot apical meristem which produces the stem units for shoot elongation first becomes active during germination (Cecich and Horner 1977), but several weeks pass before shoot elongation starts. Until then the stem units are accumulated in the rosette (Thompson 1976). Under natural conditions the consumption of stem units in shoot elongation is outpaced by their production at the apical meristem so that the rosette is retained at the shoot apex throughout the first growing season. Shoot elongation ceases at budset and the seedlings then have the typical one-year-old shoot morphology (Type 1: Thompson 1981). This is characterized by the presence of a terminal rosette of primary needles at the centre of which is a bud of variable size. The stem bears primary needles with few axillary secondary needles. After a period of winter dormancy the stem units in the rosette and the bud elongate to form the second-year shoot (Thompson 1976).

When north temperate pine seedlings are raised outdoors, their first season height growth is limited by low temperatures, low soil fertility, moisture stress, etc. To reduce these limitations and produce seedlings of saleable size more quickly, many nurserymen have invested in structures within which the growing environment may be controlled to varying degrees (Tinus and McDonald 1979). When reared under increased temperatures and long photoperiods, seedlings of north temperate pines show increased rate of stem unit elongation. However, since stem unit consumption then outpaces stem unit production, budset occurs earlier; consequently, shoot growth ceases early and overall height growth

---

[1] Research Officer, Department of Forestry, University of Aberdeen, Old Aberdeen, Scotland.

is reduced. If they are retained in the same environment after budset these seedlings develop a shoot morphology similar to that of two-year-old plants (Type 2: Thompson 1981). This is characterized by the presence of a terminal resting bud (containing a series of structures similar to those of mature trees) with a whorl of lateral buds. Almost all the primary needles on the upper part of the shoot have axillary secondary needles which are of similar length.

If Type 2 seedlings are maintained in an environment in which growing conditions are not limiting the terminal bud will eventually flush, elongate the stem units it contains and then form another terminal bud. It is not known how long this recurrent flushing phase can be maintained. After 42 weeks with a 16-hour photoperiod and a minimum temperature of 21.1 °C, Downs and Borthwick (1956) showed that Scots pine *(Pinus sylvestris* L.) of Swedish origin flushed twice, increasing their height by up to four times that at the end of the first shoot elongation period. In ponderosa pine *(P. ponderosa* Dougl.) recurrent flushing is the accepted mode of growth to obtain the desired height specifications for containerized seedlings (Tinus and McDonald 1979).

The thesis of this paper is that pine seedlings with a Type 2 shoot morphology, with or without recurrently flushed shoots, are biologically less desirable than those with a Type 1 one-year-old morphology. This conclusion is based on consistent results from several studies on Scots pine. Briefly, these studies have shown that shoot elongation started earlier, buds set earlier and shoot elongation ceased sooner in Type 2 seedlings than in Type 1 seedlings (Table 1). After one growing season Type 2 seedlings were shorter, retained fewer stem units for elongation in the second season but carried a greater foliage biomass than Type 1 seedlings. After two growing seasons, seedlings which had a Type 1 morphology remained taller than those which had a Type 2 morphology. We accept that this material has not been tested under forest conditions but it is predicted that the advantages held by the Type 1 seedlings will be maintained if not increased in subsequent years after outplanting.

Several workers have shown that shoot morphology in Scots pine seedlings can be modified by photoperiod (Wareing 1950, Downs and Borthwick 1956) and temperature (Denne 1971, Gowin *et al.* 1980). Similar studies have been carried out at Aberdeen to examine

Table 1. Differences in some components of shoot growth in Scots pine seedlings raised for 26 weeks in a heated, naturally lit greenhouse[a].

Parameter	Age (Years)	Sample No.	Shoot Type		Significance level[b]
			Type 1	Type 2	
Seedling height (mm)	1	280	196	161	**
Seedling height (mm)	2	120	451	400	**
Weeks to budset	1	280	13.9	10.5	**
Stem unit number	1	280	135	104	**
Stem unit number	2	280	203	146	**
Stem unit length (mm)	1	280	1.13	1.19	ns
Stem unit length (mm)	2	120	1.38	1.75	**
Primary needle dry wt (g)	1	160	1.19	0.67	**
Secondary needle dry wt (g)	1	160	0.93	1.80	**

[a] See Thompson (1981) for more complete details
[b] ns - not significant; ** - significant at the $\alpha = 0.01$ level

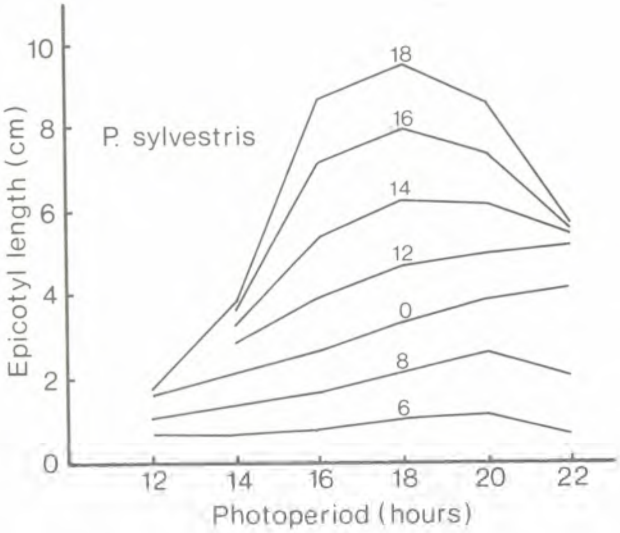


Figure 1. The effect of photoperiod on epicotyl length of Scots pine seedlings measured at 2-week intervals. (All plants received 12 hours of warm white fluorescent and incandescent light at a photon flux density of 95 mol m^{-2} s^{-1}. The photoperiodic supplements were provided by tungsten bulbs at a photon flux density of 6 mol m^{-2} s^{-1}. The day/night air temperature was 25/15°C).

more closely the effects of daylength and temperature on shoot morphology of Scots pine. When we repeated the work of Wareing (1950) we found that first season shoot elongation was most prolonged under a photoperiod of 18 hours and produced the tallest seedlings at 18 weeks after germination (Fig. 1). This was not so at 10 weeks when seedling height increased with increasing photoperiod (up to 22 hours). However, seedlings raised under a photoperiod of 22 hours had already set buds and in the following weeks they developed a Type 2 shoot morphology. At 10 weeks the seedlings raised under a photoperiod of 12 hours had also set buds but since stem unit elongation had also stopped they retained a Type 1 shoot morphology. At 18 weeks, 75% of the seedlings reared under a photoperiod of 18 hours had set buds but, since photoperiod was not limiting, shoot elongation continued to use up the stem units in the rosette. To retain Type 1 morphology a limiting factor must be introduced. Photoperiods of less than 12 hours' duration quickly induce the cessation of shoot elongation.

The effect of temperature on shoot growth morphology has also been studied. Under an 18-hour photoperiod, Scots pine seedlings were raised for 24 weeks from germination in 16 combinations of day and night temperature. At 8 weeks, for each day temperature treatment, epicotyl length increased with each increase in night temperature (Table 2). At 24 weeks, however, because of early budset under the 20 C night temperature treatments (Table 3), maximum seedling height in the day temperature treatments was at a night temperature of 15 C (Table 2). As in the photoperiod study above, shoot morphology was closely associated with time of budset. All the 20 C night temperature treatments, which had the earliest appearance of a terminal bud (Table 3), had high percentages of seedlings with a Type 2 or related shoot morphology (Table 4). Since no limiting factors were introduced during this experiment, many of the Type 2 seedlings, particularly in the 30/20 C day/night treatment, flushed their terminal buds. Some even flushed twice. The lack of limiting factors also allowed continued shoot elongation after budset in the Type 1 seedlings, which used up the stem units in the rosette. Although these seedlings produced many axillary secondary needles they did not develop the whorl of lateral buds characteristic of Type 2 seedlings.

Table 2. Epicotyl length as a percentage of the maximum attainable[a] in Scots pine seedlings raised under 16 day/night temperature combinations (n = 28).

Age (weeks)	Day temp. (°C)	Night temp. (°C)			
		5	10	15	20
8	15	14	19	36	52
	20	21	32	52	78
	25	28	42	75	100
	30	31	40	66	84
24	15	34	52	71	67
	20	45	68	89	70
	25	49	78	100	78
	30	58	86	100	68

[a] week 8 max = 31.9 mm; week 24 max = 131.9 mm

Table 3. Time to budset (weeks) for Scots pine seedlings raised under 16 day/night temperature combinations (n = 28).

Day temp. (°C)	Night temp. (°C)			
	5	10	15	20
15	16.6	17.1	14.1	11.8
20	14.5	14.8	13.5	9.9
25	14.9	14.1	12.4	9.2
30	14.6	14.4	14.4	9.1

Table 4. Percentage of Scots pine seedlings with a Type 1 or similar morphology at 24 weeks when raised under 16 day/night temperature combinations (n = 28).

Day temp. (°C)	Night temp. (°C)			
	5	10	15	20
15	100	96	80	31
20	100	100	82	15
25	100	100	79	19
30	100	96	81	7

From the evidence cited earlier it is clear that the production of Type 2 seedlings is undesirable and should be avoided. Therefore, nurserymen must develop rearing schedules that prevent the induction of early budset which would result if stem unit consumption and shoot elongation outpaced stem unit production by the apical meristem. Long photoperiods (the effect of interrupted nights has not yet been studied) and warm nights should be avoided. For the Scots pine source used in the above studies, seedlings about 15 cm tall with a Type 1 shoot morphology could be produced under a day/night temperature regime of 25/15°C with an 18-hour photoperiod until budset when a 12-hour photoperiod would be applied to stop shoot elongation. Different seed sources are likely to require different regimes to produce saleable seedlings. At Aberdeen, seedlings satisfying the same criteria can be produced in a greenhouse maintained at 25/15°C if the seeds are sown in late May and the naturally declining daylength is used to arrest shoot elongation (Thompson, unpublished data).

Clearly the same goal can be reached by different means. Difficulties will arise when nurserymen want to produce several crops in one year. Research is needed into methods of achieving dormancy and cold-hardiness that will ensure normal seedling growth in the second year, i.e., all apical stem units elongate to the same length as those of seedlings overwintered naturally outdoors.

The production of seedlings with a Type 1 shoot morphology will result in greater uniformity of product which will convey to the purchaser an impression of quality control. Type 1 seedlings, in addition to their greater second-season shoot growth potential, have a more uniform growth potential because they retain a continuum of stem units from the apical meristem to the base of the rosette. Type 2 plants lack synchrony when they start recurrent flushing (Downs and Borthwick 1956). Hence, when treatments are applied to stop height growth, the number of stem units at the apex will vary depending on the time elapsed since the previous flushing. The concept of "building a bud" must have evolved under such conditions. The uniformity of shoot growth potential in treatments which have greatly altered 1-0 seedling height (Thompson and Biggin 1980) suggests that this concept does not apply in the production of pine seedlings with a Type 1 shoot morphology.

Only when the problems of seedling survival and transplant shock have been overcome will the production of seedlings, which are predisposed to make good height growth during their first season in the forest, become a biologically and economically worthwhile objective. Through an understanding of the growth responses of pine seedlings to environmental inputs, the nurseryman will be better equipped to supply what the forester demands.

LITERATURE CITED

Cecich, R.A. and Horner, H.T., Jr.
1977. An ultrastructural and microspectrophotometric study of the shoot apex during the initiation of the first leaf in germinating **Pinus banksiana**. Am. J. Bot. 63(2):207-222.

Denne, M.P.
1971. Temperature and tracheid development in **Pinus sylvestris** seedlings. J. Exp. Bot. 22:362-370.

Downs, R.J., and Borthwick, H.A.
1956. Effects of photoperiod on growth of trees. Bot. Gaz. 117:310-326.

Gowin, T., Louritioux, A. and Mousseau, M.
1980. Influence of constant growth temperature upon the productivity and gas exchange of seedlings of Scots pine and European larch. For. Sci. 26(2):301-309.

Thompson, S.
1976. Some observations on the shoot growth of pine seedlings. Can. J. For. Res. 6:341-347.

Thompson, S.
1981. Shoot morphology and shoot growth potential in one-year-old Scots pine seedlings. Can. J. For. Res. 11:789-795.

Thompson, S, and Biggin, P.
1980. The use of clear polythene cloches to improve the growth of one-year-old lodgepole pine seedlings. Forestry 53 (1):51-63.

Tinus, R.W. and McDonald, S.E.
1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv., Rocky Mt. For. Range Exp. Stn., Fort Collins, Colo., Gen. Tech. Rep. RM-60. 256 p.

Wareing, P.F.
1950. Growth studies in woody species. I. Photoperiodism in first-year seedlings of *Pinus sylvestris* L. Physiol. Plant 3:258-276.

MYCORRHIZAL DEVELOPMENT ON CONTAINERIZED TREE SEEDLINGS

C.-Gilles Langloisl and J.-Andre Forting

Abstract.--Beneficial effects of ectomycorrhizal infection are demonstrated. At present the ability to increase production of mycorrhizal containerized tree seedlings depends on inoculum availability and effective control of cultural conditions. Efforts in these directions should lead to the production of plantable seedlings equipped with absorbing rootlets that are asssociated with selected fungi, thereby contributing to morpho-physiological quality and survival rate.

Résumé.--Cette communication fait ressortir les effets bénéfiques de l'infection ectomycorhizienne. À l'heure actuelle, la capacité d'accroître la production de semis mycorhizés d'arbres en mottes emballées dépend de la disponibilité de l'inoculum et de la maîtrise des conditions de culture. Les efforts en ce sens devraient aboutir à la production de semis plantables dont les radicelles absorbantes sont associées à des champignons sélectionnés, ce qui améliorera leur qualité morphophysiologique et augmentera leur taux de survie.

INTRODUCTION

The use of containerized tree seedlings is evolving rapidly and their production presents few problems when they are given optimal growth conditions, generously fertilized and cautiously protected by biocide treatments (Waldron 1972, Tinus et al. 1974, Tinus and McDonald 1979, Anon. 1980).

Although it is possible to surpass nature in the initial greenhouse growth period, it is after outplanting that seedlings find themselves in ecologically different environments to which they have to adapt if they are to survive (Baker 1972, Tinus 1974, Sutton 1979, van den Driessche 1980).

Field survival rates of tree seedlings are frequently lower than expected. It has been suggested that this may be due to the non-mycorrhizal nature of outplanted seedlings (Mikola 1973, Marx 1977, Cordell and Marx 1980).

The first objective of this paper is to describe the nature of the ectomycorrhizal relationship under natural conditions. The difference between the feeder roots of forest-grown and container-grown seedlings will be described, and the advantages of ectomycorrhizae will be explained briefly by an examination of their structure.

Secondly, the feasibility of producing healthy containerized seedlings bearing mycorrhizae will be illustrated and the results of successful experiments with different tree species and ectomycorrhizal strains will be reported. Desirable cultural conditions will be presented, the use of biocides commented on and the importance of strain selection and type of inoculum underlined.

Experiments on jack pine *(Pinus banksiana* Lamb.) conducted by the authors will be reported, and the importance of fertilizer balance during seedling production will be stressed. Special consideration will be given to the description and measurement of

---

[1] Ingénieur forestier, Division des Pépinières, Ministère de l'Energie et des Ressources (MERQ), Québec, Qué.

[2] Professeur, Faculté de foresterie, Université Laval, Ste-Foy, Qué.

nutrient availability in the substrate as well as to the addition of fertilizers.

Finally, considerations of container size, species, phenology and mycorrhization will be discussed along with an example showing that the precise qualification of fertilizer added can be achieved even on a production scale.

NATURE OF ECTOMYCORRHIZAE

Ecological Considerations

In nature, newly emerging roots become living elements among beneficial, neutral and detrimental organisms in the soil. They participate in soil dynamics and are influenced to a great degree by their environment (Dommergues and Krupa 1978, Krupa and Dommergues 1979).

Ecological studies of the root systems of a number of tree species indicate that the absorbing roots are associated with soil bacteria and fungi (Imshenetskii 1955, Shemakhanova 1962, Riedacker and Gagnaire-Michaud 1978). If the bacteria and fungi are virulently pathogenic, the root will struggle until senescence or death. On the other hand, if they are of a symbiotic nature, as are the mycorrhizal fungi, the root will live in harmony and remain functional for some time. The lifespan of an ectomycorrhiza may be one or two years, depending on environmental conditions (Meyer 1973, Harvey et al. 1980). Consequently, the balance between favorable and unfavorable associations of seedling rootlets greatly influences the establishment, growth, and development of trees in the field.

When the radicle emerges in an artificial substrate, such as is used in container production, it develops under privileged conditions. It successively produces roots of the second and third order, which support their uninfected, absorbing short roots and very often bear root hairs. These tender roots, succulent and unprotected, are very efficient in this particular environment. However, they are very different, both morphologically and physiologically, from those of seedlings developing under natural conditions (Boullard 1968, Harley 1969, Marks and Kozlowski 1973, Smith 1980).

During cultivation of seedlings, fertility levels are often optimized, biocides are regularly used and the substrates contain virtually no ectomycorrhizal fungi. As a result, the root systems of containerized seedlings are, ecologically speaking, deficient in ectomycorrhizae (Fortin 1972, Marx and Barnett 1974, Zak 1975) (Fig. 1).

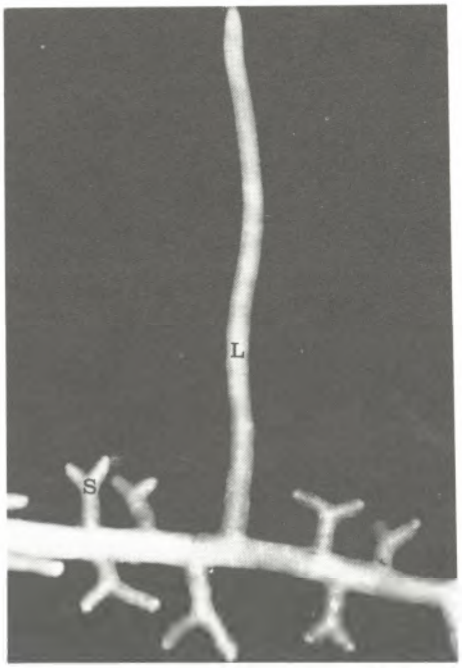


Figure 1. Long lateral roots (L) and non-mycorrhizal dichotomous short roots (S) of jack pine seedlings grown in containers.

At the forest seedling production level, it seems desirable to imitate nature as much as possible, especially if the seedlings are to be planted on all kinds of sites, more or less disturbed, for which it is difficult to predict the survival rate.

For the shoot, it is possible and even desirable to induce bud formation during the last weeks of the growth period (Tinus 1974, Sutton 1979). This is achieved by modifying fertilization regime, reducing watering and, when feasible, shortening the photoperiod and decreasing the temperature.

Similarly, it is possible and desirable to fit the root system with efficient absorbing structures, i.e., with ectomycorrhizae (Mikola 1973).

Advantages to Seedlings

Nutrient absorption and photosynthesis are interrelated processes necessary to maintain seedling growth. Consequently, soon after outplanting, the plant roots must explore the soil in search of mineral nutrients. If the absorbing roots are associated with ectomycorrhizal fungi the seedling benefits from nutritional, metabolic and prophylactic advantages (see below) (Harley 1969, Bowen 1973, Marks and Kozlowski 1973, Mark 1978) which will be reflected by increased survival rates and earlier growth responses.

Nutritional advantages

- Increased absorbing area of roots
- Availability of nutrients from a larger soil volume
- Improved competitiveness with soil microorganisms and other plants for water and nutrients
- Presence of phosphatase and/or nitrate reductase (in some ectomycorrhizal fungi)
- Improved absorption of $PO4^{--}$, Ca^{++}, le, Rb^{+}, Cl^{-}, $SO4^{--}$, Na^{t}, NO_3^{-}, $NH4^{++}$, Mg^{+}, Fe^{++}, Zn^{++}.

Metabolic advantages

- Provision of growth-regulating substances, such as vitamins and hormones, to the plant
- Excretion of many substances to create a selective microenvironment
- Assistance to the fungus in its metabolic functions by organisms living in the mycorrhizosphere.

Prophylactic advantages

- Excretion of volatile substances which select the microflora by their toxicity
- Production of antibiotics by some ectomycorrhizal fungi, which adds to the selective pressure in their vicinity
- Presence of a fungal mantle that acts as a protective barrier against some pathogenic infection
- Utilization of root exudates by the fungal associate and the mycorrhizospheric microflora, which limits their availability to soil pathogens
- Detoxification by some ectomycorrhizal fungi of the phytotoxins often present in soils
- A decrease in the detrimental effects of soil nematodes and other root pathogens in the presence of some ectomycorrhizal fungi.

Field studies conducted throughout the world have demonstrated the superiority of mycorrhizal over non-mycorrhizal seedlings (Anon. 1981, Furlan and Fortin 1981, Hacskaylo and Tompkins 1973). In North America, the Institute for Mycorrhizal Research and Development at Athens, Georgia, has a staff of experts who have evaluated field performance of mycorrhizal seedlings for many years. They state that "increases in tree survival and growth of over 25 percent have been obtained on a variety of forestation sites... routine, coal, and kaolin spoils, etc. in scattered locations in U.S.A." (Cordell and Marx 1980).

Structure and Function

An examination of the structure of an ectomycorrhiza (Fig. 2 and 3) indicates how a fungus associated with the feeder roots may help the root system to establish itself and to function more efficiently. When the hyphae of the fungal sheath of each ectomycorrhiza radiate into the soil, the surface contact area is increased considerably and a much larger soil volume is utilized. By thus increasing the absorbing area and reducing the space between the roots, the fungal hyphae are able to compete successfully with microorganisms and other plants for the available water and nutrients (Bowen 1973, Rambelli 1973), even if expansion of the root system is restricted.

Ectomycorrhizal fungi conduct toward the root system the products of their absorption (Harley 1969) and also some metabolites (Slankis 1973), by means of a network of mycelial strands extended throughout the soil (Fig. 4 and 5). Consequently, if one wishes to maximize the beneficial effects of ectomycorrhization, it is desirable to colonize the seedling feeder roots with fungal strains selected for their nutritional and metabolic characteristics (Trappe 1977).

It is also a great advantage for the feeder roots to be protected by the fungal sheath of the mycorrhizal fungus before outplanting (Zak 1964, Marx 1973). Once in the field, uninfected feeder roots soon encounter the native flora of the soil, among which many kinds of fungi are more or less pathogenic and can certainly retard the establishment of the seedling.

Rapid colonization of the substrate by the hyphae of the mycorrhizal fungus, increased efficiency and absorbing area, protection of the feeder roots and other advantages explain to a large degree why mycorrhizal seedlings should be outplanted if higher survival rates and more rapid growth responses are to be achieved.

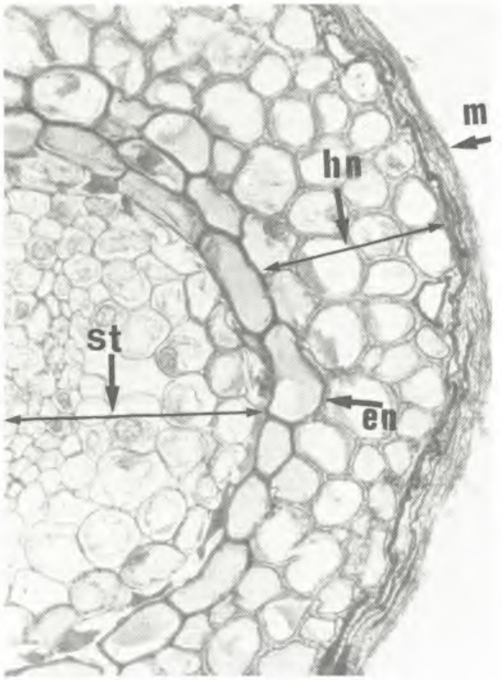


Figure 2. Transverse section showing the stele (st), the endoderma (en), the hartig net (hn) and the fungal mantle (m) of an ectomycorrhiza on balsam fir.

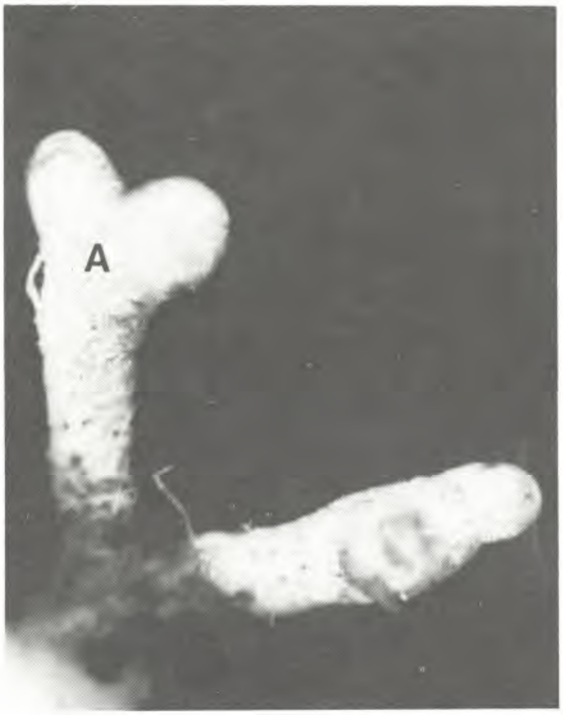


Figure 3. Dichotomous ectomycorrhizae produced in container after inoculating with *Pisolithus tinctorius* (A).

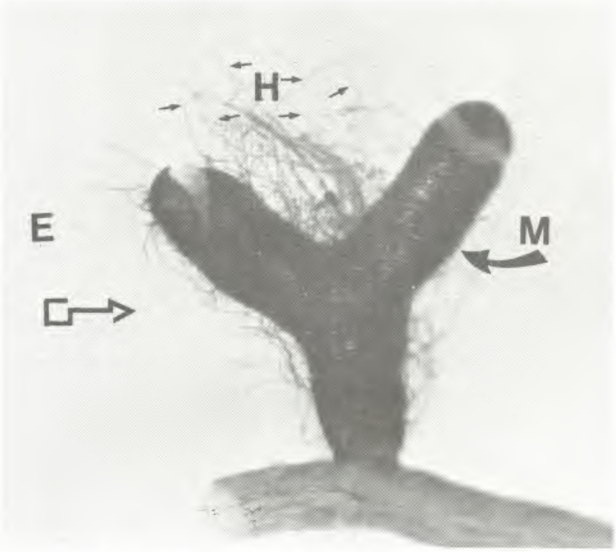


Figure 4. The feeder roots of jack pine showing dichotomous ectomycorrhizae (E), fungal mantle (M) and extramatrical hyphae (H).

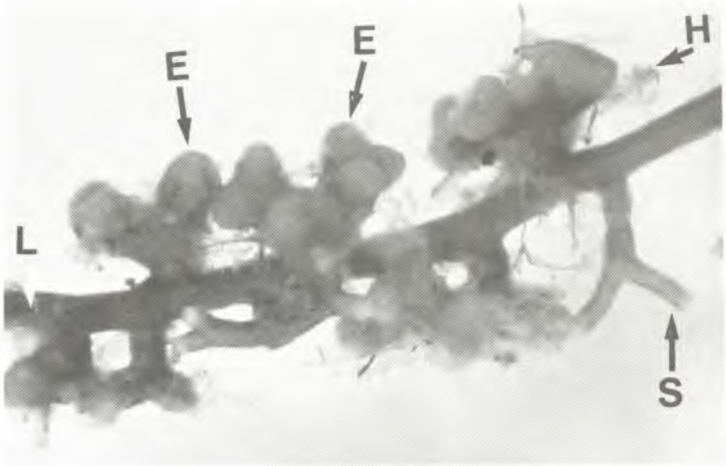


Figure 5. Segment of long lateral root (L) of jack pine bearing coralloid ectomycorrhizae (E) with extramatrical hyphae (H) and also nonmycorrhizal short roots (S).

FEASIBILITY OF MYCORRHIZATION IN CONTAINERS

Tree Species and Fungal Strains Tested

It has been adequately demonstrated that mycorrhization can be induced in containers (Marx and Barnett 1974, Richard 1975, Zak 1975, Landis and Gillman 1976, Ruehle and Marx 1977, Navratil 1978, Cordell and Marx 1979, 1980, Maronek and Hendrix 1979, 1980, Molina 1979, 1980, Ruehle 1980a, b, Anon.

1981, Ruehle et al. 1981). Mycorrhizae have been successfully induced on the following tree species:

- *Cedrus atlantica* Manetti
- *Liquidambar styraciflua L.*
- *Picea abies* (L.)Karst.; *engelmannii* Parry; *glauca* (Moench) Voss; *mariana* (Mill.) B.S.P.; *sitchensis* (Bong.) Carr.
- *Pinus aristata* Engelm.; *banksiana* (Lamb.); *caribaea* Morelet; *clausa* (Chapm.) Vasey; *contorta* Dougl.; *echinata Mill.; elliottii* Little and Dorman; *flexilis* James; *halepensis Mill.; kesya* Royle and Gordon; *merkusii* Jungh and De Vries; *nigra* Arnold; *oocarpa* Schiede; *palustris* Mill.; *pinaster* Soland.; *ponderosa* Laws.; *rigida Mill.; Mill.; sylvestris* L.; *taeda* L.
- *Pseudotsuga menziesii* (Mirb.) Franco
- *Quercus alba L.; macrocarpa* Michx.; *palustris* Muenchh.; *robur* L.; *rubra* L.; *velutina* Lam.
- *Tsuga heterophylla* (Raf.) Sarg.

Cultural Conditions

Unfortunately, most of the experiments on ectomycorrhizae performed in various parts of the world were not conducted under standard conditions. It is understandable that investigators interested in different aspects of mycorrhization worked with different tree species and fungal strains, but the cultural procedures also varied according to container size, substrate composition, fertilization regimes, etc. (Waldron 1972, Tinus et al. 1974, Carlson 1979, Tinus and McDonald 1979); consequently, it is difficult, if not impossible, to determine from the literature the proper methods for producing mycorrhizal containerized seedlings on a large scale.

The following fungal strains have been tested (asterisks indicate relative frequency of use):

Agaricus sylvaticus (Fr.) Secr.; *Amanita pantherina* (D.C. ex Fr.) Schumm.
Astraeus pteridis (Shear) Zeller; *Boletinus cavipes* Kalch
*** *Cenococcum geophilum* (Sowerby) Ferd and Winge
** *Hebeloma crustuliniforme* (Bull. ex Saint-Amans) Quel.
Hebeloma cylindrosporum
*** *Laccaria Zaccata* (Fr.) Berk. and Br.
Lycoperdon gemmatum Batsh.
** *Pisolithus arhizus* Pers.
**** *Pisolithus tinctorius* Pers. (Coker and Couch)
** *Rhizopogon luteolus; Rhizopogon roseolus* (Corda Insturm.) Fr.
Sphaerosporella brunnea (Alb. and Schw. ex Fr.)
Suillus bovinus; Suillus columnare
** *Suillus granulatus* (Fr.) Kuntze Surcek and Kub.
Suillus luteus (Fr.) S.F. Gray; *Suillus tomentosus* (Kauf.) Snell, Singer and Dick.
*** *Thelephora terrestris* Ehrhart and Fr.

Of these, *Pisolithus tinctorius, Cenococcum geophilum, Laccaria laccata* and *Thelephora terrestris* are the best known and are frequently used to form ectomycorrhizae on a variety of host species.

However, the information available permits us to indicate the range of cultural conditions favorable for mycorrhizal inoculation. Interested parties must determine, in their own facilities, the optimal conditions for the species to be cultivated. This should ensure that every inoculated seedling will become mycorrhizal, with a high proportion of ectomycorrhizal feeder roots, and that the seedlings will be in good morpho-physiological condition, suitable for outplanting, at the end of the production period.

The main physical and biological factors related to seedling production that promote mycorrhizal formulation have been assessed by a number of workers (Hatch 1937; Bjorkman 1942; Bowen 1973; Slankis 1973, 1974; Marx et al. 1977; Reid 1978; France and Reid 1981).

It has been shown that mycorrhizal development is dependent on the amount of light received by seedlings, and that most species are negatively affected by an illumination of less than 50% daylight.

The fertility level is important in relation to the extent of mycorrhization; excessive fertilization has been shown to decrease the infection. However, we think that the precise quantification of the appropriate fertility level for each cultivated species needs further investigation.

Most fungal strains have their maximal growth at pH 4-5, and no particular problems are expected if the substrate acidity can be maintained in that range during the incubation period.

The same observation applies to the admissible temperature, most fungal strains growing well between 15 °C and 30 °C.

Substrate aeration is an important factor. For instance, below 5% exorption of nutrients from roots can occur. However, the hydraulic conductivity is generally sufficient to insure a good aeration level and 15%

aeration is adequate for most physiological activities, including mycorrhization.

The water available in the substrate greatly influences the gaseous exchanges and the availability of nutrients. Hydration of the substrate to 40-50% of its maximum retention capacity will generally yield good results.

Use of Biocides

Biocides are frequently used during stock production to protect seedlings from pathogens and insects and to prevent the growth of fungi and weeds in the substrate.

Available data (Iloba 1978, Pawuk et al. 1980, Marx and Rowan 1981) on some of these biocides (Table 1) indicate that their influence on mycorrhiza development ranges from total inhibition to definite stimulation depending on the product used and on cultural conditions.

The effectiveness of these biocides is related to the buffer capacity of the substrate, the dosage used, the sensitivity of the ectomycorrhizal fungus and that of the cultivated host. Where possible, it is preferable to fumigate the substrate (Mulder 1979) in order to eliminate the competition and increase the efficiency of mycorrhizal infection.

Inoculum

<u>Different types of inoculum</u>

In containerized seedling production the promotion of mycorrhizal feeder development necessitates the introduction of a source of ectomycorrhizal fungus into the substrate. Up to now different types of inocula have been used[3], each having its advantages and disadvantages (Mikola 1973, Trappe 1977).

Actually, the shift from experimental to production level is achieved mainly by using pure culture inoculum aseptically produced in enriched peat-vermiculite mixture. This procedure permits efficient quality control and favors the fungus to be introduced rather than the many potentially harmful microorganisms that would be favored if forest humus were used.

Table 1. Noted effects of some biocides on mycorrhiza development.

1. Fumigants	
- Methyl bromide	(0)[a]
- Vapam	(-)
2. Fungicides	
- Arasan	(+)
- Banrot	(+)
- Bayleton	(+)
- Benlate (benomyl)	(+)
- Benodanil	(-)
- Captan	(+)
- Dexon (fenaminosulf)	(-)
- Mertect (thiabendazole)	(0)
- Terrachlor (quintozene)	(-)
- Truban (ethazole)	(0)
3. Insecticides	
- Lindane	(-)
- Toxaphene	(-)
4. Herbicides	
- 2-4-D, Simazine	(-)
- Others (under study at International Paper Co.)	
5. Repellents	
- Anthraquinone, endrin IMRD (under study at Institute for Mycorrhizal Research and Development)	

[a](0) = effect noted
(-) = negative effects
(+) = positive effects

Many research laboratories, including industrial laboratories, are working to upgrade inoculum quality, to increase the scale of production and to develop efficient methods of incorporation into the substrate. Pure mycelial culture in peat-vermiculite and encapsulation of seeds with basidiospores have commercial potential. However, even if the results obtained with these seem encouraging, the commercial availability of mycorrhizal inocula is dependent on the interest of potential users in improving the quality of the absorbing roots of their seedlings (Kenney 1980).

In our laboratory in Quebec we produce enough inoculum for our nursery and greenhouse experiments. It is produced in two ways, either in peat-vermiculite mix or in liquid medium. Our fungal strains are grown

---

[3] Main inoculum sources tested (asterisks indicate relative frequency of use):
* Soil and humus
mycorrhizal plant root system
** Spores and sporocarps
pure culture
*** mycelium in solid substrate
* mycelium in liquid suspension
(condensed mycelium) (Sclerotia)

in a nutritive solution similar to that defined by Marx and Bryan (1975) either in autoclavable bags filled with the peat-vermiculite mix (Fig. 6) or in flasks. We intend to inoculuate 100,000 seedlings this fall, but this number is relatively small in comparison with the current production of 3.5 million containerized seedlings in East Angus and the anticipated production in Quebec for the coming year (Dancause 1982).

Figure 6. Laboratory production of ectomycorrhizal fungi for inoculation purposes.

We are confident that, when larger quantities of inoculum are needed for large-scale inoculation, there will be companies able to provide them.

Selection of the fungal strains

In view of the many different ectomycorrhizal fungi (Trappe 1962, Smith 1974, Malloch et al. 1980, Miller 1981) which exhibit varying degrees of efficiency depending on the parameter considered (Bowen 1973, Marx 1973, Slankis 1973, Trappe 1977), studies must be carried out to select the most efficient fungal strains for each tree species and planting site.

Generally, the inoculum is incorporated into the substrate before sowing. Peat-vermiculite inoculum is either uniformly mixed or side dressed in containers while liquid suspensions are usually uniformly distributed in the substrate during irrigation.

Different factors have to be considered and each is of particular importance (Trappe 1977). For example, ease of handling with particular strains, infectivity toward some tree species, rate of spread in the substrate, potential benefits for the seedlings, and persistence and competitiveness in the soil after outplanting all have to be considered. According to Trappe (1977), "the more completely we learn the autecology of ectomycorrhizal fungi, the more intelligently we can select the species for inoculation".

Depending on the substrate used and the location of production equipment, it is possible to observe "spontaneous" mycorrhization in some cultures (Mikola 1973, Tinus and McDonald 1979, Cordell and Marx 1980). However, the extent of mycorrhization is generally low. The main sources of "spontaneous" mycorrhization are ectomycorrhizal fungus propagules in the substrate and, particularly during good sporulation seasons, airborne spores. These two types of natural inoculum can develop a mycelial phase and infect the root systems of seedlings to some degree, under appropriate conditions. The generally low degree of mycorrhization observed, the irregular distribution over the culture and the year to year variability suggest that improvement should be possible if the cultural conditions are adjusted. However, natural infection should not be considered a dependable means of producing mycorrhizal seedlings.

The fact that seedlings may sometimes become mycorrhizal after outplanting is closely related to the status of the planting site (Whitney et al. 1972, Meyer 1973, Mikola 1973, Harvey et al. 1980). This type of mycorrhization probably does not influence seedling establishment, especially since ectomycorrhizal fungus populations decline shortly after deforestation.

Consequently, if there appears to be room for improvement in present production methods and if the aim is to produce the best possible root systems, equipped with adapted absorbing roots, it seems desirable to inoculate the substrate with ecologically adapted fungi (Marx 1977, Trappe and Fogel 1977, Kormanik 1979). Even if inoculum availability at present restricts the mycorrhization of all seedlings now being produced, we are convinced that any grower can successfully produce mycorrhizae on a more modest scale (10,000 to 30,000 seedlings, for example), by using commercial inoculum or by having the microbiology laboratory of a local university produce some inoculum for his needs. Special attention must be paid to the fertility level during production of mycorrhizae, as will be stressed later. At present, information is available about many ectomycorrhizal fungi which have been used to synthesize ectomycorrhizae in containers on a variety of tree species. The decision to go ahead with the mycorrhization of tree seedlings on an operational scale is now in the hands of growers.

ECTOMYCORRHIZATION OF JACK PINE WITH REGARD TO FERTILIZATION

Fertilization is certainly one of the most important factors to consider when producing forest seedlings (Swan 1960, Ingestad 1967, Brix and van den Driessche 1974, Morrison 1974, van den Driessche 1980, Sheedy 1981), even more so when trying to induce mycorrhiza formation. The degree of mycorrhization is related to the fertility of the soil (Hatch 1937, Bjorkman 1942, Bowen 1973, Marx et al. 1977), and the relative value of the latter is a function of the species considered.

Some Experimental Results

On the basis of previous experiments with growing seedlings, we calculated that a single jack pine seedling could be grown in a container with the application of 3 to 12 mg of nitrogen, 1 to 10 mg of phosphorus and 1 to 13 mg of potassium over a 16-week growth period.

Over a period of several years, eight experiments were conducted at the Research Laboratory on Root Symbiosis at Laval University in Quebec City and at the provincial centre for containerized seedling production at East Angus to quantify the needs of jack pine seedlings grown in containers, both in the greenhouse and in growth cabinets, and to improve our understanding of the relationship between soil fertility and mycorrhization. Most of these experiments were conducted in styroblock-8s or Spencer-Lemaire "Hillson" containers.

In five of these studies, each cavity was individually fertilized, generally every other week, a peristaltic pump being used to standardize as much as possible the components of the prescribed nutrient solution with the relative amounts of nutrients recommended by Ingestad (1967). Substrate inoculation was conducted with inocula produced in our laboratory, either in solid or in liquid form.

Table 2 represents the nine fertility treatments of the inoculated section of a factorial design of 18 treatments each in four replicates of 40 seedlings. It indicates that variation in the addition of elementary phosphorus from 3.3 to 30 mg per cavity together with variation in elemental nitrogen from 3 to 12 mg per cavity promoted the height growth of jack pine from 7.2 cm to 12.1 cm. Dry weight increased from 106.4 mg to 359.7 mg for the shoots and from 70.4 mg to 162.6 mg for the roots. The shoot:root ratio also increased from 1.5 to 2.2.

Although we expected a positive effect from the addition of higher quantities of fertilizers on the growth of jack pine, the results showed increased mycorrhization also. However, comparison of inoculated with uninoculated treatments showed that inoculated seedlings were always smaller than uninoculated ones. The negative effects of inoculation were reduced with increased levels of nitrogen fertilization. For example, in the P2 regime, increasing nitrogen fertilization from NI to N3 reduced the shortfall (compared with the control) in root dry weight from 27.1% to 4.6% and in the P2 regime from 21.8% to 5.5% (Table 3).

Although the seedlings from the N3P2 and N3P3 regimes were smaller than their inoculated controls (Table 3), they were larger than the seedlings produced "normally", which were fertilized in a different manner. Here also, the dry weights of the inoculated seedlings produced under "normal" conditions were significantly reduced (Table 4).

The production of mycorrhizal jack pine seedlings smaller than the non-mycorrhizal controls indicates that seedlings have to give up a portion of their photosynthesized sugars to sustain fungal development in the substrate (Melin 1956, Meyer 1974, France and Reid 1981). However, if the seedling and the fungus live in a substrate well supplied with nutrients, an increase in absorption, due in large measure to the considerable increase of the mycelial absorbing area (Harley 1969, Bowen 1973, Langlois and Fortin 1978), leads to more photosynthesis (Kidd and Reid 1979), which in turn is reflected in an increase in total dry mass of inoculated seedlings over the controls (Fig. 7).

In another experiment conducted in a growth cabinet, seven inoculation treatments were replicated three times on 32 seedlings each; 12 mg of nitrogen and 3.3 mg of phosphorus were given to each seedling during the 16-week growth period. Seedlings were inoculated with different fungi and their influence on seedling growth varied significantly. For instance, *Cenococcum* was shown to enhance shoot height very significantly in comparison with other treatments, while shoot dry

Table 2. Mycorrhization and growth of jack pine in styroblock-8s, under nine fertility regimes, in the greenhouse.

Fertility regime	(Inoculated) mg/seedling^{-1} /16 weeks^{-1}		Shoot height (cm)	Dry weight Shoot (mg)	Dry weight Root (mg)	Shoot:root ratio	Mycorrhization (%)
1		N_1 3.3	7.20_a*	106.46_a	$70.45_{a,b}$	1.50_a	0-5
2	P_1 3.3	N_2 6.0	8.41_b	171.71_b	89.39_b	$1.92_{a,b,c}$	0-5
3		N_3 12.0	10.60_c	282.71_c	143.13_c	$1.97_{b,c}$	5-25
4		N_1 3.0	7.25_a	103.87_a	65.67_a	$1.59_{a,b}$	25-50
5	P_2 10.0	N_2 6.0	$7.68_{a,b}$	$156.46_{a,b}$	90.39_b	$1.74_{a,b}$	5-25
6		N_3 12.0	11.54_d	342.53_d	156.66_c	2.18_c	25-50
7		N_1 3.0	6.94_a	113.26_a	$72.37_{a,b}$	$1.58_{a,b}$	50+
8	P_3 30.0	N_2 6.0	8.60_b	175.94_b	102.25_b	$1.72_{a,b}$	50+
9		N_3 12.0	12.11_d	359.78_d	162.65_c	2.22_c	50+

*Vertically, values with different letters are significantly different at the 99% level.

weight, root dry weight and root collar diameter were unaffected. A similar response was found in seedlings inoculated with *Suillus* or *Laccaria*. On the other hand, seedlings inoculated with *Hebeloma*, *Pisolithus* or *Thelephora* showed significant decreases in shoot and root dry weights and in root collar diameter (Table 5).

Hence, it appears that, under a given set of conditions, these fungi differ in their nutritional needs, and this is reflected by the different sizes of the seedlings. Although the extent of mycorrhization varied depending on the fungus used, *Cenococcum* and *Hebeloma* inoculation produced seedlings which differed significantly in size while exhibiting a comparable degree of mycorrhization.

In this last experiment, where inoculation with three of the fungal strains did not reduce seedling dry weight significantly, better control of fertility with appropriate fertilization can enhance the advantages of ectomycorrhizal infection during the initial growth period.

Significance of Fertility and Fertilization

The mycorrhization of containerized jack pine seedlings is shown to be feasible with

Table 3. Effect of substrate inoculation on the growth of jack pine at different fertility levels.

	Difference from control (%) N_1	N_2	N_3
		P_1: 3.3 mg	
Total length	- 6.33	- 5.94	- 4.84
Shoot height	- 8.58	- 10.14	- 10.55
Total dry weight	- 23.71	- 23.72	- 16.81
Shoot dry weight	- 28.06	- 23.45	- 21.58
Root dry weight	- 16.09	- 24.25	- 5.41
		P_2: 10 mg	
Total length	- 2.27	- 5.46	- 9.20
Shoot height	- 7.99	- 17.41	- 19.95
Total dry weight	- 31.18	- 28.23	- 18.39
Shoot dry weight	- 33.54	- 31.52	- 23.44
Root dry weight	- 27.11	- 21.81	- 4.57
		P_3: 30 mg	
Total length	- 4.68	- 4.79	- 2.31
Shoot height	- 14.21	- 9.95	- 8.18
Total dry weight	- 28.11	- 30.38	- 15.48
Shoot dry weight	- 28.67	- 35.40	- 19.31
Root dry weight	- 21.83	- 18.59	- 5.57

Figure 7. Mycorrhizal induction and mycelium development in the substrate inoculated with *Hebeloma cylindrosporum*.

Table 4. Growth of jack pine with and without inoculum (n = 30).

	With inoculum	Without inoculum[a]
Shoot height (cm)	10.56	11.28*
Root length (cm)	15.15	15.03*
Total dry weight (mg)	398.36	487.65***
Shoot dry weight (mg)	261.17	309.78**
Root dry weight (mg)	137.19	177.86***
Shoot:root ratio	1.95	1.75*

No significant difference (*); different at 95% level (**); different at 99% level (***).

[a] With vermiculite added.

different fungi in the greenhouse as well as in growth cabinets. However, seedlings produced so far are small in comparison with MERQ specifications for reforestation. In addition, the low percentage of mycorrhization observed and the difficulty of reproducing these results from one experiment to another when the substrate is different or when containers of different sizes are used persuaded us to investigate the significance of the usual expressions of fertility and fertilization.

Table 6 shows that the distribution of 100 g of fertilizer in a 251.52 m^2 greenhouse corresponds to 3.975 kg per ha; however, the actual quantity received by each cavity depends on the area of the container. In addition to this, even for a given container, the concentration of the added fertilizer is a function of substrate dry weight, and thus of the substrate density. There will be a variation of 4 to 57 in ppm added if substrate densities are comparable with those of nursery soils (1.3) or peat moss (0.09).

The quantity of nutrients available to the seedling will vary, at a given fertility level, according to container volume and substrate density. Variations from 0.05 to 3.31 mg per cavity are expected with different combinations of container size and substrate density (Table 7).

Even if the concentration of the fertilizing solution and the area to be fertilized are known, the quantity applied, the frequency of application and the area of the container must be taken into account in order to evaluate the quantity received in each cavity. For example, a variation from 5 to 31 mg of nitrogen per cavity can be induced by combining these three factors (Table 8).

In order to define as precisely as possible the fertilizer regime used in the aforementioned growth cabinet experiment, five different expressions of the nutrient regime are given in Table 9. Thus, 3.16 mg of phosphorus were given to each seedling during the 16-week growth period, although each fertilization treatment did not necessarily contain the same quantity of the three major elements. Each treatment contributed to an increase in the concentration of a given element, which was quantified as ppm added to the substrate. The concentration of the fertilizing solution was calculated, on the basis of the addition of 5 ml of solution to each seedling at each fertilization. Note that the concentration of the fertilizing solution is not related to the concentration added to the substance. Finally, an equivalent in kg per ha per fertilization treatment was calculated; it varied from 1.3 to 3.9 for elemental phosphorus, depending on the intensity of the fertilization.

The greenhouse fertilization treatment can be evaluated in the same way. Jack pine seedlings in the greenhouse can be colonized

Table 5. Effect of inoculation with liquid suspensions of different fungi on the growth of jack pine in a growth cabinet, in Spencer-Lemaire "Hinson" containers.

	Fungus inoculum[a]						
	C	Hc	Pt	Cg	St	Lacc.	Tt
Shoot height (cm)	4.4	4.12	5.15	6.8	5.3	5.1	4.55
	a,b	a	b,c	d	c	b,c	b,c
Shoot dry weight (mg)	796	441	514	786	873	848	512
	b	a	a	b	b	b	a
Root dry weight (mg)	312	148	197	297	283	317	159
	b	a	a	b	b	b	a,b
Root-collar diameter (mm)	1.7	1.3	1.56	1.75	1.7	1.7	1.46
	c,d	a	b,c	d	c,d	c,d	a,b
% mycorrhization	0	51-75	5-10	51-65	0-5	10-15	20-25
Quality index (Dickson et al. 1960)	0.216	0.102	0.115	0.141	0.173	0.192	0.106

Horizontally, values with different letters are significantly different at the 99% level.

[a] Control Hc = *Hebeloma cylindrosporum*, 75.1; Pt = *Pisolithus tinctorius*, 76.1; Cg = *Cenococcum geophilum*, XX.50; St = *Suillus tomentosus*, 78.1; Lacc. = *Laccaria spp.*, B79.7; Tt = *Thelephora terrestris*, XX.36.

Table 6. Significance of applying 100 g of fertilizer over a 251.52 m^2 area as a function of container type and substrate density.

	Volume (cm^3)	Surface area (cm^2)	Substrate density (g/cm^{-3})	Substrate dry weight (g)	Fertilizer		
					kg/ha^{-1}	$mg/cavity^{-1}$	ppm added
Styroblock-2A	35	4.52	0.09	3.15	3.975	0.179	56.82
			0.60	21.00	3.975	0.179	8.52
			1.30	45.50	3.975	0.179	3.93
MERQ container	95	10.75	0.09	8.55	3.975	0.427	49.70
			0.60	57.00	3.975	0.427	7.49
			1.30	123.50	3.975	0.427	3.45
Spencer-Lemaire "Hillson"	150	14.44	0.09	13.50	3.975	0.574	42.51
			0.60	90.00	3.975	0.574	6.37
			1.30	195.00	3.975	0.574	2.94

Table 7. Significance of a fertility level of 17 ppm as a function of container type and substrate density.

Container	Volume (cm^3)	Surface area (cm^2)	Substrate density (g/cm^{-3})	Substrate dry weight (g)	Fertility	
					ppm	mg/cavity^{-1}
Styroblock-2A	35	4.52	0.09	3.15	17	0.05
			0.60	21.00	17	0.36
			1.30	45.50	17	0.77
MERQ container	95	10.75	0.09	8.55	17	0.14
			0.60	57.00	17	0.97
			1.30	123.50	17	2.10
Spencer-Lemaire "Hillson"	150	14.44	0.09	13.50	17	0.22
			0.60	90.00	17	1.53
			1.30	195.00	17	3.31

Table 8. Significance of applying 150 ppm N solution over an area of 251.52 m^2 as a function of container type and quantity applied.

Container	Quantity per pass (L)	Number of passes	Surface area per cavity (cm^2)	Fertilizer received	
				ml/cavity^{-1}	mg N/cavity^{-1}
Styroblock-2A	373	50	4.52	33.51	5.02
		70		46.92	7.03
		90		60.32	9.04
	532	50		47.80	7.17
		70		66.92	10.03
		90		86.04	12.90
MERQ container	373	50	10.75	79.71	11.95
		70		111.59	16.73
		90		143.47	21.52
	532	50		113.68	17.05
		70		159.16	23.87
		90		204.63	30.69

by ectomycorrhizal fungi when fertilized with 3.3 to 30 mg of elemental phosphorus during the 16-week growing period in a manner such that each fertilization increased the concentration of phosphorus in the substrate by 12 to 107 ppm (Table 10).

Three conclusions can be drawn from our studies with jack pine seedlings:

1) Mycorrhizal infection of containerized jack pine seedlings is feasible if specific growing conditions are met and specific fungi are used.

2) Different fungi have different effects on seedling growth.

3) It is necessary to quantify fertility and fertilization simultaneously, with different expressions, in order to optimize mycorrhizal infection and the morphological quality of the seedling in different containers and substrates.

Practical Considerations

Container size

Container size must be considered when establishing fertilization regime. This became clear to us when we used styroblock-2As in a joint experiment with the Canadian International Paper Company. The precise quantity of nutrients needed for each jack pine seedling during the growing period was determined previously. It is probable that, when this quantity of fertilizer was applied weekly to these smaller containers, the concentration of fertilizer in the substrate after each application was too high since mycorrhization was inhibited. Therefore, the fertilization regime should be adjusted to satisfy the needs of the seedlings without impeding mycorrhizal development, i.e., by repeated additions of low concentrations of fertilizer to ensure that the concentration of mineral in the substrate is compatible with mycorrhiza formation.

Species, phenology and mycorrhization

Our unpublished results indicate that nursery-grown jack pine, red pine *(Pinus resinosa* Ait.), white spruce *(Picea glauca* [Moench] Voss), black spruce *(P. mariana* [Mill.] B.S.P.) and balsam fir *(Abies balsamea* [L.] Mill.) possess particular growth patterns during the season. From this it can be inferred that these species differ in both timing and intensity of nutrient absorption.

Thus, the metabolism of these species is not synchronized, and this is probably the case with their receptivity to mycorrhizal infection as well. For example, nursery-grown jack pine and black spruce seedlings showed strong correlations between bud set, root activity, phosphate absorption and increase in trehalose content of their root systems, which are indicative of the extent of the ectomycorrhizal infection. However, these activities did not occur at the same time or with the same intensity in the two species; for example, natural ectomycorrhizal infection occurred earlier on black spruce than on jack pine.

In containers, it is possible to observe, after the reduction of fertilization and during the hardening period, some sporophores of ectomycorrhizal fungi in the cavity or even under the containers, near draining holes; generally this happens with both *Laccaria* sp. and/or *Thelephora terrestris.* Their presence, however, is not necessarily related to a high level of mycorrhizal infection. It is generally accepted that only seedlings bearing more than 50% mycorrhizal absorbing roots can be considered fully mycorrhizal. Consequently, even if standard cultural practices permit a certain degree of ectomycorrhization, closer monitoring will be necessary to maximize mycorrhizal colonization. Such monitoring will also facilitate the introduction of selected fungal inocula.

It is even probable that the overall benefits of seedling inoculation will be greater for very demanding species or for seedlings which are to be outplanted in soils of low fertility levels.

INCREASING PRODUCTION

The worksheet in the Appendix illustrates how fertilizer requirements may be precisely determined. If one knows the exact amount of fertilizer to give to each seedling during the growing period, the amount to be applied during the production period can be calculated; alternatively, if the overall production regime is known, the quantity of nutrients received by each seedling may be calculated.

In our view, quantification of the nutrients given to seedlings during culture could prove very useful, as it would permit producers to control the growth of seedlings more efficiently and to cope better with any problems which might arise if procedures were changed.

Table 9. Evaluation of fertilization treatments in the growth cabinet experiment.

Expression of fertilization		N	P	K
1. mg/seedling^{-1} /(16 weeks)$^{-1}$		11.35	3.16	4.55
2. mg/ seedling^{-1} /fertilization^{-1}	fac. 1	0.71	0.18	0.28
	fac. 2	1.42	0.37	0.57
	fac. 3	2.13	0.56	0.85
3. ppm added to the substrate /fertilization^{-1}	fac. 1	47.29	12.39	18.96
	fac. 2	94.58	24.78	37.92
	fac. 3	141.87	37.18	56.87
4. ppm in the fertilizing solution	fac. 1	141.87	37.18	56.87
	fac. 2	283.75	74.35	113.75
	fac. 3	425.62	113.53	170.62
5. kg/ha^{-1} /fertilization^{-1}	fac. 1	4.91	1.29	1.97
	fac.2	9.82	2.57	3.98
	fac. 3	14.74	3.86	5.91

It may be difficult to specify quantities of commercial fertilizer, especially if two or three different formulations are used at different times or simultaneously during the growth period. To facilitate computation, a worksheet was constructed (Appendix) for use in determining the ratio of different formulations to be used when a particular quantity of fertilizer is needed. In this way it is possible to know precisely what the seedlings receive each time they are fertilized, and the formulation can easily be modified when necessary. This procedure was tested successfully in the spring of 1981, when 3.5 million containerized seedlings were produced according to a precise nutrient schedule.

CONCLUSION

The presence of ectomycorrhizae on the root systems of seedlings has been shown by several workers to increase survival rate and hasten growth of the seedlings after outplanting (Shemakhanova 1962; Mikola 1973, Kormanik 1979, Ruehle 1980c, Ruehle et al. 1981).

Table 10. Evaluation of fertilization treatments in the greenhouse experiment.

Expression of fertilization		N	P	K
1. mg/seedling^{-1} /(16 weeks)$^{-1}$	1	3.00	3.30	7.00
	2	6.00	10.00	
	3	12.00	30.00	
2. mg/seedling^{-1} /fertilization^{-1}	1	0.43	0.47	1.00
	2	0.86	1.43	
	3	1.72	4.28	
3. ppm added to the substrate /fertilization	1	10.71	11.78	25.00
	2	21.43	35.72	
	3	42.86	107.14	
4. ppm in the fertilizing solution	1	85.71	94.28	200.00
	2	171.43	285.72	
	3	342.85	857.14	
5. kg/ha^{-1} /fertilization	1	3.78	4.15	8.82
	2	7.56	12.60	
	3	15.12	37.78	

The production of containerized mycorrhizal seedlings necessitates close monitoring of cultural conditions, if good-sized seedlings bearing numerous ectomycorrhizae are to be obtained. These seedlings will possess highly effective absorbing organs, especially when inoculated with carefully selected fungal strains (Mikola 1973, Marx 1977, Trappe 1977).

We believe that, by controlling the concentration of nutrients in the substrate, and by adjusting the frequency of fertilization to the growth pattern of the species involved, it should be possible to satisfy the needs of the seedlings even if they are grown in a substrate of low nutrient concentration, and to establish a good mycorrhizal root system.

As growers, we are at the initial stage in the development of a multi-operational process aimed at the production of new forests. Should our responsibility be limited to delivering the seedlings or should we bear part of the responsibility for mortality rate as well, because we do not yet have a precise understanding of the necessary morpho-physiological qualities of seedlings (Russell 1977, Van Eerden and Kinghorn 1978, Harley and Russell 1979, Sutton 1979)? Research and development in plant biology should be encouraged and the findings used to improve our understanding of the many factors that contribute to seedling quality and performance.

LITERATURE CITED

Anon.
1980. Atelier de travail sur la culture des semis en recipients Quebec 18-20 mars 1980. Centre de recherche forestiere des Laurentides/Min. Energie Ressour. Que./ Ordre Ing. For. Que.

Anon.
1981. Program and Abstracts: Fifth North American Conference on Mycorrhizae, Univ. Laval, Fac. For. 83 p.

Bjorkman, E.
1942. Conditions favoring the formation of mycorrhizae in pine and spruce. Symb. Bot. Upsal. 6:1-191.

Boullard, B.
1968. Les mycorrhizes. Coll. Monogr. Bot. Biol. veg., Monogr. 2, 135 p. Masson & Cie.

Bowen, G.D.
1973. Mineral nutrition of ectomycorrhizae. p. 151-206 in Marks, G.C. and Kozlowski, T.T., *Ed.* Ectomycorrhizae, Their Ecology and Physiology. Academic Press, New York.

Brix, H. and van den Driessche, R.
1974. Mineral nutrition of container-grown tree seedlings. p. 77-84 in R.W. Tinus, W.I. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Carlson, L.W.
1979. Guidelines for rearing containerized conifers seedlings in the prairie provinces. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-214. 62 p.

Cordell, C.E. and Marx, D.H.
1979. Results of 1978 **Pisolithus tinctorius** ectomycorrhizae national evaluation in 33 bareroot nurseries and 18 container seedling studies. p. 52-56 in U.S. Northeastern Area Nurserymen's Conference Proceedings, Bloomington, Indiana.

Cordell, C.E. and Marx, D.H.
1980. Ectomycorrhizae: Benefits and practical application in forest tree nurseries and field plantings. p. 217-214 in North American Forest Tree Nursery Soils Workshop, Syracuse, N.Y.

Dancause, A.
1982. The status of container planting programs in Canada. 6. Quebec. p. 35-38 in J.B. Scarratt, C. Glerum and C.A. Plexman, Ed. Proceedings of the Canadian Containerized Tree Seedling Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. O-P-10.

Dickson, A., Leaf, A.L. and Hosner, J.F.
1960. Quality appraisal of white spruce and white pine seedling stock in nurseries. For. Chron. 36:10-13.

Dommergues, Y.R. and Krupa, S.V., *Ed.*
1978. Interactions between non-pathogenic soil microorganisms and plants. Devel. Agric. Managed For. Ecol. - 4. Elsevier Sci. Publ. Co., N.Y.

Fortin, J.A.
1972. The potential use of mycorrhizae inoculation in the production of forest trees. p. 77-82 in Waldron, R.M., *Ed.* Proceedings of a Workshop on Container Planting in Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. DPC-X-2.

France, R.C. and Reid, C.P.P.
1982. Interactions of nitrogen and carbon in the physiology of ectomycorrhizae. Can. J. Bot. (in press).

Furlan, V. and Fortin, J.A.
1981. First international directory of mycorrhizae researchers. Dep. Ecol. Pedol., Fac. For., Univ. Laval, Quebec. 104 p.

Hacskaylo, E.
1973. Carbohydrate physiology of ectomycorrhizae. p. 207-230 in Marks, G.C. and Kozlowski, T.T., Ed. Ectomycorrhizae, their ecology and physiology. Academic Press, New York.

Hacskaylo, E. and Tompkins, C.M.
1973. World literature on mycorrhizae. Contrib. of Reed Herbarium, No. XXII.

Harley, J.L.
1969. The biology of mycorrhizae. 2nd ed. Leonard Hill, London. 334 p.

Harley, J.L. and Russell, R.S., *Ed.*
1979. The soil-root interface. Proceedings of an international symposium, Oxford, England.

Harvey, A.E. et al.
1980. Ecology of ectomycorrhizae in northern Rocky Mountain forests. USDA For. Serv., Gen. Tech. Rep. INT. 90.

Hatch, A.B.
1937. The physical basis of mycotrophy in the genus *Pinus.* Black Rock For. Bull. 6:1-168.

Iloba, C.
1978. The influence of 2.4.D on ectomycorrhizal symbiosis in pine and spruce seedlings. Eur. J. For. Pathol. 8:379-383.

Imshenetskii, A.A.
1955. Mycotrophy in plants. [Transl. from Russian] Available from U.S. Dep. Commerce, Clearinghouse for Fed. Sci. and Tech. Information, Springfield, Va. 382 p.

Ingestad, T.
1967. Methods for uniform optimum fertilization of forest plants. XIV. IUFRO - Kongrirs, Section 22, Munich, p. 265-269.

Kenney, D.S.
1980. Mycorrhizae and microorganisms, significance in nurseries: Commercial production. p 225 in North American Forest Tree Nursery Soil Workshop, Syracuse, N.Y.

Kidd, F. and Reid, C.P.P.
1979. Effect of ectomycorrhizal infection on increasing net photosynthesis in pine seedlings. Program and abstracts, Fourth North American Mycorrhizal Conference. Colorado State Univ., Fort Collins.

Kormanik, P.P.
1979. Biological means of improving uptake in trees. p. 293-311 *in* Ford, E.D., Malcolm, D.C. and Atterson, J., *Ed.* The ecology of even-aged forest plantations. Proceedings of Division 1. IUFRO.

Krupa, S.V. and Dommergues, Y.R., *Ed.*
1979. Ecology of root pathogens. Developments in Agricultural and Managed Forest Ecology No. 5. Elsevier Sci. Publ. Co.

Landis, T.D. and Gillman, L.
1976. Mycorrhizal inoculation of container grown ponderosa pine seedlings. USDA For. Serv., Rocky Mt. Reg., Tech. Rep. R2-3.

Langlois, C.G. and Fortin, J.A.
1978. Absorption of phosphorus (^{32}P) by excised ectomycorrhizae of balsam fir from low concentration of H2PO4. Nat. Can. 105: 417-424.

Malloch, D.W., Pirozynski, K.A. and Raven, P.H.
1980. Ecological and evolutionary significance of mycorrhizal symbioses in vascular plants (a review). Proc. Natl. Acad. Sci. 77: 2113-2118.

Marks, G.C. and Kozlowski, T.T.
1973. Ectomycorrhizae, their ecology and physiology. Academic Press, New York. 444 p.

Maronek, D.M. and Hendrix, J.W.
1979. Growth acceleration of pin oak seed lings with a mycorrhizal fungus. HortScience 5:627-628.

Maronek, D.M. and Hendrix, J.W.
1980. Synthesis of *Pisolithus tinctorius* ectomycorrhizae on seedlings of four woody species. J. Am. Soc. Hort. Sci. 105(6):823-825.

Marx, D.H.
1973. Mycorrhizae and feeder root diseases. p. 351-382 in Marks, G.C. and Kozlowski, T.T., *Ed.* Ectomycorrhizae, their ecology and physiology. Academic Press, New York.

Marx, D.H.
1977. The role of mycorrhizae in forest production. p. 151-161 in Annu. Meet. TAPI Conf., Atlanta, Ga.

Marx, D.H. and Barnett, J.P.
1974. Mycorrhizae and containerized forest tree seedlings. p. 85-91 in R.W. Tinus, W.I. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Marx, D.H. and Bryan, W.C.
1975. Growth and ectomycorrhizal development of loblolly pine seedlings in fumigated soil infested with the fungal symbiont *Pisolithus tinctorius.* For. Sci. 2:245-254.

Marx, D.H., Hatch, A.B. and Mendicino, J.F.
1977. High soil fertility decreases sucrose content and susceptibility of loblolly pine roots to ectomycorrhizal infection by *Pisolithus tinctorius.* Can. J. Bot. 55:1569-1574.

Marx, D.H. and Rowan, S.J.
1981. Fungicides influence growth and development of specific ectomycorrhizae on loblolly pine seedlings. For. Sci. 27(1):167-176.

Melin, E.
1956. Physiological aspects of mycorrhizae in forest trees. p. 247-263 *in* Kozlowski, T.T., *Ed.* Tree Growth. Ronald Press, New York.

Meyer, F.H.
1973. Distribution of ectomycorrhizae in native and man-made forests. p. 79-105 *in* Marks, G.C. and Kozlowski, T.T., *Ed.* Ectomycorrhizae, their ecology and physiology. Academic Press, New York.

Meyer, F.H.
1974. Physiology of mycorrhizae. Annu. Rev. Plant Physiol. 25:567-586.

Mikola, P.
1973. Application of mycorrhizal symbiosis in forestry practice. p. 383-406 *in* Marks, G.C. and Kozlowski, T.T., *Ed.* Ectomycorrhizae, their ecology and physiology. Academic Press, New York.

Miller, O.K.
1982. Ectomycorrhizae in the agaricales and gasteromycetes. Can. J. Bot. (in press).

Molina, R.
1979. Ectomycorrhizal inoculation of containerized Douglas fir and lodgepole pine seedlings with six isolates of *Pisolithus tinctorius.* For. Sci. 25:585-590.

Molina, R.
1980. Ectomycorrhizal inoculation of containerized western conifer seedlings. USDA For. Serv., Note PNW 357.

Morrison, I.K.
1974. Mineral nutrition of conifers with special reference to nutrient status interpretation: A review of literature. Dep. Environ., Can. For. Serv., Ottawa, Ont. Publ. No. 1343. 74 p.

Mulder, D.
1979. Soil disinfestation. Developments in agricultural and managed forest ecology No. 6. Elsevier Sci. Publ. Co.

Navratil, S.
1978. Manipulation of mycorrhizae. Preliminary report for Ontario Ministry of Natural Resources. Lakehead Univ., Sch. For. 15 p.

Pawuk, W.H., Ruehle, J.L. and Marx, D.H.
1980. Fungicide drenches affect ectomycorrhizal development of container-grown *Pinus palustris* seedlings. Can. J. For. Res. 10:61-64.

Rambelli, A.
1973. The rhizosphere of mycorrhizae. p. 299-349 in Marks, G.C. and Kozlowski, T.T. *Ed.* Ectomycorrhizae, their ecology and physiology. Academic Press, New York.

Reid, C.P.P.
1978. Mycorrhizae and water stress. p. 392-408 in Symposium on Root Physiology and Symbiosis. Nancy, France.

Richard, C.
1975. Quelques essais d'inoculation mycorrhizienne. For. Chron. 51:188-194.

Riedacker, A. and Gagnaire-Michaud, J. *Ed.*
1978. Symposium on Root Physiology and Symbiosis. Nancy, France.

Ruehle, J.L.
1980a. Inoculation of containerized loblolly pine seedlings with basidiospores of *Pisolithus tinctorius.* USDA For. Serv., Res. Note SE-291.

Ruehle, J.L.
1980b. Ectomycorrhizal colonization of container grown northern red oak as affected by fertility. USDA For. Serv., Res. Note SE-297.

Ruehle, J.L.
1980c. Growth of containerized loblolly pine with specific ectomycorrhizae after 2 years on an amended borrow pit. Reclam. Rev. 3:95-101.

Ruehle, J.L. and Marx, D.H.
1977. Developing ectomycorrhizae pine seedlings. USDA For. Serv., Southeast. For. Exp. Stn., Asheville, N.C. Res. Note SE-242. 8 p.

Ruehle, J.L., Marx, D.H., Barnett, J.P., and Pawuk, W.H.
1981. Survival and growth of container grown and bare-root shortleaf pine seedlings with *Pisolithus* and *Thelephora* ectomycorrhizae. South. J. Appl. For. 5(1):20-24.

Russell, R.S.
1977. Plant root systems: their function and interaction with the soil. McGraw-Hill Book Co., London. 298 p.

Sheedy, G.
1981. Production en serre de semis de pin gris et d'epinette noire dans deux types de recipients soumis à trois calendriers de fertilisation. Serv. Rech. M.E.R., Rap. Int. No. 215.

Shemakhanova, N.M.
1962. Mycotrophy of woody plants. [Translated from Russian] Available from U.S. Dep. Commerce, Clearinghouse for Fed. Sci. and Tech. Inf., Springfield, Va. 329 p.

Slankis, V.
1973. Hormonal relationships in mycorrhizal development. p. 231-298 *in* Marks, G.C. and Kozlowski, T.T., *Ed.* Ectomycorrhizae, their ecology and physiology. Academic Press, New York.

Slankis, V.
1974. Soil factors influencing formation of mycorrhizae. Annu. Rev. Phytopathol. 12:437-457.

Smith, S.E.
1974. Mycorrhizal fungi. p. 273-313 in CRC Crit. Rev. Microbiol., June.

Smith, S.S.E.
1980. Mycorrhizas of autotrophic higher plants. Biol. Rev. 55:475-510.

Sutton, R.F.
1979. Planting stock quality and grading. For. Ecol. Manage. 2:123-132.

Swan, H.S.D.
1960. The mineral nutrition of Canadian pulpwood species. Pulp Pap. Res. Inst. Can., Woodl. Res. Index 116. 66 p.

Tinus, R.W.
1974. Characteristics of seedlings with high survival potential. p. 276-281 in R.W. Tinus, W.I. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Tinus, R.W., Stein, W.E., and Balmer, W.E., *Ed.*
1974. Proceedings of the North American containerized forest tree seedling symposium. Denver, Colorado, August 26-29, 1974. Great Plains Agric. Counc. Publ. No. 68.

Tinus, R.W. and McDonald, S.E.
1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv., Rocky Mt. For. Range Exp. Stn., Fort Collins, Colo. Gen. Tech. Rep. RM-60. 256 p.

Trappe, J.M.
1962. Fungus associates of ectotrophic mycorrhizae. Bot. Rev. 28:538.

Trappe, J.M.
1977. Selection of fungi for ectomycorrhizal inoculation in nurseries. Ann. Rev. Phytopath. 15:203-222.

Trappe, J.M. and Fogel, R.D.
1977. Ecosystematic functions of mycorrhizae. P. 205-214 in J.K. Marshall, *Ed.* The Below Ground Ecosystem: A Synthesis of Plant-associated Processes. Colorado State Univ., Fort Collins. 351 p.

van den Driessche, R.
1980. Health, vigour and quality of conifer seedlings in relation to nursery soil fertility. p. 100-120 *in* North American Forest Tree Nursery Soils Workshop, Syracuse, N.Y.

van Eerden, E. and Kinghorn, J.M., *Ed.*
1978. Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can.For. Serv. Joint Rep. No. 8. 357 p.

Waldron, R.M., *Ed.*
1972. Proceedings of a workshop on container planting in Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. DPC-X-2. 168 p.

Whitney, R.D., Bohaychuk, W.P. and Briant, M.A.
1972. Mycorrhizae of jack pine seedlings in Saskatchewan and Manitoba. Can. J. For. Res. 2:228-235.

Zak, B.
1964. Role of mycorrhizae in root disease. Annu. Rev. Phytopathol. 2:377.

Zak, B.
1975. Mycorrhizae and container seedlings. Proc. 23rd Annu. W. Int. For. Dis. Work Conf.

Appendix overleaf

APPENDIX

Calculation of fertilizer requirements for jack pine production

A. WHAT TO PROVIDE

1. Evaluation of seedlings' requirements for phosphorus:

$$\underset{(a)}{1{,}000\ \text{mg}} \times \underset{(b)}{0.25\%}\ (\text{P}) = \underline{2.5\ \text{mg (P)}}$$

(a) - desired dry weight
(b) - phosphorus content in tissue

2. Cultural need:

$$2.5\ \text{mg (P)} \times \frac{100\%}{20\%\ (a)} = \underline{12.5\ \text{mg (P)}}$$

(a) - takes into account the usual availability factor for phosphates.

3. Substrate analysis:

$$\frac{17\ \text{mg (P)}}{10^6\ \text{mg}} \underset{(a)}{\ } \times \underset{(b)}{13{,}500\ \text{mg}} = \underline{0.229\ \text{mg (P)}}$$

(a) - example of 17 ppm (P)
(b) - dry weight of substrate

4. Amount to supply:

$$12.5\ \text{mg (P)} - 0.229\ \text{mg (P)} = \underline{12.271\ \text{mg (P)}}$$

5. "ppm added" per application:

$$\frac{12.271\ \text{mg (P)}}{13{,}500\ \text{mg}} \times 10^6 = \underline{908.96\ \text{ppm}}$$

6. Number of fertilizer applications:

$$\frac{908.96\ \text{ppm}}{50\ \text{ppm}\quad (a)} = 18.179 \text{ or } \underline{18}$$

(a) - if we want to add about 50 ppm at each fertilizer application

7. Quantity of fertilizer per seedling per fertilizer application:

$$\frac{12.271\ \text{mg (P)}}{18\ \text{fertilizations}} = \underline{0.681\ \text{mg (P) per fertilization}}$$

8. If fertilizing one greenhouse:

$$0.681\ \text{mg (P)} \times \frac{251.44 \times 10^4\ \text{cm}^2\ (a)}{14.44\ \text{cm}^2\ (b)} = \underline{118.58\ \text{g (P)}}$$

(a) - area under the spray system
(b) - area of each cavity

9. If using commercial fertilizer:

$$\frac{118.58\ \text{g (P)}}{8.7\%\quad (a)} = 1{,}362.99\ \text{g (20-20-20)}$$

(a) - phosphorus content for 20-20-20

B. HOW TO SUPPLY IT

10. Volume distributed per cavity per pass:

$$\underset{(a)}{117\ \text{gal}} \times 4.546\ \text{L} \times \frac{14.4\ \text{cm}^2}{251.44 \times 10^4\ \text{cm}^2}\ \begin{matrix}(b)\\(c)\end{matrix} = \underline{3.05\ \text{ml}}$$

(a) - 117 imp. gal per pass
(b) - area of each cavity
(c) - area under the spray system

11. If using 2 passes per fertilization treatment:

Volume per cavity = 3.05 ml X 2 = 6.1 ml

Total volume needed = 2 x 117 gal x 4.546 = 1,063.76 L

12. Concentration of fertilizer solution:

$$\frac{0.681\ \text{mg (P)}}{6.1\ \text{ml}} \times 1{,}000 = \underline{111.63\ \text{ppm (P)}}$$

13. If using concentrate injection system:

$$1{,}063.76\ \text{L} \times \frac{1}{190\ (a)} = \underline{5.598\ \text{L}}$$

(a) - actual distribution factor of the injector

14. Concentration of fertilizer concentrate:

$$\frac{1{,}362{,}99\ \text{g}}{5.598\ \text{L}} = \underline{243.478\ \text{g/L}}\ \text{(20-20-20)}$$

Note: To avoid solubility problems, the concentrate should contain less than 150 g/L. Total volume of fertilizer solution or distribution factor of the injector may be modified to achieve this.

15. Concentrate to prepare:

$$6\ \text{L} \times 243.478\ \text{g/L} = \underline{1{,}461\ \text{g}}\ \text{(20-20-20)}$$

BOX-PRUNING THE ROOTS OF CONTAINER-GROWN TREE SEEDLINGS

A.N. Burdett'

Abstract.--The use of planting stock with a box-pruned root system can reduce or prevent mechanical instability in plantations of susceptible pine species. It can also increase early height growth. This paper describes both chemical and mechanical root pruning techniques for the production of container stock with a box-pruned root.

Résumé.--L'utilisation de semis dont les racines ont été élaguées dans les contenants peut réduire ou empêcher l'instabilité mécanique dans les plantations d'essences de pins fragiles et peut même augmenter la croissance en hauteur précoce. Cette communication décrit à la fois des méthodes chimiques et mécaniques d'élagage des racines pour la production de ce type de semis.

INTRODUCTION

Mechanical instability in planted lodgepole pine *(Pinus contorta* Dougl.) and some other species of pine has been associated with the effects of nursery culture and planting on root form (Clarke 1956, Chavasse 1978, Burdett 1979). Instability leading to toppling or windthrow appears to be particularly severe in plantations established with container-grown stock (Burdett 1979). To eliminate the characteristic effect of the container on root form and thereby improve stability after outplanting, a chemical root pruning technique has been developed for the production of lodgepole pine container stock with a box-pruned root system (Burdett 1978). The technique involves the use of seedling containers coated on the inside with latex paint containing cupric carbonate. Contact with the wall coating is inhibitory to root growth. Thus, instead of growing down or around the container wall, lateral roots reaching the side of the container cease to elongate. The result is a tree with a box-pruned root system.

This paper reports the effect of this root pruning technique on root morphogenesis and height growth in field planted lodgepole pine. Limitations on the use of the technique for lodgepole pine and other species are indicated. A versatile mechanical root pruning technique for box-pruning the roots of container-grown stock is also described.

METHOD

In 1977 three provenances of lodgepole pine were grown in both copper painted and unpainted styroblock containers at the B.C. Ministry of Forests Skimikin Nursery near Salmon Arm. The containers were 2 cm in diameter, 11 cm deep and had a volume of 30 cm^3. The copper paint was prepared as follows. One kilogram of basic cupric carbonate powder (malachite) was slurried with 5 L of water. The slurry was then mixed into 10 L of white exterior latex paint (Baprok paint supplied by Bapco Paint Co., a subsidiary of Canadian Industries Limited). The styroblock containers were subsequently coated with copper paint by dipping them. When the paint had dried, the containers were filled with a 3:1 peat:vermiculite mix containing 3 kg/m^3

---

[1] Research Scientist, Ministry of Forests, Research Branch, Victoria, British Columbia.

of dolomitic lime (12 mesh and finer). The pH of the peat was about 3.5 and the pH of the mix between 4.5 and 5.0. The containers were seeded in April. Germination took place in a heated greenhouse, after which the containers were moved outdoors. Nutrients were supplied twice weekly with the irrigation water. The trees were extracted from the containers in November and cold-stored until spring.

RESULTS AND DISCUSSION

In the spring of 1978, seedling samples were planted at two locations, Lassie Lake in the Nelson Region and Devick Lake in the Kamloops Region. First season survival and growth of the chemically root-pruned stock was virtually identical to that of the non-root-pruned plug stock (Table 1).

Table 1. First season survival and growth of 1-0 lodgepole pine from copper painted and unpainted styroblock containers.

Location	Container	Survival[a] (%)	Growth[a] (cm)
Kamloops	unpainted	96.4	--
	copper-painted	95.4	--
Nelson	unpainted	100.0	3.8
	copper-painted	97.3	3.7

[a] Mean values for three provenances. At each location there were four or six replicates of 25 trees of each provenance from unpainted containers, and two or three replicates of 25 trees of each provenance from copper painted containers.

Major differences in root form were revealed by excavation of seedlings in the second and fourth years after planting. In the plug seedlings which had not been root-pruned, few roots emerged from the root plug except at the bottom (Fig. 1). However, in the chemically root-pruned stock the main lateral roots emerged from the uppermost part of the root plug very close to the soil surface (Fig. 2). The trees with the box-pruned roots had developed a root system comparable in form with that of a naturally established tree (Fig. 3).

As yet the trees in these plots average less than 1 m in height and therefore are not at the stage when they might be expected to topple. In view of the effect of the root pruning treatment on root morphogenesis it may confidently be predicted, however, that if toppling does occur it will be largely, if not entirely, restricted to the trees that were not chemically root pruned.

In the first two years after planting, shoot extension in the chemically root-pruned trees was comparable with that of the regular plug stock. In the third and fourth years, however, height growth in the chemically root pruned stock was 15% greater than in the conventional plug seedlings (Table 2). A preliminary analysis of the fourth year height growth data, based upon the treatment means, indicates that the effect is highly significant.

Table 2. Annual height growth of chemically box-pruned and unpruned lodgepole pine plug seedlings planted at Lassie Lake, Nelson Forest Region.

	Mean increase in height[a]		
Year	Pruned (cm)	Unpruned (cm)	Pruned as % of unpruned
1	3.7	3.8	97
2	9.3	9.0	103
3	23.6	20.6	115
4	29.3	25.6	115

[a] Mean values for three provenances. At each location there were four or six replicates of 25 trees of each provenance from unpainted containers, and two or three replicates of 25 trees of each provenance from copper painted containers.

The practical significance of this effect depends on its reproducibility and persistence. Its potential significance is indicated by consideration of the fact that, with the first generation of seed orchards, it is expected that a lodgepole pine improvement program in B.C. will achieve something like a 10% increase in rate of height growth (Dr. C. Ying, personal communication). It is possible, therefore, that because of a difference in root form, genetically improved lodgepole pine established by conventional planting techniques will grow more slowly than unimproved trees established naturally. In plantations where there is some natural regeneration the result of this could be the removal of the genetically improved planted trees when the stand is spaced.

Experience with lodgepole pine suggests that the chemical root-pruning technique is useful only when the container is small. The reason for this is that, by the time an extractable plug has been formed in a large container, a second order lateral root,

Figure 1. Root of an ordinary lodgepole pine plug seedling two seasons after planting.

Figure 2. Chemically box-pruned root of a lodgepole pine plug seedling two seasons after planting.

Figure 3. Chemically box-pruned root of a lodgepole pine plug seedling two seasons after planting (right) compared with the root of a naturally established tree.

growing from near the tip of the chemically inhibited first order lateral, will have developed into a major sinker root. This root, being either ageotropic or positively geotropic, grows directly downwards close to, but not in contact with, the container wall. Thus the tree acquires an array of major lateral roots growing down the sides of the root plug which are similar in appearance, though not in origin, to the main lateral roots of an ordinary plug seedling. Moreover, when the tree is planted, the second order sinker roots extend vigorously from the bottom of the root plug while the chemically inhibited first order laterals remain inactive. Whether the failure of the first order lateral roots to elongate after planting is due to correlative inhibition--the well developed second order sinker roots exerting dominance over the chemically inhibited primary roots--or to the abortion of the primary root meristem has not been determined. In either case, the result is that the chemically root-pruned seedling is unable to form a system of major lateral roots growing straight out from the tap root.

In order to assess the influence of the characteristic effect of container growing on root form on the performance of species other than lodgepole pine, the chemical root pruning technique has been tested on nine other coniferous species. Without modification, however, the technique used with lodgepole pine was fully effective only with Scots pine *(Pinus sylvestris* L.). Experiments currently in progress indicate that by increasing the copper content of the wall coating or by reducing the lime content of the growing medium the treatment may be made effective with a number of western conifers. Much remains to be done, however, to define the conditions necessary for a satisfactory result in each species.

That the chemical root pruning technique is not universally applicable without modification constitutes a major limitation to its usefulness. For this reason a more versatile mechanical root pruning technique for box-pruning the roots of container-grown stock has been devised. The method depends upon the use of a slot-sided tray in which seedlings are grown on a grid-spacing. To prune the roots the tray is passed under a set of knives which pass through the slots in the sides of the tray and between the rows of trees (Fig. 4). After the first pass, the tray is rotated through 90° and passed under the knives again. In this way the roots of each seedling are cut on four sides. It is possible with this technique to produce stock of any species and size with a box-pruned root system. By judicious timing, the root pruning treatment should provide a means of controlling height growth, top:root ratio, and possibly root growth capacity.

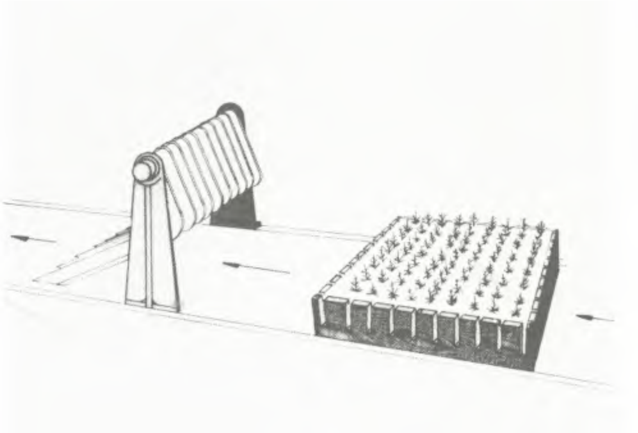


Figure 4. A mechanical system for box-pruning the roots of container-grown stock.

LITERATURE CITED

Burdett, A.N.
1978. Control of root morphogenesis for improved mechanical stability in container-grown lodgepole pine. Can. J. For. Res. 8:483-486.

Burdett, A.N.
1979. Juvenile instability in planted pines. Ir. For. 36:36-47.

Chavasse, C.G.R.
1978. The root form and stability of planted trees, with special reference to nursery and establishment practices. p. 54-64 *in* E. Van Eerden and J.M. Kinghorn, *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8.

Clarke, R.W.
1956. Wind damage in planted stock and natural regeneration of *Pinus radiata* at Mount Stranlo A.C.T. Aust. For. 20:37-39.

ROOT DEVELOPMENT CONTROL MEASURES IN CONTAINERS: RECENT FINDINGS

Stephen E. McDonald[1], Richard W. Tinus[2], and C.P. Patrick Reid[3]

Abstract.--Coating the inside surfaces of containers with cupric carbonate (CuCO3) caused roots of Ponderosa pine *(Pinus ponderosa* Laws.) to stop growth at the container wall. Higher order laterals then proliferated and were arrested. These roots resumed growth radially when the container was removed. Degree of root crowding had little influence on treatment effect. Indole butyric acid (IBA) worked also, but not as well as CuCO3. The CuCO3 treatment was complementary to mycorrhizal inoculation of the growing medium. Combination of the two treatments resulted in bigger trees, more lateral roots, and more mycorrhizal infection than either treatment alone.

Résumé.--Au contact des parois intérieures des récipients enduites de carbonate de cuivre ($CuCO_3$), les racines de pin Ponderosa *(Pinus ponderosa* Laws.) arrêtent de croître. Ensuite, les racines latérales d'un ordre plus élevé prolifèrent mais sont arrêtées de même; elles reprennent leur croissance radiale quand on sort le plant du récipient. Le degré d'encombrement des racines n'influe que peu sur l'effet du traitement. L'acide indole-butyrique est efficace, mais pas autant que $CuCO_3$. Ce dernier agit complémentairement à une inoculation mycorrhizienne du milieu de croissance. La combinaison des deux traitements donne des arbres plus gros, des racines latérales plus nombreuses ainsi qu'une infection mycorrhizienne plus importante que ne le peut un seul d'eux.

INTRODUCTION

The work on control of tree seedling root development in containers, which is discussed in this paper, was stimulated by Burdett's (1978) report, in which the author stated that "lodgepole pine seedlings were grown in styroblocks painted with root growth inhibitor (exterior latex paint containing 100 gm/1 cupric carbonate). This inhibited elongation of lateral roots while in the container, but these roots resumed growth when the tree was removed from the container. Consequently the tree soon acquired a root system form similar to that of a naturally established one." We will not go into detail here as to why these findings may be so important to reforestation, but will simply refer you to all the problems with root deformation of planted trees described in the proceedings of the 1978 Victoria symposium on the subject (Van Eerden and Kinghorn 1978). Suffice it to say that it appeared that Burdett's technique, or an elaboration of it, might enable a nurseryman to produce a tree capable of rapidly sending out lateral roots immediately after planting. This could result in planted trees that reliably grow as

---

[1] Forestation and Tree Improvement Specialist, USDA Forest Service, Washington, D.C.; [2] Principal Plant Physiologist, Rocky Mountain Forest and Range Experiment Station, Bottineau, N.D.; [3] Professor of Forest Biology, Colorado State University, Fort Collins, Colorado.

Note: The use of trade names in this publication does not constitute or imply endorsement by the USDA Forest well as, or better than, seeded trees, and are windfirm.

Consequently, in 1978, the authors set out to:

1. duplicate Burdett's experiments, using Ponderosa pine *(Pinus ponderosa* Laws.), the most widely distributed commercial forest tree species in the western United States;

2. see if some other chemicals or other cupric carbonate concentrations would have similar effects on tree root morphogenesis in containers;

3. acquire knowledge about the treatment effect in relation to the degree of root development in the container;

4. see what interactive effects the treatment had when combined with mycorrhizal inoculation of container growing medium.

In the following discussion of methods and results relating to each of these areas of investigation, the methodology will be discussed only briefly. Full details are given in McDonald (1981).

TESTS OF OTHER CUPRIC CARBONATE CONCENTRATIONS AND OTHER INHIBITORS

Method

In a short-term study the roots of Ponderosa pine seedlings were exposed to various concentrations of cupric carbonate (CuCO3), indole butyric acid (IBA), and trifluralin herbicide (Table 1). This was done by combining the chemicals with exterior latex paint and coating the interior walls of Spencer-Lemaire "Rootrainers" with the solution. The paint was allowed to dry and then the seedlings were reared in the containers as directed by Tinus and McDonald (1979).

After 26 weeks half the seedlings in each treatment (six) were measured (top height, number of needle fascicles, average length of secondary needles, number of roots air pruned, number of roots encountering the wall and turning downward, and root and top dry weights). At the same time the other six trees of each treatment were removed from the containers and planted in a 20 x 20 cm grid pattern in damp vermiculite in a greenhouse bench. After five weeks these trees were carefully removed from the vermiculite. The number and length of roots extending beyond the original root "plug" were measured, and care was taken to distinguish between those growing from the sides and those growing from the bottom of the "plug".

The first measurements were taken to examine treatment effects at time of removal from the container. The second set was taken to determine if treatments actually influenced side root development after simulated outplanting.

Results

Trifluralin, at all concentrations, had pronounced adverse effects on the seedlings; it was not used thereafter.

The highest concentration of CuCO3 (100 g/L) not only reduced root deflections (from an average of 12 per tree to 3 per tree) in comparison with no treatment, but also resulted in significantly bigger trees (48% taller and 74% heavier) (Table 2).

However, the paint-only treatment significantly reduced growth in comparison with that of trees from untreated containers. High concentrations of CuCO3 in the paint overrode this negative carrier effect. Low concentrations of CuCO3 had little effect.

High concentrations of IBA appeared to cause trees to grow better than those reared in the paint-only treatment, but the effect was weak and erratic in comparison with the CuCO3 effect.

Trees treated with CuCO3 (at 100 g/L) and reared in the vermiculite bench for 5 weeks after container removal had 27% of

Table 1. Chemical root inhibitor treatments

Chemical/paint treatment	Concentrations (g/L)					
No treatment	-	-	-	-	-	-
Paint only	-	-	-	-	-	-
Trifluralin	70.88	14.18	2.84	0.56	-	-
$CuCO_3$	100.00	10.00	3.00	1.00	-	-
IBA	50.00	5.00	0.05	0.005	0.005	0.0005

Table 2. Comparison of size and root deflections of Ponderosa pine seedlings from copper-painted containers (mean of six trees).

$CuCO_3$ concentration (g/L paint)	Height (mm)	Shoot dry wt (g)	Root dry wt (g)	Roots deflected
0.1	44.2	0.49	0.35	12.2
1.0	48.7	0.60	0.39	7.5
3.0	54.8	0.92	0.54**	9.0
10.0	54.8	0.81	0.48	9.7
100.0	65.2*	1.00**	0.61*	3.7*
No paint	58.7*	0.78	0.50	) Not
Paint only	46.8	0.51	0.35	)measured

*,** Significant (5% probability) or highly significant (1% probability) differences, respectively from paint-only (t-test)

their roots as side roots in comparison with 8% for untreated trees, three times more side root length than untreated trees, about the same total egressed root length (side and bottom) as untreated trees, and significant increases in height growth over untreated trees (Table 3).

Conclusions

A few generalizations can be made from this first study:

1. Treatment of the containers with the higher concentrations of CuCO3 (and, to a lesser extent, IBA) resulted in a greater proliferation of side roots of Ponderosa pine following greenhouse transplanting. Lower concentrations were relatively ineffective.

2. The latex paint carrier may be phytotoxic, but the effect is overridden by the CuCO3 or IBA treatment at higher concentrations. Another carrier might be better.

3. Treflan (trifluralin), at the concentrations tested, is too phytotoxic for use in this manner.

4. Our findings using CuCO3 with Ponderosa pine were similar to those of Burdett (1978) with lodgepole pine *(Pinus contorta* Dougl. ex Loud.).

TESTS WITH CuCO3/IBA AND VARIOUS MECHANICAL TREATMENTS

Plants kept in containers too long will form undesirable, constricted root systems from which they may never recover when planted in their permanent location (Harris et al. 1971). These negative effects have long been observed (Knight 1809). Armson (1978) has pointed out that three things really determine the nature of the root system generated in a container: (1) the length of time the tree grew in the container, (2) the rate of seedling growth, and (3) the nature of the container. Ideally, seedlings should be reared in the container only until there is sufficient root development to hold the growing medium together (Carlson and

Table 3. Post-planting data for Ponderosa pine seedlings treated with $CuCO_3$ (6 trees/treatment).

$CuCO_3$ concentrated (g/L paint)	Mean side roots as % of total roots	Mean length of side roots (cm)	Mean total root length (cm)	Mean root collar diameter (cm)	Mean stem height (cm)
No paint	7.8	19.3	248.5	2.8	58.0
0.0	9.4	12.0	64.0**	3.0	59.3
1.0	4.7	3.7*	78.8**	2.2	38.7*
3.0	12.1	19.1	158.0	3.0	64.3
10.0	12.0	25.7	214.3	3.3	63.8
100.0	27.1	61.2**	226.0	3.3	70.0*

*, ** Significant (5% probability) or highly significant (1% probability) differences, respectively, from no-paint treatment.

Nairn 1977). However, we know that this is often operationally impractical. A root morphology control procedure may be doubly important if it results in a better root system (than that of a tree from an untreated container) when the tree is left in the container longer than desirable.

Method

Ponderosa pine seedlings were reared in treated Ray Leach super cells. Four container treatments were used: (1) no treatment, (2) $CuCO_3$ in latex paint at 50 g/L painted on the inside of the cells, (3) IBA at 5 g/L in paint as in (2), (4) five mechanical treatments consisting of various patterns of slots and holes cut into the walls of the cells. The seedlings were grown to a common state of top development. Budset was then induced and root growth was continued for 1, 2, 3, or 4 months before being stopped completely. Following a cold storage period, 10 trees of each container treatment/root development combination were measured (stem diameter, top height, number of roots deflected downward at the container wall, and number of roots at the drainage hole). Another 10 trees were transplanted into 7 L pots filled with moist peat for continued growth in a shadehouse. These transplanted trees were allowed to grow for two months, then were removed from the pots. The peat was carefully removed from the roots extending beyond the original container root plug volume. The side and bottom roots of these trees were then measured (number and fresh weight), as were stem heights and root collar diameters.

Results

Upon removal of the seedlings from the Leach cells it was found that the added time allowed for root development had no significant effect on any of the measured parameters. However, when all the trees in a container treatment were compared, regardless of time allowed for root development, the copper-treated trees had a highly significant reduction in root deflections at the container wall in comparison with those from containers with no treatment. Trees grown in mechanically treated containers had a significant reduction in root deflection, hut the trees were also stunted. Average survival in mechanically treated containers was 39%. Survival in containers with no slots or holes was 93%. Containers with slots or holes allowed the growing medium to dry out under a normal greenhouse irrigation regime.

Seedlings transplanted from containers to pots were compared, one treatment/root development combination to another, in a two-way analysis of variance routine (ANOVA). Container treatments (IBA, $CuCO_3$, slots) had highly significant effects on nearly all growth parameters. Duration of root development period following top growth cessation had little effect over all. This would suggest that (1) the degree of root development differential was insufficient to induce an effect or (2) the treatment ($CuCO_3$) ameliorated the effect of root crowding in the containers.

Conclusions

The correlation with $CuCO_3$ treatment, fewer root deflections at the root-container wall interface, and enhanced side root development following removal of the trees from the container, observed in previous work, was reproduced in this test. Again, $CuCO_3$-treated trees grew bigger than those in other treatments.

The synthetic auxin analog, IBA, was again a weak substitute for $CuCO_3$. The application method apparently does not keep this powerful root growth inhibitor at the root-container wall interface in sufficient amounts.

Finally, there were no differences in root egress rates of the seedlings grown to four different degrees of root development. There is some question as to whether enough root compression was achieved to acquire a real effect, but if there was, these results mean that the $CuCO_3$ treatment effectively retarded root growth distortion because of crowding. More work is needed to see if this is indeed true.

TESTING EFFECTS OF CUPRIC CARBONATE TREATMENT-MYCORRHIZAL INOCULATION INTERACTION

The preceding work, and Burdett's work, indicate that cupric carbonate, used as described, brings about changes in root system morphogenesis in containerized lodgepole and Ponderosa pine.

The $CuCO_3$ treatment results in a proliferation of lateral roots which arise from the inhibited primary laterals. This may provide a root system more susceptible to infection by mycorrhizal fungi in the container (Hatch 1933). On the other hand, it is possible that the $CuCO_3$ treatment would inhibit formation of mycorrhizae. Inoculation of growing medium in treated and untreated (CuCO3) containers and measurement of the development of mycorrhizae on seedlings grown in the medium would resolve the question. If the results were positive it could mean that the combined effect of mycorrhizal inoculation and the CuCO3 treatment would result in an enlargement of the seedlings' nutrient absorbing root surface area (additive effect) (Bjorkman 1970).

Method

Two species of known mycorrhizal fungi, *Suillus granulatus* (L. ex Fr.) O. Kutze isolate #133, and *Pisolithus tinctorius* (Pers.) Coker and Couch isolate #75-20, were prepared as inoculum, according to Marx and Bryan's procedure (1975), by Steven Grossnickle at the Forest Tree Physiology Laboratory at Colorado State University. The washed mycelial fungal inoculum was combined, at a rate of 10% (v/v), with a peat/vermiculite growing medium. Inoculated and uninoculated growing media were used to grow both Ponderosa pine and lodgepole pine seedlings in Spencer-Lemaire "Rootrainers". Some of the containers were treated with cupric carbonate, and some were not (Table 4). This resulted in a 2 (tree species) x 2 (container treatment) x 3 (mycorrhizae treatment) factorial experiment.

The tree seedlings were grown to the point at which the root-growing medium matrix could easily be removed intact from the container. Budset was then induced, and the trees were removed and measured (height, root-collar diameter, number of roots deflected, and number of short roots infected and not infected with mycorrhizal fungi).

Results

The data were summarized, and a three-way ANOVA, comparing container treatment, tree species, and species of fungus, was calculated on each of the measured parameters.

Trees grown in copper treated containers were somewhat bigger with respect to stem height and diameter than those grown in untreated containers (Fig. 1 and 2), as were the trees grown in inoculated medium (plain containers) in comparison with those grown in uninoculated medium (25-40% larger). Trees subjected to the combined treatments (copper and mycorrhizae) often had greater height and diameter, especially in Ponderosa pine, than when either treatment was used alone. In no case was stem height or caliper reduced by the combined treatment.

The cupric carbonate treatment greatly reduced root deflections at the container wall and numbers of roots reaching the bottom of the container (Fig. 3 and 4). This occurred whether the medium was inoculated or not in both tree species.

The copper treatment alone resulted in increased numbers of short roots and incidental mycorrhizal infection (Fig. 5 and 6). The copper-mycorrhizal inoculum combinations were very effective in increasing the number of short roots and percentage of mycorrhizal roots for Ponderosa pine, but were less effective or neutral for lodgepole pine.

Table 4. Summary of treatments in the cupric carbonate-mycorrhizal infection interaction experiment.

Mycorrhizal inoculum treatment	Container treatment		
	None	$CuCO_3$ (50 g/L)	Total no. of trees
	- - - - - 10 trees each species - - - -		
None	PP/LP*	PP/LP	40
P. tinctorius	PP/LP	PP/LP	40
S. granulatus	PP/LP	PP/LP	40
Total trees	60	60	120

*PP = ponderosa pine, LP = lodgepole pine

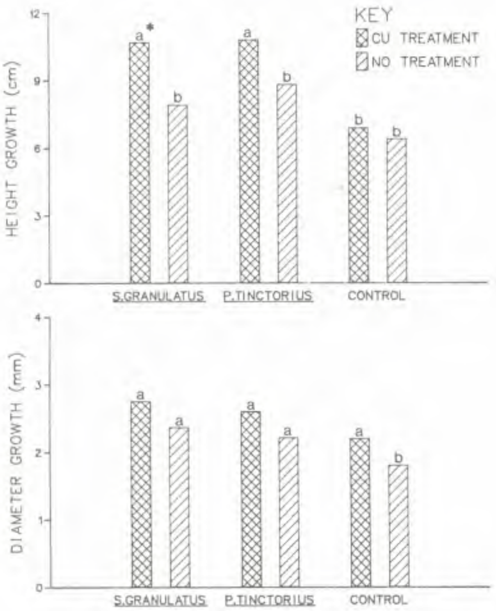


Figure 1. Height and diameter growth of *P. ponderosa* with mycorrhizal fungus-cupric carbonate interactions. (Means within a given copper-mycorrhizal treatment with a common letter are not significantly different at $\alpha = 0.05$ as determined by Tukey's mean separation test.)

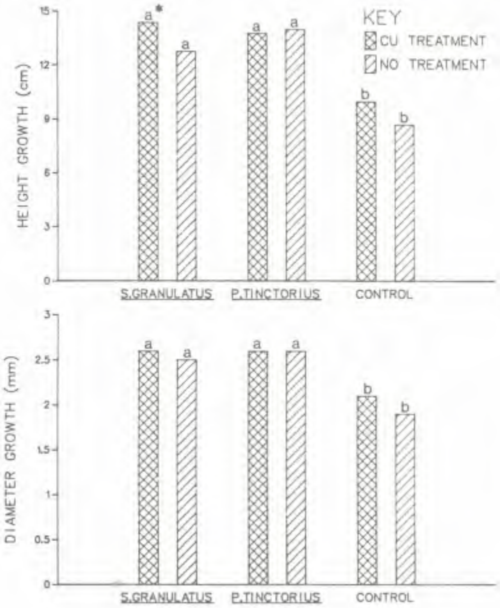


Figure 2. Height and diameter growth of *P. contorta* with mycorrhizal fungus-cupric carbonate interactions. (Means within a given copper-mycorrhizal treatment with a common letter are not significantly different at $\alpha = 0.05$ as determined by Tukey's mean separation test.)

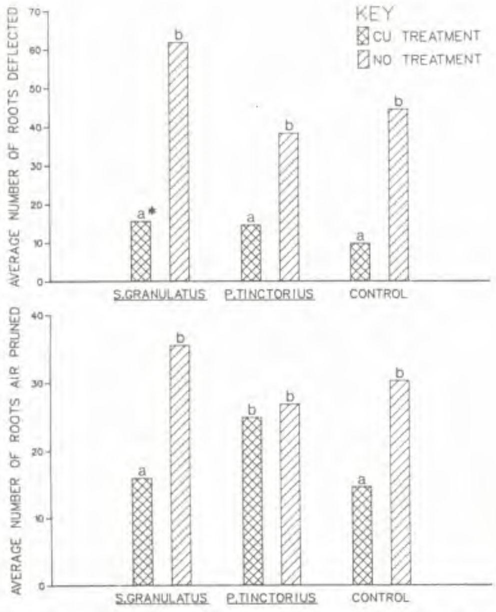


Figure 3. Root development characteristics of *P. ponderosa* with mycorrhizal fungus-cupric carbonate interactions. (Details as in Figure 1.)

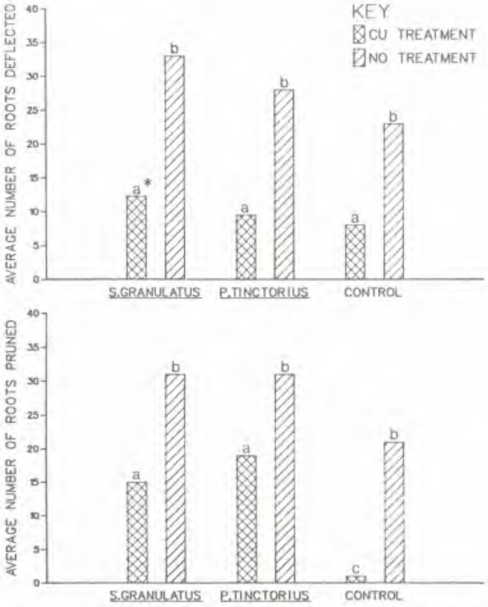


Figure 4. Root development characteristics of *P. contorta* with mycorrhizal fungus-cupric carbonate interactions. (Details as in Figure 2.)

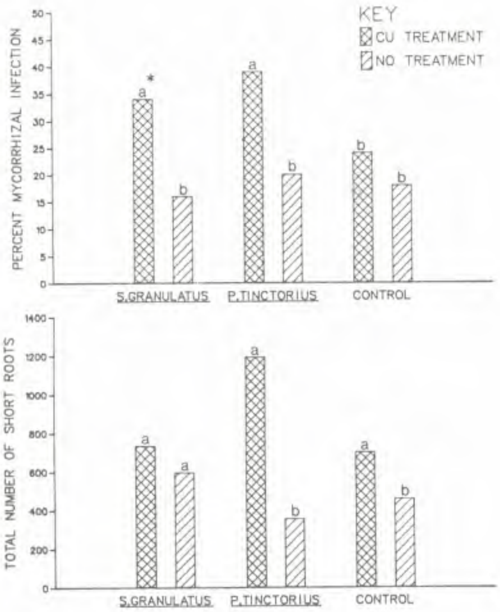


Figure 5. Percent mycorrhizal infection and total number of short roots of *P. ponderosa* with mycorrhizal fungus-cupric carbonate interaction. (Details as in Figure 1.)

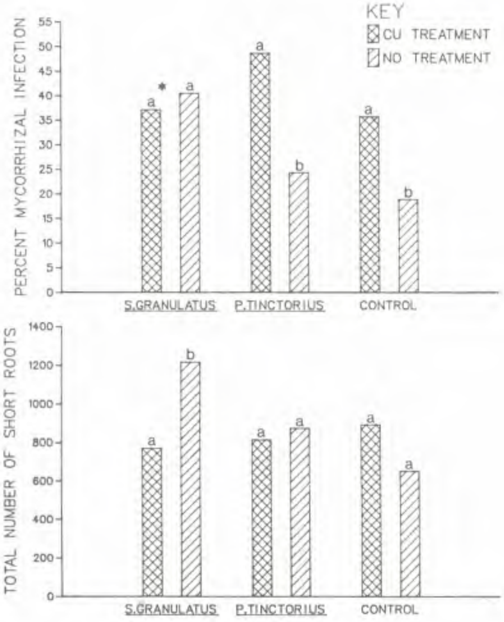


Figure 6. Percent mycorrhizal infection and total number of short roots of *P. contorta* with mycorrhizal fungus-cupric carbonate interaction. (Details as in Figure 2.)

Conclusions

The cupric carbonate treatment generally had beneficial effects on tree morphology (bigger trees, fewer root deflections) and, at the same time, no detrimental effects on the fungal association (percentage of mycorrhizal roots). Indeed, the proportion of mycorrhizal roots was usually much higher where trees were copper-treated. Lodgepole pine appeared to be more readily infected than Ponderosa pine. However, there were some differences in performance of the fungi in association with the different tree species.

This was a small test. Preliminary indications were most encouraging, but more work is needed to confirm these findings.

GENERAL SUMMARY AND CONCLUSIONS

Our findings with cupric carbonate and Ponderosa pine are in agreement with those of Burdett (1978) with lodgepole pine. This validation is based largely on root egress from the root plug following simulated outplanting. The message is clear: coating the interior of containers with acrylic latex paint and cupric carbonate (at concentrations of 50 to 100 g/L of paint) does cause lateral root growth to be arrested at the root-container wall interface. This subsequently leads to a proliferation of higher order laterals which are similarly arrested. These arrested root tips resume growth when the seedling is removed from the container and planted. Consequently, a much higher proportion of the roots emerge from the sides of the root plug than is usually seen when untreated containers are used.

The cupric carbonate treatment caused Ponderosa pine seedlings to be taller and heavier in these tests.

Container type used appears to have little or no influence on the $CuCO_3$ treatment effect.

The synthetic auxin analog, IBA, was effective in high concentrations, but was not as effective as $CuCO_3$. The problem seems to be in keeping IBA at the root-wall interface where it can be effective. A carrier other than latex paint may be better.

The carrier, latex paint, was phytotoxic. However, the $CuCO_3$ effect overrides this phytotoxicity so that this paint can be used until a better carrier is found.

Mechanical treatments (holes, slots in the containers) were disappointing. Trees became stunted or died because the containers tended to dry out in the greenhouse.

The effect of added root crowding on root morphology seemed to be ameliorated by the CuCO3 treatment. While more study on this is needed, these results could be very important where containerized seedlings cannot be planted on schedule.

Seedlings grown in copper-treated containers and in growing medium inoculated with mycorrhizal fungi generally were bigger and had a greater percentage of mycorrhizal roots than comparable seedlings grown in untreated containers and uninoculated medium. The combined treatment was usually better than either treatment alone.

When seedlings were removed from created containers the interior coating of inhibitor was usually left intact. CuCO3-paint mixture coatings may be useful for more than one crop of trees, but this was not tested.

Field plantation tests under way in Canada (by Burdett) and the United States (by the authors) will help determine the long-term effects of the treatment on growth and stability of these pines. In five years or so the results should indicate how valuable the enhanced side root development is. We suspect that the treated trees will grow faster and be more windfirm than untreated trees.

We would urge those of you interested in this procedure to try it now on a small scale. It is simple to do and needs to be tried on other species of trees and at other locations.

LITERATURE CITED

Armson, K.A.
1978. Roots of the new forest. For. Chron. 54(5):268-270.

Bjorkman, E.
1970. Forest tree mycorrhiza--the conditions for its formation and the significance for tree growth and afforestation. Plant and Soil 32:589-610.

Burdett, A.N.
1978. Control of root morphogenesis for improved mechanical stability of container-grown lodgepole pine. Can. J. For. Res. 8:483-486.

Carlson, L.W. and Nairn, L.D.
1977. Root deformities in some container-grown jack pine in southeastern Manitoba. For. Chron. 53:147-149.

Harris, R.W., Davis, W.B., Stice, N.W. and Long, D.
1971. Effects of root pruning and time of transplanting in nursery liner production. Calif. Agric. 25(12):8-10.

Hatch, A.B., and Doak, K.D.
1933. Mycorrhizal and other features of the root system of *Pinus.* *J.* Arnold Arbor. 14:85-99.

Knight, T.A.
1809. On the origin and formation of roots. Proc. R. Soc. Phil., Part 1. p. 169-176.

Marx, D.H. and Bryan, W.C.
1975. Growth and ectomycorrhizal development of loblolly pine seedlings in fumigated soils infested with the fungal symbiont *Pisolithus tinctorius.* For. Sci. 21:245-254.

McDonald, S.E.
1981. Root development control measures for Ponderosa pine seedlings grown in containers. Ph.D. dissertation, Colorado State Univ., Fort Collins. 178 p.

Tinus, R.W. and McDonald, S.E.
1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv., Rocky Mt. For. Range Exp. Stn., Fort Collins, Colo. Gen. Tech. Rep. RM-60. 256 p.

Van Eerden, E. and Kinghorn, J., *Ed.*
1978. Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8.

DISEASES AND INSECTS AND THEIR MANAGEMENT IN CONTAINER NURSERIES

Jack R. Sutherland, W. Lock, and Lee E. Benson[1]

Abstract.--This paper reviews the major non-pathological and pathological diseases (gray mold, storage mold, *Sirococcus* blight) and insects in container nurseries, especially in British Columbia, and relates their incidence, damage and management to hosts, production and cultural practices. Emphasis is on preventive control via manipulation of cultural practices rather than on eradication of established pests by means of pesticides.

Résumé.--Cette communication passe en revue les principales affections pathologiques ou non pathologiques (moisissure grise, moisissure des plants en stockage, brûlure des pousses) et les principaux insectes relevés dans les pépinières de plants en mottes emballées, particulièrement en Colombie-Britannique. Elle établit le rapport entre l'incidence de ces agents, leur dégâts, leur répression et le rendement de leurs hôtes et les techniques culturales y applicables. L'accent est mis sur la lutte préventive par la modification des techniques culturales plutôt que sur l'élimination des colonies de ravageurs au moyen d'insecticides.

INTRODUCTION

Because of the comparatively long history of producing container-grown seedlings in British Columbia (B.C.), the important, and potentially important, diseases and insect pests have been identified and management practices have been developed (Sutherland and Van Eerden 1980). Management practices have been modified and improved as more becomes known about the pests, their hosts and the container-nursery environment. To date, most of the pests recorded locally on container seedlings had previously been reported from bare-root nurseries. However, their relative incidence has differed in that shoot diseases are much more important in container than in bare-root nurseries, where soil-borne root diseases and damping-off predominate. The lesson here is that changes in seedling growing practices may simply alter the relative importance of certain pests rather than eliminate them. Moreover, as container nursery practices change, so will the kinds and importance of pests and pest management strategies.

In B.C. nurseries, the policy is one of pest prevention rather than eradication of established problems. A vital component of this approach is the pest diagnosis and control recommendation service that the Canadian Forestry Service provides for the B.C. Ministry of Forests (BCMF) and forest industry nurseries throughout the province. This service has been provided since the inception of container nursery production; hence, records for several years are available on pest incidence, damage, identity and the relative success of various control practices. These data serve as the basis for this paper, which has the dual purpose of describing disease and insect problems, and their management, in B.C. container nurseries and of relating the incidence of these pests to certain cultural practices and production changes. This approach will benefit managers of existing container facilities and help

---

[1] The first and second authors are research scientist and technician, respectively, Pacific Forest Research Centre, Canadian Forestry Service, Victoria, B.C.; the third author is a casual employee, Silviculture Branch, British Columbia Ministry of Forests, Victoria.

others to anticipate potential pests in recently established or planned nurseries.

SEEDLING PRODUCTION AND PRACTICES

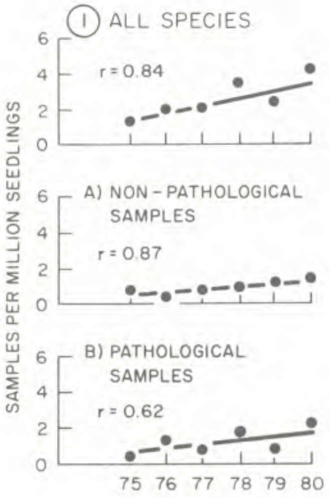
Following research and development of the container concept in the 1960s, BCMF began producing container stock on an operational basis early in the 1970s (Bamford 1974). Production has been limited almost exclusively to conifers and, until 1980, almost all stock was grown by BCMF. From an initial production in 1970 of approximately 750,000 seedlings, consisting of about equal amounts of the coastal form (Hosie 1979) of Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) and western hemlock *(Tsuga heterophylla* [Raf.] Sarg.), production has increased steadily to 37.5 million seedlings in 1980. Production then was made up of about 35% Interior spruce, i.e., white spruce *(Picea glauca* [Moench] Voss) or Engelmann spruce *(Picea engelmannii* Parry) or their hybrids, 23% lodgepole pine *(Pinus contorta* Dougl.), 21% western hemlock, 5.3% coastal Douglas-fir, 3.5% western red cedar *(Thuja plicata* Donn), 3.1% Interior Douglas-fir, 3% Sitka spruce *(Picea sitchensis* [Bong.] Carr.), 1.6% each of mountain hemlock *(Tsuga mertensiana* [Bong.] Carr.) and western larch *(Larix occidentalis* Nutt.), 1% total for Ponderosa pine *(Pinus ponderosa* Laws.) and yellow cypress *(Chamaecyparis nootkatensis* [D. Don] Spach) and 1.4% total for the firs *Abies amabilis* (Dougl.) Forbes, *A. grandis* (Dougl.) Lindl., *A. lasiocarpa* (Hook.) Nutt. and *A. procera* Rehd. Although seedling species are designated according to provenance (Dobbs et al. 1976), it is not uncommon for Interior tree species, especially spruces and Douglas-fir, to be grown in coastal nurseries, but the reverse is seldom practised. Experience suggests that nursery location and pest presence, rather than tree provenance, dictate disease and insect incidence. Smyth (1980) gives the localities, production capacities, tree species grown and other characteristics of B.C. container nurseries and Sjoberg and Matthews (1977) have updated the types of growing facilities and cultural practices employed.

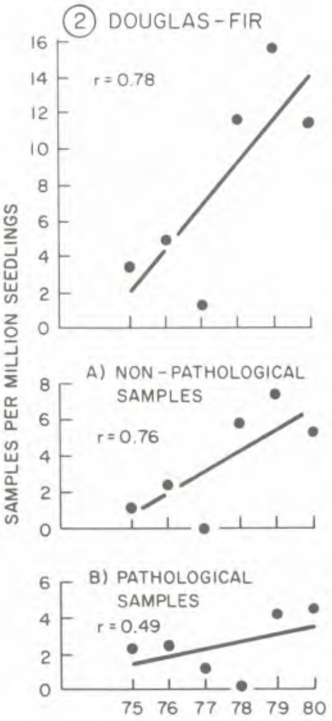
TYPES OF PESTS

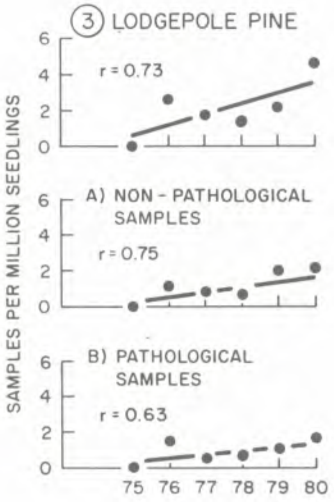
Because few pests have been recorded in British Columbia on seedlings of species other than Douglas-fir, lodgepole pine, spruces (aLl species) and western hemlock, and because records are most complete for the 1975-1980 period, the remainder of this paper deals only with seedlings of the above-mentioned species over those six years. Figure 1 shows that total pest (non-pathological [abiotic, physiological or noninfectious] plus pathological [biotic or infectious] diseases plus insects) samples per million seedlings produced increased at a constant rate between 1975 and 1980. The trend was similar for non-pathological and pathological samples (Fig. 1A and 1B); numbers of insect samples received over the six years were too few and too inconsistent for any trend to be detected. When the total numbers of pest samples over the 1975-1980 period were partitioned according to seedling species (Fig. 2-5), the data showed that numbers of samples increased sharply for Douglas-fir but less so for lodgepole pine and spruces, and remained fairly constant for western hemlock. The increases for Douglas-fir and lodgepole pine were attributable to increases in non-pathological and pathological disease samples (Fig. 2A and 2B, 3A and 3B), while the increasing numbers of spruce samples were only for pathological diseases (Fig. 4A and 4B), particularly *Sirococcus* blight *(Sirococcus strobilinus* Preuss). Like the overall trend for western hemlock (Fig. 5), neither non-pathological nor pathological samples increased (Fig. 5A and 5B) between 1975 and 1980.

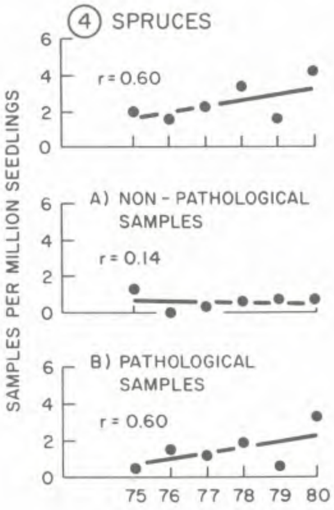
Figure 6 summarizes the numbers and nature of pest samples for the four major kinds of seedlings grown from 1975 to 1980. On a per capita basis, non-pathological and pathological samples were most numerous for Douglas-fir and about equal on lodgepole pine and western hemlock, while pathological problems were most prevalent on spruces. Fertilizer burn of shoots (usually attributable to nitrogen) is the most frequent non-pathological problem on all seedling species, but it seldom causes much direct damage; probably its greatest significance is in predisposing seedlings to gray mold *(Botrytis cinerea* [Fries] Persoon). Fertilizer burn usually results from failure to wash off fertilizers which are applied through overhead irrigation systems or as granular top dressings. Sometimes excessive amounts of fertilizers are applied accidentally and they cause root or shoot killing, or both.

To date, only fungi have been implicated in pathogen-caused diseases of container seedlings. Shoot diseases and, in particular, gray mold and *Sirococcus* blight , are by far the most significant. Gray mold affects all seedlings in the nursery and during storage (designated storage mold), while spruces, lodgepole pine and, infrequently, western hemlock, but never Douglas-fir, are affected by *Sirococcus* (Fig. 6). The most common insects encountered include root/vine weevils, cutworms and shoot- or root-feeding aphids (Sutherland and Van Eerden 1980).









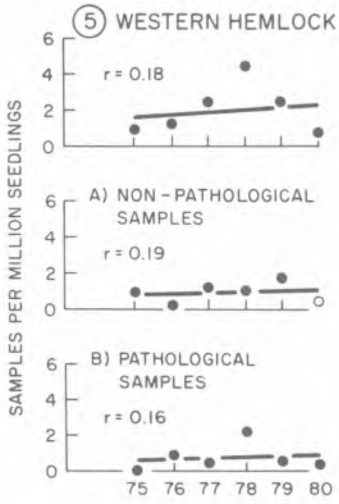


Figure 1. Total, and non-pathological (1A) and pathological (1B) disease samples received (1975-1980) per million seedlings of the four major species (Douglas-fir, lodgepole pine, spruces and western hemlock) produced in B.C. container nurseries; insect samples were insignificant and are not included.

Figures 2-5. Total, and non-pathological (sections A) and pathological (sections B) samples received (1975-1980) per million seedlings of Douglas-fir (Fig. 2), lodgepole pine (Fig. 3), spruces (Fig. 4) and western hemlock (Fig. 5) produced in B.C. container nurseries; insect samples were insignificant and are not included.

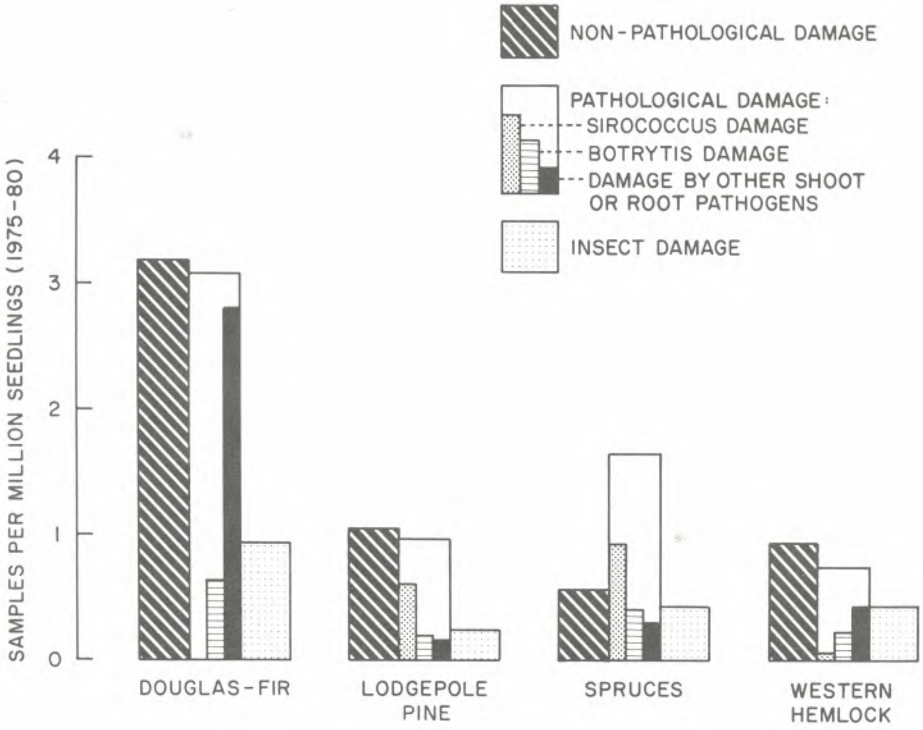


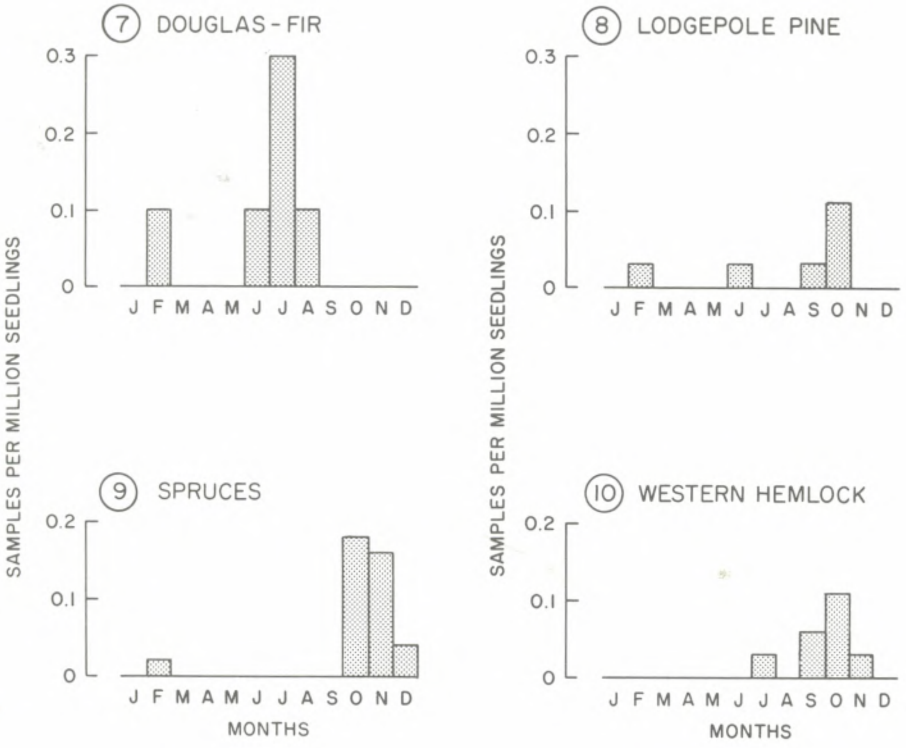
Figure 6. Summary of non-pathological and pathological diseases and insect samples received (1975-1980) per million Douglas-fir, lodgepole pine, spruces and western hemlock seedlings produced; pathological diseases are denoted as gray mold, *Sirococcus* blight and other shoot diseases; other insignificant diseases are not shown.

Gray Mold and Storage Mold

On container-grown seedlings, both diseases are caused by the fungus *Botrytis cinerea.* Gray mold affects seedlings during nursery growth, while storage mold damages them in storage. Frequently, storage mold is a further development of incipient gray mold carried over from the nursery. Damage from both diseases is apparently confined to seedling shoots.

Gray mold: the pathogen and disease

The ubiquitous fungus *B. cinerea* normally lives on dead organic matter, but it can, under certain circumstances, attack living plants. This is how it operates in container nurseries, where it first becomes established on dead (e.g., fertilizer burned) or senescent needles and then spreads to living tissues. Following infection, the pathogen may remain latent until conditions favor disease development. Damage usually occurs from mid- to late summer onward after the seedling canopy has closed. This, plus the weather, provides a combination of conditions favoring the problem: i.e., poor air circulation and high humidity, cooler temperatures, shading and dying of lower needles. In B.C., Douglas-fir and western hemlock are more likely to be affected by gray mold (i.e., *B. cinerea)* infection during the April through August growing season than are lodgepole pine and spruces (Fig. 7-10). Initial symptoms include a watery molding and killing of lower or fertilizer-burned needles which spreads upward, killing needles and woody portions of the shoot. Grayish brown webs of the pathogen's vegetative growth and spores are often present on affected seedlings. Initially, the disease occurs on individual seedlings and spreads to form patches of diseased seedlings, which often coalesce. Spread occurs via vegetative growth of the pathogen or by the massive numbers of air-borne spores. Although the complete life cycle of the pathogen, particularly its method of overwintering, is not known for container nurseries, the pathogen is probably reintroduced annually as air-borne spores from outside the container nursery. Most seedling species are susceptible to gray mold, but the disease seems to be less damaging to species such as pines, whose upright growth habit probably



Figures 7-10. Samples per million seedlings produced of *Botrytis* affected Douglas-fir (Fig. 7), lodgepole pine (Fig. 8), spruces (Fig. 9) and western hemlock (Fig. 10) received (1975-1980) per month.

creates a less favorable microclimate for the pathogen.

Gray mold: management

Because there are no practical methods for excluding spores of the pathogen from container nurseries, management recommendations are based, where practical, on making the nursery environment less favorable for gray mold and applying fungicides to prevent, rather than eradicate, the disease. Cultural practices that should be employed from late summer onward include increasing spacing between containers, improving air circulation and decreasing irrigation--all of which help to reduce relative humidity--and perhaps increasing temperatures in cool greenhouses. Fertilizer-burned or frost-damaged stock should be monitored closely for gray mold development. Sanitation procedures include removal and destruction of plant debris and diseased plants upon which the fungus sporulates. One or more applications of a protective or systemic fungicide prior to canopy closing should be useful. Another option is the application of alternate sprays of protective and systemic fungicides or of one or two sprays of a systemic fungicide prior to or during the high danger period. Continuous use of a single fungicide, particularly certain systemics, is not recommended, since tolerant strains of *B. cinerea* may develop (Cooley 1981, Hopkins 1980). Even when two or more materials are used in rotation, checks should be made to determine if *B. cinerea* tolerance has developed. Often the quantity of fungicide(s) used can be minimized by applying the materials only to those areas in which disease is evident. Fungicides alone will never give satisfactory control unless used in conjunction with cultural controls (Cooley 1981). Reduction in fungicide use can often be achieved by ensuring that application equipment is as efficient as possible. Obtaining good control of gray mold by combined cultural practices and minimal fungicide use is becoming increasingly necessary, since outplanting crews may be reluctant to handle fungicide-treated seedlings.

Storage mold: the pathogen and disease

Experience in B.C. shows that *B. cinerea* is the sole fungus responsible for molding of stored container stock (Hopkins 1980). Storage mold (September through February) of Douglas-fir and western hemlock, but not spruces and lodgepole pine, seems to be preceded by detectable gray mold in the nursery (Fig. 7-10). Perhaps storage mold of seedlings of the latter two species is simply not a carry-over problem from the nursery, or perhaps *B. cinerea* from the nursery remains latent and undetectable until the stock is stored. Storage mold of Douglas-fir and western hemlock in particular (Fig. 7 and 10) is simply a further development of an already existing, but often undetected, gray mold problem. Seedlings damaged by fertilizer burn, frost or other physiological disorders which create food bases for the pathogen, are especially prone to storage mold. As expected, storage mold symptoms and hosts affected are much the same as for gray mold in the nursery, but seedlings of species that can be stored frozen usually suffer less than seedlings of species such as western hemlock that do not withstand subfreezing storage temperatures.

Storage mold: management

Preventing gray mold outbreaks and incipient disease in the nursery, which will be carried over to storage, is the best approach to reducing storage mold losses. The following procedures are also recommended: store stock, particularly fertilizer-burned or frost-damaged seedlings, for the shortest period possible; avoid storing wet stock; store stock at as low a temperature as it will withstand, even -1 or -2 C if possible; inspect stock frequently; try to outplant stock with incipient mold and ensure that stock is "hardened off" before storing. Also, one or more applications of systemic fungicide late in the growing season may be worthwhile.

Sirococcus Blight

The pathogen and disease

The fungus *Sirococcus strobilinus* causes a shoot blight of conifers in nurseries and juvenile stands throughout the North Temperate Zone of North America and Europe. Incidence of *Sirococcus* blight on *Picea* spp. in B.C. increased steadily (Fig. 11) between 1975 and 1980, paralleling the increased spruce production. Recent studies (Sutherland *et* al. 1980) showed that the fungus can be seed-borne on interior and Sitka spruce container seedlings in B.C. Quite likely it is seed-borne elsewhere, since it has been recorded on cones in the Prairie Provinces and New Brunswick. Besides spruces, other hosts such as lodgepole and Ponderosa pines and, rarely, western hemlock may be affected, but evidence indicates that the pathogen is not seed-borne on them.

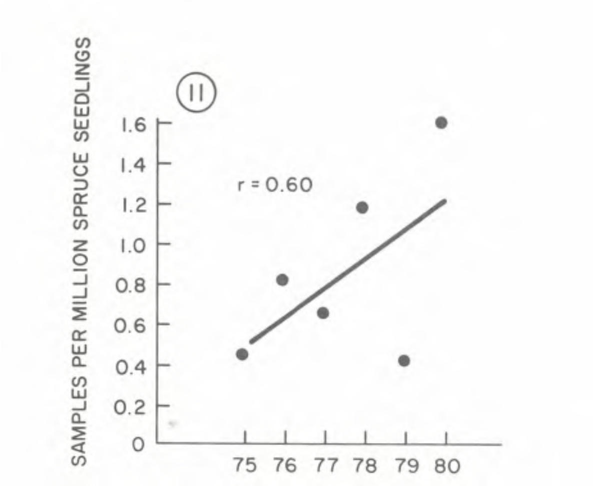
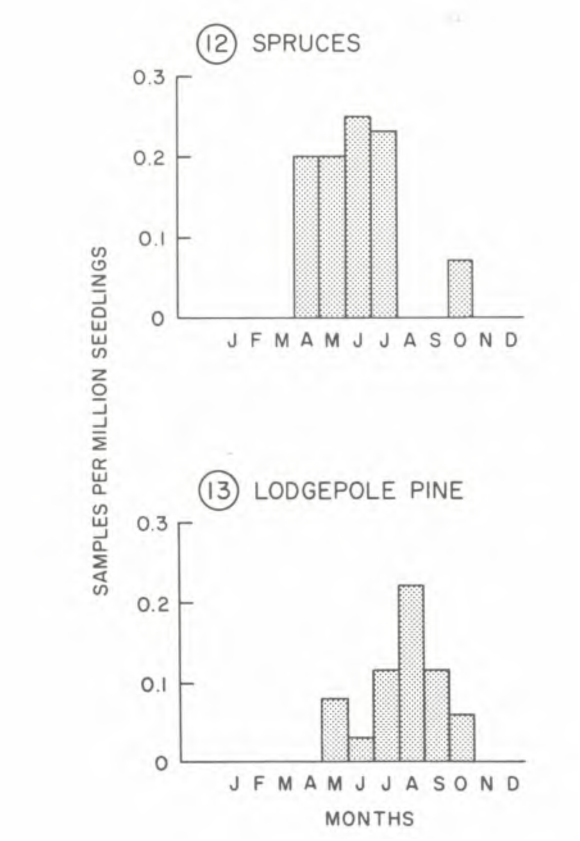


Figure 11. Samples, per million seedlings produced, of spruces affected by *Sirococcus* blight.

Inoculation of seedlings of these species occurs via water or rain-splashed spores originating from seed-borne diseased spruces or diseased trees adjacent to the nursery. Regardless of the primary source of the pathogen, spores for subsequent spread originate from diseased nursery seedlings of any species. On container-grown spruce, symptoms usually appear first on randomly distributed germinants between the period before seedcoat shed through to secondary needle appearance and leader development (Fig. 12). On species such as lodgepole pine (Fig. 13), where the inoculum is apparently not seed-borne, damage tends to appear after secondary needles have developed. When seed-borne, the disease is distinctly noticeable on specific spruce seedlots. Characteristically, the disease kills needles from the base upward and moves up the epicotyl. Small, irregularly shaped, light tan to dark spore-producing bodies (pycnidia) form on killed tissues. Diseased needles are light to reddish brown, desiccated rather than decayed, and killed seedlings remain upright.

Management

At present, most seeds are collected from wild trees; hence, there are no practical methods for reducing or preventing infection of seeds, i.e., seed-borne inoculum, but the incidence of *Sirococcus* blight should diminish as disease-free seeds produced in seed orchards come on stream. Meanwhile, nursery managers should be alerted before sowing seedlots with blight histories so that remedial practices, such as roguing diseased seedlings and applying protective fungicides, can be taken at first appearance of the disease. Confining infested seedlots to a specific nursery area may help prevent disease spread, and removal of diseased trees or application of fungicides to diseased trees adjacent to the nursery would be beneficial. Other recommendations include, where practical, reducing relative humidity, increasing the temperature in cool greenhouses, and supplying supplemental light during periods of excessive cloudiness.



Figures 12 and 13. Monthly incidences (samples received) of *Sirococcus* blight from 1975-1980 on spruces (Fig. 12) and lodgepole pine seedlings (Fig. 13).

Insects

Kinds and damage

There are many incidental insects such as defoliators that are wind-blown or otherwise invade container nurseries from nearby forests or agricultural areas. Frequently neither the container nursery environment nor the food sources are suitable for the invaders and minimal seedling damage results. Occasionally, container seedlings are damaged by insects that are host specific on forest trees or on young plants, or both. Examples (Sutherland and Van Eerden 1980) include cutworms, spider mites, numerous aphids and root and vine weevils. Since most container nurseries produce only one crop per year, these pests must re-invade the nursery annually. Some insects thrive in container nurseries, where conditions such as high temperatures (autumn through spring) may shorten generation time, decrease overwintering mortality or allow overwintering of life stages advantageous to population increases during the growing season. In B.C., root and vine weevil larvae are among the most prevalent, destructive and difficult to control. They consume seedling roots and can migrate through styroblocks to reach seedlings in adjacent cavities. These pests also have been reported from container nurseries in Ontario and New Brunswick.

Insect problems that have been experienced across Canada are outlined briefly on the next page. To date, no insect damage has been noted on stored container stock.

Management

The rapid and often erratic population buildup of many insects in container nurseries hinders implementation of preventive measures. However, devices such as pheromones, light traps and sticky traps for detecting adults of certain pest insects are becoming commonplace. Ordinarily, it is easier to detect and control adults (which often do little damage) than larvae, particularly larvae that inhabit or hide in the container growing medium. Control of these larvae, especially with insecticide drenches, is further complicated by the short efficacy period and poor ability of most insecticides to penetrate the container growing medium. Standard insecticide sprays or sometimes insecticidal soaps are routinely employed against foliage insects such as aphids. Insect-proofing and pre-sowing fumigation and sanitation of greenhouses and other growing areas should be standard practices. Cull piles and the like that harbor insects should be eliminated. Insecticidal baits are often effective against container nursery insects; their application can be restricted to specific areas where damage occurs or to refuges around the nursery.

Insect	Type of damage	Hosts
Various defoliators	Consume foliage	Numerous
Aphids	Cause chlorosis and unthriftiness	Numerous, often host specific
Cutworms	Clip off and consume very young seedlings	Many
Root/vine weevils	Consume roots	Numerous

DISCUSSION

Experience in B.C. shows that the total number of pest samples (non-pathological and pathological disease plus insects) of container-grown Douglas-fir, lodgepole pine, spruces and western hemlock received by the Canadian Forestry Service increased steadily between 1975 and 1980 (Fig. 1). We strongly suspect that the corresponding increases in seedling production alone were only marginally responsible for the larger numbers of pest samples. Undoubtedly other more important factors were: (i) increased staff awareness of pests resulting from training sessions emphasizing pest identification and abatement, especially preventive practices and control at incipient stages, and (ii) increased production of certain seedling species such as spruces that are more affected by host-specific pests. The best support for these hypotheses is that while pest reports increased per million seedlings produced from 1975 to 1980, no major disease or insect losses were recorded. Incidence of non-pathological diseases (section A of Fig. 2-5 and Fig. 6) such as fertilizer burn should decrease as nursery staff gain more experience with the nutrient requirements and toxicity tolerances of specific seedling species. The use of medium-incorporated, encapsulated fertilizers may also help to reduce the incidence of foliage damage.

Ideal conditions such as crowding, high humidity and shading of lower needles certainly account for the high incidence of shoot diseases, particularly gray mold, in container nurseries. This disease is the greatest threat in B.C. and the major problem in the Maritimes (R.D. Hallett, personal communication) and United States container nurseries (Tinus and McDonald 1979). It seems to be of less concern in Alberta and Ontario, perhaps because seedlings there are outplanted before reaching the canopy-closing stage. If the need arose for larger seedlings or for storing stock, or both, gray mold and storage mold could become more troublesome in these localities.

ACKNOWLEDGMENT

We thank staff members of the British Columbia Ministry of Forests for providing seedling production data and Carol Lawko for preparing the resume.

LITERATURE CITED

Bamford, A.H.
1974. Development of the British Columbia container program. p. 53-60 *in* R.W. Tinus, W.I. Stein, and W.E. Balmer, Ed. Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Cooley, S.J.
1981. Fungicide tolerance of *Botrytis cinerea* from conifer seedlings. USDA For. Serv., For. Pest Manage., Reg. 6, Portland, Oreg., 13 p.

Dobbs, R.D., Edwards, D.G.W., Konishi, J. and Wallinger, D.
1976. Guideline to collecting cones of B.C. conifers. B.C. Min. For./Can. For. Serv., Victoria, B.C. Jt. Rep. No. 3. 98 p.

Hopkins, J.C.
1980. Storage moulding. (Abstr.) Proc. West. For. Conf., Victoria, B.C.

Hosie, R.C.
1979. Native trees of Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. 380 p.

Sjoberg, N.E. and Matthews, R.G.
1977. Small containers used in forestry may provide breakthrough for ornamental industry. Am. Nurseryman 145(11):12-13; 55-59.

Smyth, J.H.
1980. A directory of forest tree nurseries in Canada. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Report 0-X-305. 51 p. + Appendix.

Sutherland, J.R., Lock, W. and Farris, S.H.
1980. *Sirococcus* blight: a seed-borne disease of container-grown spruce seedlings in coastal British Columbia forest nurseries. Can. J. Bot. 59:559-562.

Sutherland, J.R. and Van Eerden, E.
1980. Diseases and insect pests in British Columbia forest nurseries. B.C. Min. For./Can. For. Serv., Victoria, B.C. Jt. Rep. No. 12. 55 p.

Tinus, R.W. and McDonald, S.E.
1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. Gen. Tech. Rep. RM-60. 256 p.

AN INTEGRATED INDUSTRIAL SYSTEM FOR THE PRODUCTION OF TREE SEEDLING CONTAINERS

Adrian Barbulescu[1]

Abstract.--A new type of container was developed as well as the process and machines required for its industrial production. Last winter, 3.5 million tree seedlings were produced and grown in the greenhouses of the Ministere de l'Energie et des Ressources du Quebec. Productivity, quality, reliability and costs are discussed and new challenges are outlined for future development.

Résumé.--Un nouveau type de récipient, ainsi que le procédé et les machines nécessaires pour sa production industrielle, ont été mis au point. L'hiver dernier, 3.5 millions de semis d'arbres ont été produits et cultivés dans les serres du Ministère de l'Énergie et des Ressources du Québec. La productivité, la qualité, la fiabilité et les coûts sont discutés et des nouveaux défis pour l'avenir sont exposés.

INTRODUCTION

A strong trend toward the use of containerized seedlings in reforestation started in the early 1970s and all provinces of Canada have now implemented container planting programs of varying complexity. Many types of container have been considered and tested by different organizations since then and a great deal of research and development work has been accomplished.

The program in Quebec was one of the few that sought a container system amenable to integration of the production process. Such a process was seen to include not only such operations as peat treatment, filling, sowing and packaging, but also forming of the container itself (Bonin 1972).

A long-term project was initiated by the Ministere de l'Energie et des Ressources du Quebec (MERQ) in the mid-1970s to develop the above container program. The Centre de Recherche Industrielle du Quebec (CRIQ) received the mandate to investigate the mechanical aspects of the program, *viz.:*

- to define an appropriate container in terms of its configuration, components, rooting medium and package;
- to develop an integrated industrial process for producing the containers;
- to design the necessary specialized machinery.

At the end of the fifth year of the project 3.5 million seedlings were produced in the East Angus greenhouses of the Centre de Culture des Plants en Recipients. This paper reviews the principal developments to date and outlines the challenges for the future.

Although the different objectives of the development activity are interdependent, for ease of discussion it is convenient to divide the program into three distinct parts, viz.: the product, the process and the machinery. What follows disregards the intermediate steps.

THE PRODUCT

The configuration, dimensions and components of the container as defined by the project are illustrated in Figure 1.

---

[1] Ingénieur, Centre de Recherche Industrielle du Québec, Ste-Foy, Québec.

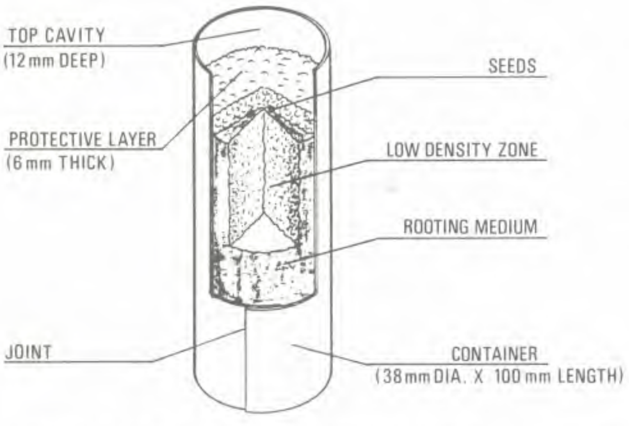


Figure 1. Schematic representation of container.

The container consists of two layers of disposable paper, the innermost being a synthetic material that resists the effects of water in the greenhouse. The tube is formed by joining the two edges of a continuous sheet and lap-sealing them with a quick-drying glue. The container is removed before planting.

The rooting medium is normally a wet peat with a moisture content (wet basis) of about 80%. However, the manufacture and mechanical handling of the containers can be accomplished equally well at moisture contents (wet basis) ranging from 70 to 85%.

The quality of the peat is a critical parameter for seedling growth (Helium 1975). There are certain guidelines which should be followed in order to avoid crop failures, viz..

- best results are obtained with a sphagnum-type peat (e.g., Pointe aux Peres, coarse A);
- peat has to be clean and free of all material larger than 8 mm;
- density of the rooting medium should be kept at about 0.1 g/cm^3 of dry material;
- a reduction in the particle size of the peat (e.g., during peat preparation) should be avoided as much as possible in order to keep the hydraulic permeability at a minimum of 500 cm/day (Bernier et al. 1978).

The container is filled with peat to within about 12 mm of the top of the tube. This is found to aid moisture retention, thereby improving the growth of the seedlings. The central zone has a lower density which may facilitate aeration and wetting of the rooting medium.

Once the tubes are filled, one or more selected and treated seeds are sown in the centre of each filled cavity. The seeds are then covered with a 6 mm thick layer of sand to stabilize them and protect them against adverse external factors.

The filled containers, as described above, are packed on a tray in groups of 48 units (Fig. 2) for easier handling. They are subsequently placed in wooden pallets for the duration of the growth period in the greenhouse.

Figure 2. Package of 48 containers.

THE PROCESS

The discovery that a mixture of peat and water can be stored at 80% moisture content (wet basis) and more was a turning point in the project, and resulted in the division of the manufacturing process into two separate phases: peat treatment and container production.

The main operations involved in the container production process, including treatment of the growing medium, are illustrated in Figure 3. A general view of the equipment installed at East Angus is shown in Figure 4.

Peat Treatment

The peat is fed into the process in 0.17 m^3 bags that are opened manually above a grating, at which point the largest sticks and foreign particles are removed. Lumps of peat are always present in the bags, and these are broken up in a rotary delumper-sifter which also serves to separate any foreign particles larger than 8 mm.

The sifted peat is then wetted in a custom-built double-shaft mixer with adjustable paddles. Water is metered through sprinklers directly onto the peat which is fed by a belt elevator into the mixer. The peat and water must be blended until the peat is uniformly moist. The wet peat is then stored in a live-bottom bin for later use.

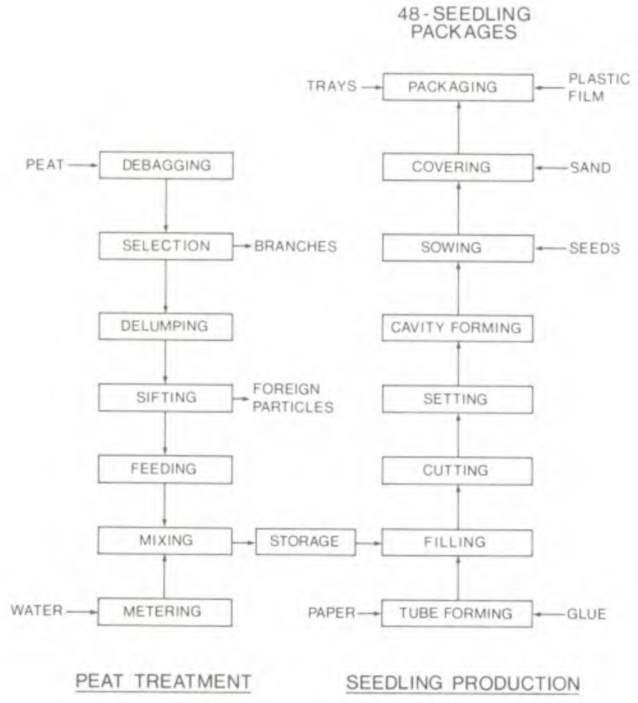


Figure 3. Flow chart of production process.

Container Production

The containers are formed from a sheet of paper that is fed continuously around a pipe, connected to the filling device, to shape it. A bead of glue is then applied between the edges of the sheet to seal them and thus form a tube.

The previously stored peat-water mixture is fed into the filling device, which consists of screw conveyors with unequal pitch, diameter and speed. These are arranged in series so as to fill the tubelike container that is being formed around the pipe. The resultant continuously filled container is cut with a rotary cutter into a series of cylinders of predetermined length. The radius of the cutting edge of the spiral blade increases gradually during each revolution, so that the blade penetrates progressively into the container. The continuously delivered horizontal cylinders are finally separated into eight rows by a distributing conveyor, after which a chute mechanism guides them toward a supporting conveyor in a vertical position, ready for seeding.

The cavities in the upper 12 mm of the containers are formed as the containers pass under a rotating drum, the external surface of which is fitted with appropriately sized dibbles. The forward velocity of the feed conveyor and drum are synchronized accordingly.

Sowing is carried out by a device arranged above the conveyor, which consists of a rotating cagelike drum with peripheral, longitudinally perforated tubes. The tubes are alternately placed under suction and pressure so that they pick up seeds from a receptacle and discharge them into the cavities in the containers. The seeds are then covered with sand. The sander consists of a rotating drum with scoops around its circumference, which is designed to pick up an adequate amount of sand from a reservoir to cover the seeds in each container.

The final operation, packaging, is carried out automatically by a machine at the end of the conveyor. It consists of (i) a pusher that moves a batch of 48 containers from the conveyor onto a tray, (ii) a mechanism that closes and welds polyethylene film around the package of containers, and (iii) a mechanism to move the packaging unit along at the same speed as the supporting conveyor and to bring it back as the cycle is finished. The transfer of the packages to pallets and subsequently to the greenhouse is a manual operation at present.

THE MACHINERY

In developing the process we have endeavored to use as many commercially available components as possible (e.g., standard screw conveyors, belt elevators, paddle mixer, flow meter, live-bottom bin, gluing unit, transmissions, controls, etc.).

Nevertheless, several specialized devices had to be designed and built in order to complete the production process, viz.: paper-forming device, filling screw conveyors, rotary cutter, distributing conveyor and vertical chute mechanism, supporting conveyor, cavity-forming drum, sowing drum, sanding device, packaging machine. Patents for the various features of these machines and devices have been either applied for or obtained (Barbulescu et al. 1981).

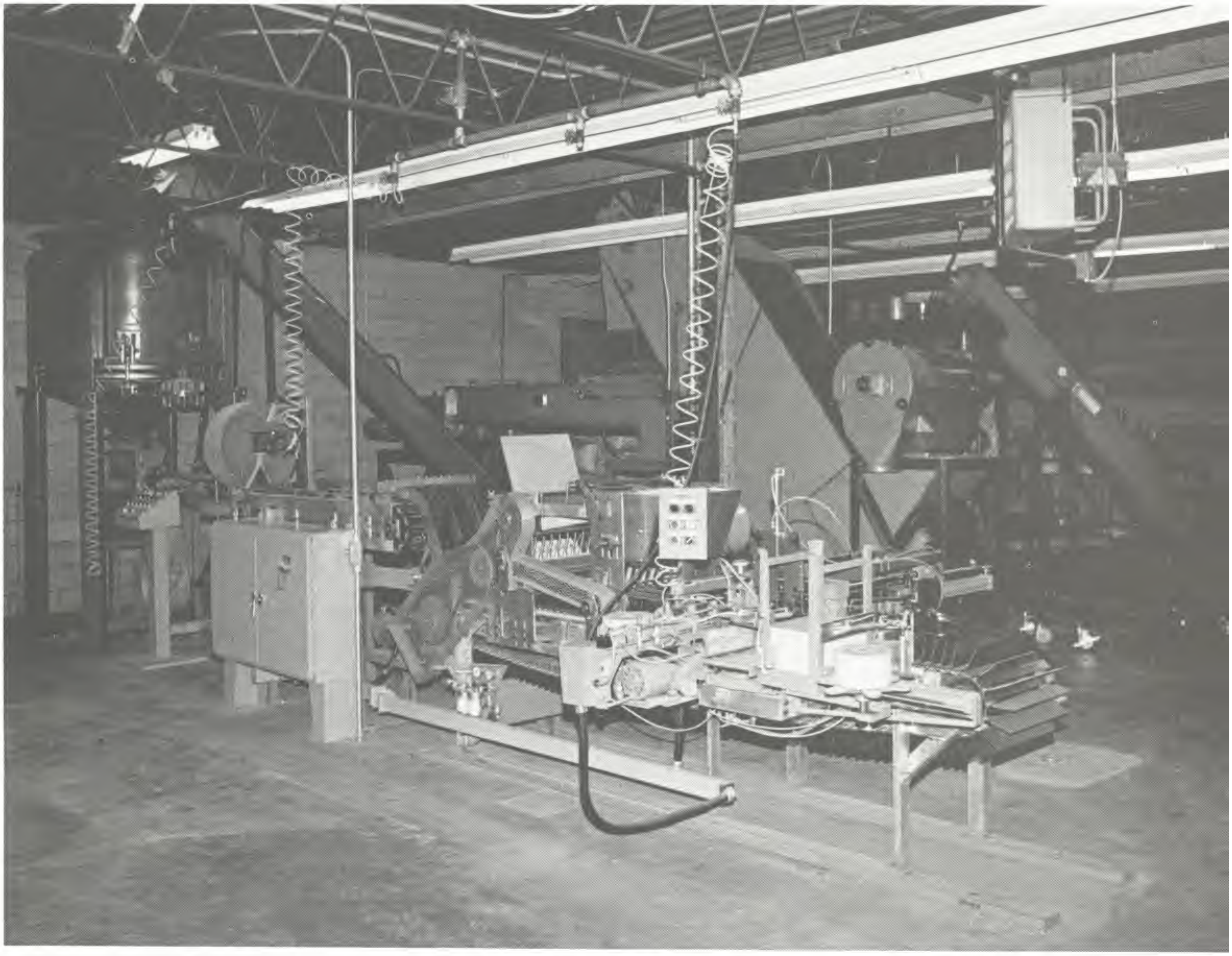


Figure 4. General view of equipment.

INITIAL PRODUCTION

In the fall of 1980, it was decided to proceed with a first operational production of containerized seedlings using the newly developed process and related machinery.

The delivery of filled containers to the East Angus greenhouses began on 15 December 1980, and the whole task was completed by 15 February 1981. In all, 3.5 million containers were produced in about two months.

Some average performances of the filling line were as follows:

- Daily production (two shifts) - 120,000 containers
- Number of operators required - 4
- Peat consumption - 0.08 m^3 (3 ft^3)/1000 containers
- Energy consumption - 3 KWh/1000 containers

Seedling growth in the greenhouse as well as overall survival were comparable with those of other containerized systems. A tendency to root spiralling was noted in some instances, but appears to be inherent in this type of container (Bergman et al. 1973).

Average production costs calculated by Czobor (1981) were found to be significantly better than those for other containerized systems.

CONCLUSION

There are now 53 container filling lines in Canada, and they delivered nearly 130 million units in 1980--an average of 2.5 million containers per machine. The one developed in Quebec compares favorably with the others, and in its first operational use produced 3.5 million container units. In summary, the new process offers the following advantages:

- The production process is continuous.
- Container forming, peat treatment and packaging are integrated into a single process.
- Filling and seeding operations are almost completely mechanized.
- Labor and production costs are significantly better than those for other container systems.

Some areas requiring further improvement were noted during the first operational production, viz.:

- Root spiralling in the containers should be thoroughly investigated and the most promising solutions tested.
- Higher productivity should be pursued by increasing the speed and reliability of the machinery.
- Machine parts subject to rapid wear should be improved by redesign or the use of more appropriate materials.

Despite these difficulties we are encouraged by the results obtained to date.

LITERATURE CITED

Barbulescu, B., Boulet, R., Charland, J.P. and Fortin, P.
1981. Apparatus for making seedling tubes. U.S. Patent 4, 245, 431.

Bergman, F. and HaggstrOm, B.
1973. Some important facts considering planting with rooted forest plants. Sveriges Skogsvardsforbunds Tidskrift 71(6):565-578.

Bernier, B., Plamondon, A. and Laflamme, Y.
1978. Les proprietes de la tourbe d'extrusion servant a la croissance de semis, d'arbres forestiers. Min. Terres For. Que., Serv. restaur.

Bonin, P.
1972. Programme de culture en contenants de la province de Quebec. Min. Terres For. Que.

Czobor, E.C.
1981. Valorisation de la machine a semis. Centre Rech. Ind. Que.

Helium, A.K.
1975. Selecting peat for rearing coniferous container seedlings. For. Chron. 51(5):200-202.

PERFORMANCE OF SOME BIODEGRADABLE PAPERS USED FOR TREE SEEDLING CONTAINERS

E.A.N. Sugden[1] and J.B. Scarratt[2]

Abstract.--Four experimental papers, composed of various mixtures of natural and synthetic fibres, were developed and tested in greenhouse trials with black spruce *(Picea mariana* [Mill.] B.S.P.) and jack pine *(Pinus* banksiana Lamb.). Mass and tensile strength retentions of the papers and quality of the seedlings were determined and compared with those of commercial controls. Mass and strength retentions and seedling quality varied with paper type.

Résumé.--Au cours d'expériences, on a mis au point quatre types de cartons composés de divers mélanges de fibres naturelles et synthétiques et on les a essayés en serre avec l'épinette noire *(Picea mariana* [Mill.] B.S.P.) et le pin gris *(Pinus banksiana* Lamb.). Pour chaque carton on a déterminé la capacité de rétention de la masse et de la force de tension ainsi que la qualité des pousses et on les a comparées avec celles de témoins du commerce. Ces caractéristiques ont varié selon le type de carton.

INTRODUCTION

Tree seedling containers have been developed, manufactured and used for many years. Materials used in the various systems have included hard plastics, Styrofoam, compressed peat, polyethylene sheet, and composite papers. Much discussion has centred around the relative merits of different container systems, and undoubtedly this will continue in the future.

The concept of 'containerizing' tree seedlings is based on the premise that seedlings grown in this manner will have a protected root system which will develop without restraint after the seedling is outplanted. For container systems in which the seedling is outplanted complete with container -- as opposed to container-grown 'plug' seedlings -- there are obvious difficulties relating to the development and choice of a suitable container material. Full protection of the seedling's roots can be effected by the use of a robust container, although root egress after outplanting may be adversely affected. At the other extreme, a container which allows early normal root development may be impractical because of difficulties in separating individual containers prior to planting.

Thus, the choice of a suitable material for tree seedling containers is generally based on a compromise between pre-planting strength and post-planting destruction. Clearly, biodegradable materials are preferred. Microbiological agents that will assist in the eventual destruction of a biodegradable container at the planting site are already present in the greenhouse. The container material is therefore subjected to microbiological stress immediately upon being placed in service in the greenhouse. A successful container material will have a controlled rate of biodegradability, retain-

---

[1] Senior Research Scientist, Ontario Research Foundation, Mississauga, Ontario, and
[2] Research Scientist, Great Lakes Forest Research Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario.

ing enough strength during the greenhouse phase, but continuing to become weaker and allowing normal root development after outplanting.

An obvious choice, and perhaps the best, is a thin layer of material which incorporates components that will be destroyed under microbiological attack as well as components that are resistant. A composite paper is such a material. Papers containing wood pulp fibres, synthetic staple fibres and one or more bonding agents blended in a variety of different combinations will have varying rates of biodegradation. The choice of component blend will be dictated by the container performance required in relation to species, length of greenhouse production cycle, desired size and age of planting stock, etc. This paper describes a study to evaluate the suitability of a number of experimental composite paper blends for use as container materials for growing and planting black spruce *(Picea mariana [Mill.]* B.S.P.) and jack pine *(Pinus banksiana* Lamb.).

EXPERIMENTAL METHOD

Work on biodegradable papers suitable for tree seedling containers was initiated in 1979 at the Ontario Research Foundation (ORF). The work was sponsored by the Ontario Ministry of Natural Resources in order to develop papers compatible with a process for container production being developed by the Ministry. Greenhouse trials and seedling evaluations were carried out at the Great Lakes Forest Research Centre (Canadian Forestry Service).

In the initial work, two commercially available papers and several experimental papers developed at ORF were evaluated. The results of this initial trial indicated that the commercial papers[3] were totally unsuitable for use in the greenhouse culture of tree seedlings, and that the experimental papers left a lot to be desired. However, they did provide us with considerable insight into what was required for the next generation of experimental papers.

A second study was begun in late 1980. First, a wide range of experimental papers, based on various combinations of natural and synthetic fibres plus resin binders, was prepared at ORF. These papers were screened by accelerated biodegradation tests with a mixed spore suspension of wood-destroying fungi, as well as by standard physical tests for paper. Three paper types were selected for further study and evaluation; a fourth type, the best from the first study (DFK), was included as a reference point.

Hand-made paper at ca 70 g/m^2 basis weight was made in sheets approximately 30 cm^2, using a Williams sheet mold. These sheets were pressed and dried under physical restraint prior to further treatment. The materials used to make the four paper types are listed in Table 1.

Table 1. Composition of four experimental paper types.

Type	Composition
DFK	65% unbleached softwood kraft 25% Fybrel 990 SWP 10% polyester 1/4 in. staple fibre
MF	50% unbleached softwood kraft 15% Fybrel 990 SWP 31% vinyon 1/4 in. staple fibre 4% melamine formaldehyde resin solids
VA	45% unbleached softwood kraft 20% Fybrel 990 SWP 20% vinyon 1/4 in. staple fibre 15% vinyl acetate resin solids
AC	50% unbleached softwood kraft 20% Fybrel 990 SWP 10% polyester 1/4 in. staple fibre 20% methyl methacrylate/acrylic resin solids

All four papers contained a 'synthetic wood pulp' made from polyethylene (Fybrel 990). The fybrids, incorporated into the paper, required heat bonding to create a network. Therefore, each type of paper was heat cured under pressure. Types VA and AC were subsequently impregnated with their respective resin additions and cured. Type MF incorporated melamine formaldehyde in its fibre furnish and required only heat treatment for curing.

The finished papers were cut to size and made up into cylindrical containers 3.7 cm in diameter and 7.5 cm long with a hot melt adhesive to form the seal. Approximately 1000

---

[3] A heavy unbleached kraft wrapping paper and a urea-formaldehyde impregnated paper with high wet-strength properties.

containers were made from each paper type, of which 960 were used for greenhouse testing.

In addition to the four experimental containers, the study included two commercial controls consisting of FH 408 Japanese paperpots. In one the paperpots were used in the matrix form (PP) -- the normal configuration in which this commercial container is used for seedling production. The second control (PPS) attempted to simulate the configuration of the handpacked experimental containers, and involved separating the filled paperpots, gently rolling them into a cylindrical form and repacking them into the holding tray. This created air spaces between the repacked paperpots, comparable with those between the experimental containers.

A further treatment was added to the greenhouse study to provide a comparison of seedling growth with no container present. Seeds were sown directly into holding trays filled with the same growing medium used for the containers and were grown as bare-root (BR) seedlings under otherwise identical experimental conditions.

All containers were filled by hand with a 50:50 peat:vermiculite growing medium, sown with black spruce or jack pine and set out in the greenhouse in blocks, replicated four times. Sowing dates for the spruce and pine were 9 March and 27 April, 1981, respectively. Fertilizer applications (100 ppm N of 10-52-10 Plant-Prod soluble fertilizer) were started at 24 days from sowing for both species. These were increased to 200 ppm N of 20-20-20 Plant-Prod water-soluble fertilizer at 38 days from sowing. This is a fairly typical nutrient schedule for containerized seedling production; fertilizers were applied continuously at each watering.

Two weeks after sowing and every two weeks thereafter, 10 containers per replicate were removed from each container type. This was continued for 18 weeks for spruce and 12 weeks for pine. The seedlings and growing medium were carefully removed from five of the containers and the paper was returned to ORF for testing; the other five containers were retained for seedling growth measurements. Regular observations were made to quantify foliage chlorosis (Munsell 1963). Shoot height, total dry weight, and root-collar diameter of seedlings were measured and quantitative observations of root egress through the container wall were made.

The five containers returned to ORF were washed to remove surplus growing medium, brought to equilibrium moisture content at 50% RH and 23 C, and weighed. Two specimens, 1.5 x 7.5 cm, were cut from each weighed container and their tensile strength was determined at a constant rate of elongation on an Instron tester. Average weights and tensile strengths were compared with those of unexposed paper specimens tested immediately after manufacture. Mass and tensile strength retentions were calculated and expressed as percentages.

RESULTS AND DISCUSSION

Container Paper Performance

The four experimental and two control containers performed differently in terms of mass and tensile strength retentions. Both the black spruce and the jack pine trials gave the same relative ranking of containers. With mass retention the containers were ranked, in descending order, MF > AC > VA PPS > PP > DFK (Fig. 1). With tensile strength retention the ranking, in descending order, was quite different: PPS > PP > MF AC > VA > DFK (Fig. 2).

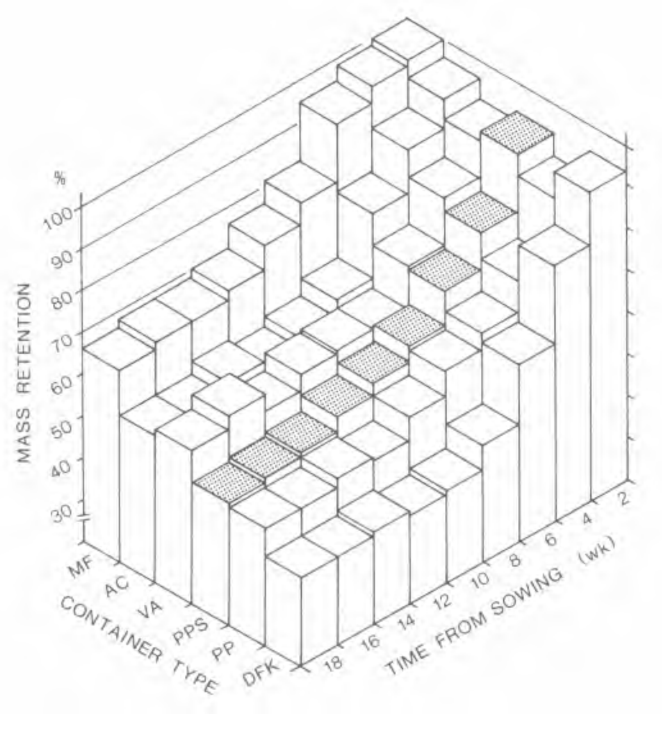


Figure 1. Mass retention in black spruce containers.

Mass and tensile strength retentions were compared for both species at equivalent exposure levels (i.e., time from sowing). The values for pine were generally lower than those for spruce, particularly in the PPS and PP containers, although the differences between the experimental containers were fairly small (Fig. 3). It is suggested that the

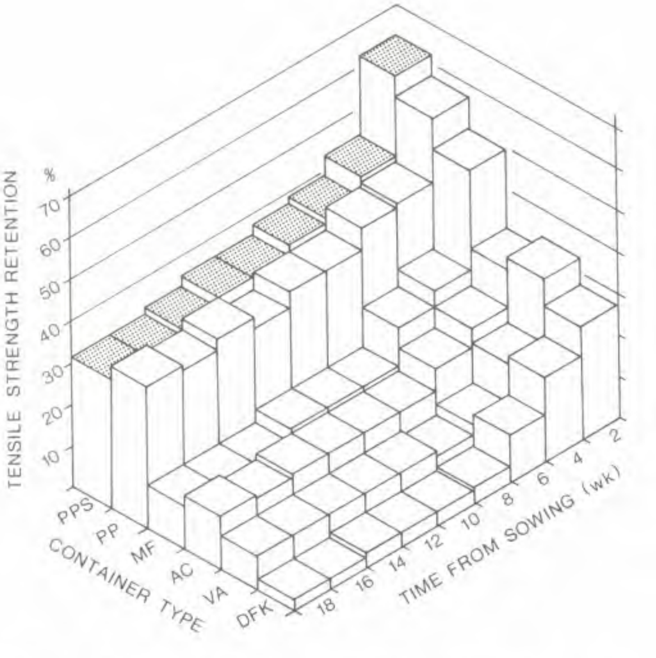


Figure 2. Tensile strength retention in black spruce containers.

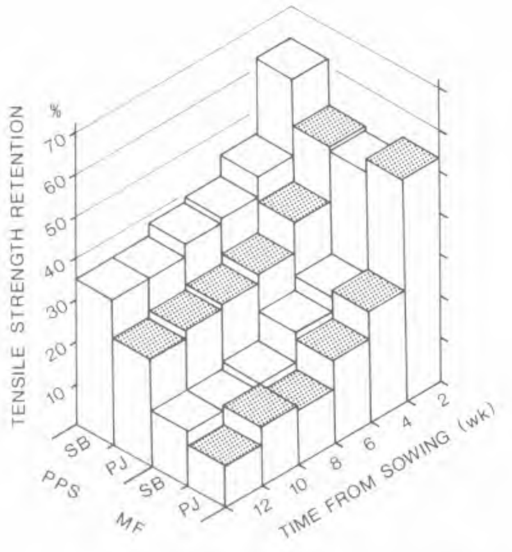


Figure 3. Comparative tensile strength retentions over time for Type PPS and MF containers.

difference between species was related to the 7-week difference in sowing dates and the concomitant higher average temperatures in the greenhouse during the pine trial. Higher ambient temperatures, because of increased solar insolation, would be expected to increase microbiological activity in and around the container, resulting in accelerated degradation of the paper. The difference in performance of the two containers illustrated in Figure 3 can perhaps be explained by the fact that the MF containers rapidly reached a point at which additional exposure caused very slight reductions in tensile strength retention. The PPS containers, being at higher retention levels (because of their binder content), still have the potential for further reductions in tensile strength.

When we compared the performance of papers from the four experimental containers at the end of the black spruce trial period (18 weeks), we found a wide range in mass retention values. Since the composition of these papers is known, and if it is assumed that only kraft pulp fibres are subject to biodegradation, it is possible to determine the residual biodegradable content. This can he expressed as the percentage by weight of kraft fibre remaining in the paper at the end of 18 weeks.

The residual biodegradable content ranged from a high of 17% for Type MF paper to a low of 3% for Type VA (Table 2). If we examine tensile strength retention it will be noted that a somewhat smaller range occurs, and that the maximum and minimum values do not coincide with those of residual biodegradable content. If the ratio of tensile strength retention to residual biodegradable content is calculated, the result can be described as the tensile index. On this basis, Types AC and VA appear to have performed better than either Type MF or Type DFK. In fact, the performance ranking for tensile index is VA > AC > MF > DFK, which does not coincide with the observed handling characteristics of the containers. In subjective handling tests we would rank the containers, in descending order of practical value, MF > AC = PP = PPS > VA > DFK.

To this point we have considered tensile strength retention rather than actual tensile strength. The former was selected because it is a sensitive and reproducible variable. It can he determined on the small samples dictated by the container dimensions. However, the one drawback to this parameter is that machine-made papers are anisotropic whereas handmade papers are almost always isotropic (Table 3).

From Table 3 we see that machine direction tensile strength of Type PPS paper is twice that of its cross-directional tensile strength. The differences between cross-directional tensile strength of Type PPS and

Table 2. Tensile strength retention and residual biodegradable content at 18 weeks in black spruce trial.

Container type	Mass retention (%)	Bio-resistant components content (%)	Residual biodegradable content (%)	Tensile strength retention (%)	Tensile index
MF	67	50	17	11	0.6
AC	55	50	5	14	2.8
VA	58	55	3	10	3.3
DFK	43	35	8	4	0.5

Table 3. Tensile strengths of container papers at 18 weeks in black spruce trial.

Container type	Tensile strength (g/15 mm width)	Percentage of PPS control
PPS (CD)[a]	1103	100
PPS (MD)	2210	200
PP (CD)	1198	109
PP (MD)	2397	217
AC	866	78
MF	482	44
VA	376	34
DFK	81	7

[a](CD) = cross direction (i.e., perpendicular to paper travel on machine)
(MD) = machine direction (i.e., parallel to paper direction on machine)

that of Types AC and MF are considerably less than the corresponding differences in tensile strength retention. This is due to the method used for calculating average tensile strength for the Type PP and PPS papers, *viz:*

$$\text{Average tensile strength} = \sqrt{\frac{\text{MDts}^2 + \text{CDts}^2}{2}}$$

where: MDts = machine direction tensile strength
CDts = cross-direction tensile strength

The weakest point in the fibre matrix is important in terms of resistance to root egress. Hence, the cross—directional tensile strength of Types PP and PPS is probably a more realistic parameter by which to compare them with the experimental papers.

The superior performance, in terms of tensile strength, of Type AC paper is partly explained by reference to Figure 4, which illustrates tensile energy absorption (TEA) versus incubation time in an accelerated biodegradation study. The differences in performance of Types AC and PP versus those of Types MF, VA and DFK indicate an interesting phenomenon. As the kraft pulp fibre is destroyed by microorganisms, the elastic nature of the bonding agent (methylmethacrylate/acrylic) in Type AC takes over and allows additional mechanical stress to be absorbed as elongation. With Types MF, VA and DFK the bonding agent is inelastic relative to the kraft—Fybrel matrix. As the kraft fibre is destroyed the bonding agents are unable to convert mechanical stress into elongation and therefore yield very low TEA values. The similarity between the curves for Types AC and PP suggests that the bonding system used in commercial paperpot material is similar to that incorporated into the Type AC experimental paper.

Seedling Growth

The performance of the seedlings in the different containers varied considerably. Progressions of average shoot heights and total dry weights in jack pine are illustrated in Figures 6 and 7, respectively; dry weight progressions in black spruce are illustrated in Figure 8. Root—collar diameters showed similar patterns of growth.

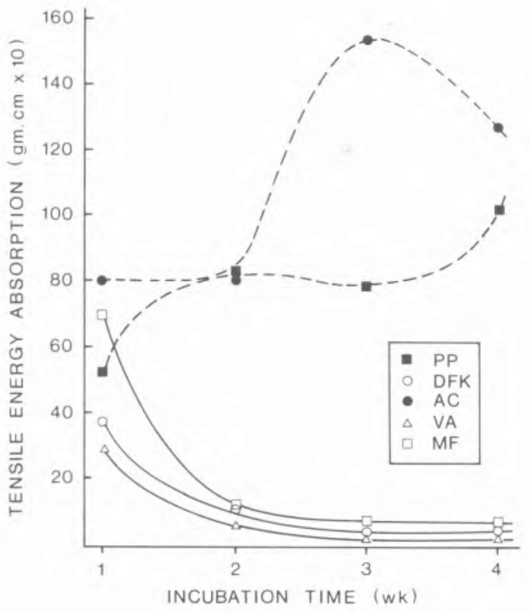


Figure 4. Tensile energy absorption over time in an accelerated biodegradation test.

In general, seedlings grown in the experimental containers were smaller on any given date than were those in the control containers or those grown bare-root (BR). Significant differences in shoot height and total dry weight between container types were evident as early as 8 weeks from sowing in both species, and, in jack pine especially (Fig. 5), were accompanied by some initial chlorosis of seedlings in the experimental containers. This chlorosis, and the associated depression in growth rates, undoubtedly resulted from utilization and depletion of available nitrogen in the growing medium by soil microorganisms during decomposition of the cellulose component of the container wall. Foliage chlorosis was most pronounced and persistent in Types VA and DFK (Munsell 5GY[7/6-7/8] compared with 5GY[6/6] in BR and Types PP and PPS), probably because of more severe nitrogen depletion resulting from the more accessible carbohydrate source (i.e., kraft pulp fibres) in these container types. It will be noted that seedlings grown in Types VA and DFK also suffered the most severe depression in dry matter accumulation.

Figure 5. Bare-root and containerized jack pine seedlings at 8 weeks from sowing.

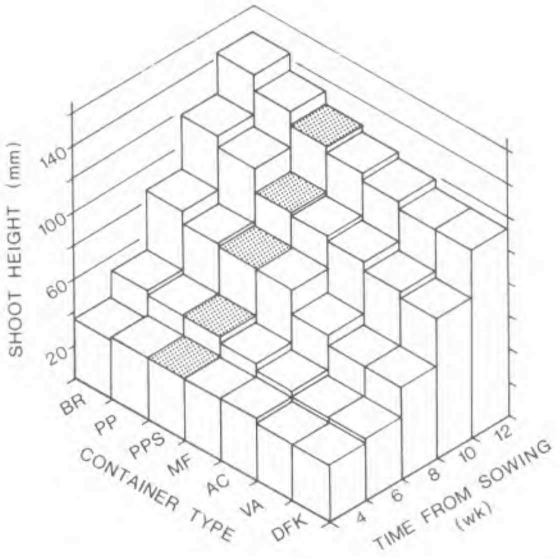


Figure 6. Progression of mean shoot height in jack pine seedlings.

Foliage chlorosis diminished after a few weeks, and all seedlings had recovered their color well before the end of their normal greenhouse production cycle. However, while relative differences in shoot height between container types also tended to diminish (Fig. 6), there were still significant residual differences in both species at the end of the greenhouse study. Shoot heights of black spruce seedlings in Types VA and AC, and of jack pine in Types VA, AC and DFK, were significantly lower than those of bare-root seedlings and those in the commercial container Types PP and PPS. The exception was Type MF, which occupied an intermediate position in both species throughout the study, and in which shoot heights were never significantly less than those of seedlings in Type PP. By the final sampling date no significant height differences existed between seedlings from container Types MF, PP or PPS.

Seedling dry weights followed the same pattern as shoot height up to the final sampling date (Fig. 7 and 8), when anomalies attributed to inadequate watering of the larger seedlings began to obscure the relationships between BR, Type PP and Type PPS. Differences in seedling response in the experimental containers were most pronounced in jack pine. Types MF and AC yielded seedlings with the highest total dry weights in both species and, as with shoot height, Type MF seedlings were statistically equivalent to those in Type PP containers at all sampling dates. Type AC seedlings lagged behind somewhat early in the study, but final dry weights were not significantly different from those of Type MF or PP seedlings.

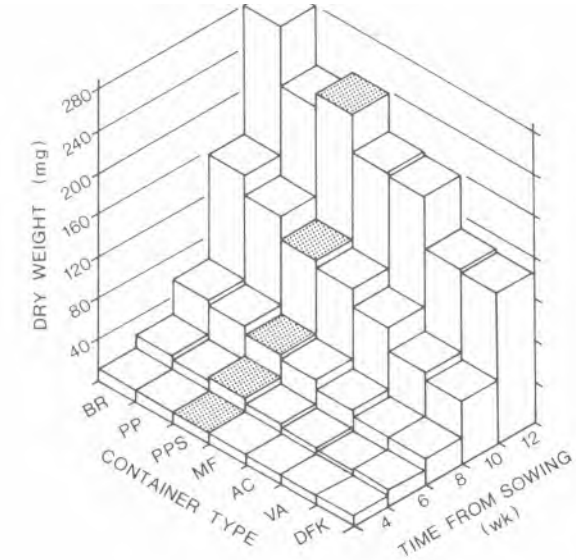


Figure 7. Progression of mean dry weight in jack pine seedlings.

It is noteworthy that growth rates of bare-root seedlings and seedlings grown in matrix format paperpots (Type PP) were appreciably, though not significantly, superior to those of the separated paperpot control (Type PPS) for much of the greenhouse cycle. This is attributed to the more uniform moisture conditions prevailing in these treatments, resulting from improved lateral moisture movement and the absence of air spaces between individual containers. In Type PPS and the experimental containers, moisture conductivity between containers was presumably less because of a much lower contact area between container walls.

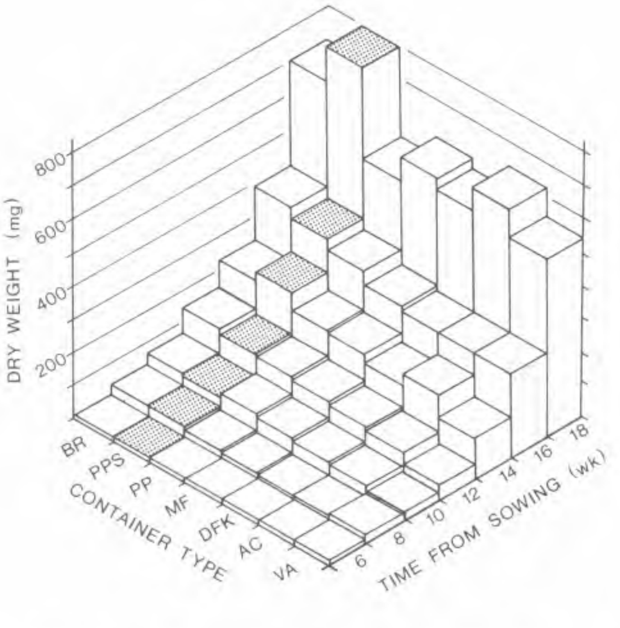


Figure 8. Progression of mean dry weight in black spruce seedlings.

While significant differences in seedling growth occurred in the various types of container, in practice any loss in growth could be made up by extending the growing period in the greenhouse. Of greater importance, perhaps, than the loss of growth potential are the resistance of the container to root egress and its handling characteristics. It has already been noted that we subjectively ranked the handling characteristics of the containers in descending order of practical value: MF > AC = PP = PPS > VA >DFK. Data for root egress through the container wall, the extent of which determines ease of separation of containers and the amount of inter-rooting (themselves expressions of handling characteristics) matched this order closely (Table 4). There was less root egress from Type MF and Type AC containers at the end of the greenhouse cycle than from Types PP and PPS, and this suggests the likelihood of less root damage during handling and planting. However, while the Type MF container had excellent residual integrity, some tendency to root deformation was noted, an indication that the material used was perhaps too tough and might restrict initial root growth after outplanting. This could best be adjusted by reducing the resin content of the paper.

Table 4. Root egress through the container wall at end of greenhouse cycle.

Species	Number of roots emerging through container wall in Type: MF	AC	PP	PPS	VA	DFK
Black spruce (18 weeks)	0.3	0.7	1.2	2.3	5.4	24.9
Jack pine (12 weeks)	0.6	1.5	3.2	4.0	5.2	13.4

CONCLUSIONS

Two materials (Types MF and AC) have been developed which appear to have considerable potential for use in the manufacture of tree seedling containers. The important attributes of these container materials are high residual mass retention values, and relatively high residual tensile strengths brought about by bio-resistant resin bonds between their natural and synthetic fibre components. No adverse effects upon seedling growth rates in the greenhouse have been found, and the containers produced from these materials have excellent handling characteristics under the seedling production schedules currently employed in Ontario. A final conclusion on the suitability of these materials for container manufacture must await the results of current outplanting trials.

ACKNOWLEDGMENTS

The financial support of the Ontario Ministry of Natural Resources, Forest Resources Branch is gratefully acknowledged. The support and encouragement of Mr. K.H. Reese of the Forest Resources Branch has been of tremendous assistance to both principal investigators. We thank the Ministry for permission to make this contribution to the Symposium proceedings.

LITERATURE CITED

Anon.
1963. Munsell color charts for plant tissues; 2nd ed. Munsell Color Company Inc., Baltimore, Maryland.

COLD STORAGE OF CONTAINERIZED PLANTING STOCK AND SUBSEQUENT PERFORMANCE AFTER OUTPLANTING

Anders Mattsson[1]

Abstract.--Two-year growth performance of containerized Scots pine *(Pinus sylvestris* L.) seedlings overwintered outdoors was compared with that of cold stored (-5 C) seedlings. When planted early in the spring before the onset of shoot growth, seedlings overwintered outdoors were of superior quality and performed better than cold stored stock, particularly in the second growing season. The results also indicate that cold stored seedlings do not perform well when planted late in the growing season.

Résumé.--Après deux ans de croissance, on a comparé des plants en mottes emballées de pin écossais *(Pinus sylvestris* L.) qui avaient passé l'hiver à l'extérieur et d'autres qui avaient été stockés au froid (-5°C). Plantés tôt le printemps avant le début de la croissance des pousses, les plants qui avaient passé l'hiver à l'extérieur étaient de qualité supérieure à ceux qui avaient été stockés au froid, particulièrement au cours de la deuxième saison de croissance. Les résultats montrent aussi que les plants stockés au froid se développent mal lorsqu'ils sont plantés vers la fin de la saison de croissance.

INTRODUCTION

Good plantation establishment is the key to economical reforestation. About 200 million containerized seedlings are planted annually in Sweden at a total cost of about $55 million. This cost includes seedling production, transportation, site preparation, and planting. Poor plantation establishment therefore results in large financial losses.

In Sweden the best time for planting is that period in spring from the time the frost is out of the ground until the trees start their shoot elongation. This normally ranges from early April to early June, depending on latitude. The short spring planting period, with its rapid increases in soil and air temperatures, creates problems in the handling of containerized planting stock, particularly in relation to the initiation of shoot growth prior to planting. However, cold storage during winter and early spring prevents seedling shoot and root growth before planting, thereby allowing delivery of seedlings to the planting site with their growth processes in phase with the environment of the site. This enables the planting season to be extended, while the seedlings can be packed ready for shipping as soon as there is demand from the field. For these reasons, cold storage has frequently been used for handling seedlings in Sweden during the past 5 years.

Containerized seedlings that are to be cold stored over winter are put into storage when the shoot is fully dormant (normally October for mid-Sweden [60 N]). The seedlings must be dry when put into storage to prevent fungal growth, but there is normally no pre-conditioning of the seedlings before or after packing. Seedlings are packed into waxed cardboard boxes and placed directly

---

[1] Forest Officer, Department of Forest Yield Research, Swedish University of Agricultural Sciences, Garpenberg, Sweden.

into storage, where the boxes are stacked in such a way that air can circulate around them.

In Sweden the usual type of storage facility has a direct refrigeration system with a temperature range of -3 to -5 °C. With this system and at temperatures below 0 °C it is difficult to maintain relative humidities over 80%. Consequently, it is essential that the boxes be airtight to prevent the seedlings from drying out during long-term storage.

Sub-zero storage temperatures are used mainly to keep the trees dormant, with their respiration rate as low as possible to prevent fungal development. Many studies in Scandinavia, the United States and Canada have demonstrated problems with high respiration rates and fungus growth associated with long-term storage of coniferous seedlings at above-freezing storage temperatures (Sandvik 1964, Hocking and Nyland 1971, Young 1976, Uhlig 1977).

Seedlings are normally shipped during May or June and are stored at the planting site in the boxes used for cold storage. The boxes are delivered to the planting site, and holes are punched in them to permit some light to reach the seedlings. In this way, photosynthesis can take place, and dry weight losses due to respiration can be prevented. The use of partly closed boxes during storage at the planting site also prevents drying of the growing medium (normally sphagnum peat) and helps to avoid extreme day and night temperatures until the growing medium is thawed and the seedlings can be planted. The period from shipping to planting is usually 1-2 weeks. If the seedlings are not planted within this period the boxes must be opened fully and the growing medium kept moist.

Recently, there have been indications that some cold stored seedlings handled in the above manner exhibit high mortality and poor growth. In view of the large-scale adoption of sub-0 °C refrigerated storage of forest tree seedlings in Sweden, it is essential that we determine whether there is a need to change or improve current techniques for long-term (6-8 month) storage. Initial investigations will evaluate the effects of timing and duration of cold storage upon the survival and growth of outplanted seedlings.

This paper presents some preliminary results from a comparison of the growth performance after outplanting of Scots pine *(Pinus sylvestris* L.) seedlings overwintered (a) under normal long-term cold storage at -5 °C, and (b) in an outdoor storage area under snow from early December to the end of March.

EXPERIMENTAL METHOD

Scots pine containerized stock from a mid-Swedish provenance (60 °N) at 200 m altitude was used in this study. The seedlings were grown in FH 408 paperpots (70 cm^3), the most commonly used container in Sweden, filled with peat chips. The seeds were sown in early April and the seedlings were grown in the greenhouse until early June. The containers were then moved outdoors and kept there until mid-October when part of the crop was put into cold storage at -5 °C. The remainder were left over winter in the nursery, where they were covered with snow from early December until the end of March. Temperatures in the growing medium were close to 0 °C during the winter and never fell below -2 °C.

The following spring seedlings were planted successively during the growing season. All the seedlings overwintered outdoors were planted in early May before shoot growth occurred. Cold stored seedlings were also planted at the same time. However, some cold stored stock was also planted in early June and July to study the possibility of using it for extending the planting season. All seedlings were graded by height to keep variation between treatments within ±1 cm; they were planted in a randomized block design at the nursery.

RESULTS AND DISCUSSION

The following results are from the first two growing seasons after planting and are shown as averages of 25 or 50 seedlings per treatment. Because there was no mortality, the results are based on living seedlings.

Height increments for cold stored and outdoor overwintered stock in the first year after planting are presented in Figure 1. The fact that no differences in shoot height growth were observed suggests that there was no difference between the two storage methods. However, it may also reflect nursery conditions during storage or good growing conditions at the planting site during this first year. The shoot growth of cold stored stock began about one week later than that of stock overwintered outdoors, and this indicates that cold stored stock was more dormant at time of planting.

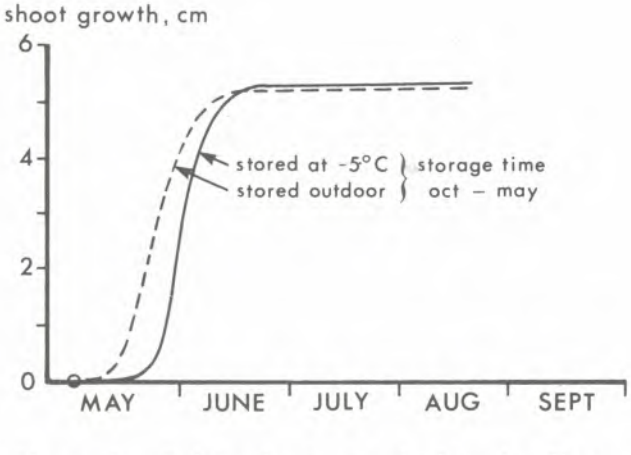


Figure 1. Height increment during the first year after planting (n = 50).

At the beginning of each month throughout the growing season, seedlings were analyzed for the starch content of their needles. Starch content was determined by a method originally outlined by Hansen and Wier (1975). Soluble carbohydrates were extracted by percolation with 80% ethanol, starch being extracted by percolation with 35% perchloric acid. The starch content of the percolates was determined using anthrone dissolved in sulphuric acid, followed by spectrophotometric detection. The standard solution for the determinations was glucose, which was converted into amylose equivalents before the starch content of the samples was estimated. Primary needles were sampled until all secondary needles were over 1 cm. Large differences in starch content occurred between the two storage treatments at the beginning of May (Table 1). Seedlings that had been stored outdoors over winter had a starch content of 22% of needle dry weight in comparison with 5% for stock that had been stored at -5°C. The data show only starch contents, the main storage product in woody plants, and do not take into account other carbohydrate reserves which may have been present.

Table 1. Starch content in primary needles during the growing season (n = 100).

Storage	May	June	July	Aug.
	Starch as % of needle dry weight			
Outdoors	22	22	14	9
-5°C	5	21	14	9

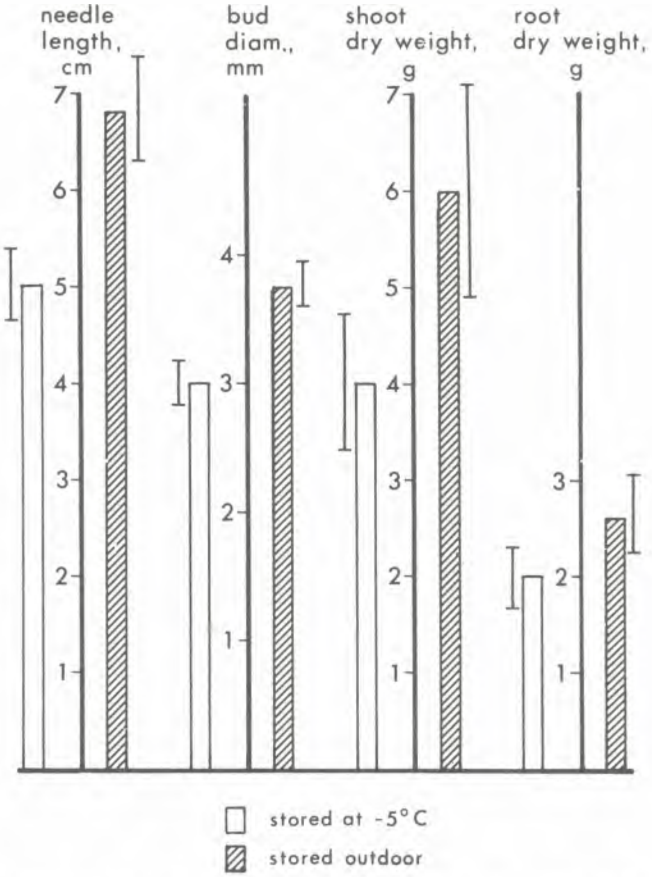


Figure 2. Seedling development at the end of the first growing season (n = 25).

It appears that cold stored stock may miss the period in early spring when carbohydrates are able to accumulate. Low carbohydrate reserves during a period of intensive shoot growth could imply a stress situation that, except for first year height growth, could produce a seedling which enters the fall season with few needle primordia on an under-developed bud. The results indicate that such stress also has an adverse effect upon root growth and needle length (Fig. 2).

Seedlings that had been overwintered outdoors were, except in height growth, significantly superior at the end of the first growing season to those stored at -5°C in terms of secondary needle length, bud diameter and shoot dry weight. This suggests a physiological difference between treatments that would be likely to affect the next year's growth. That this was so became apparent when the seedlings were analyzed after the second growing season (Fig. 3).

Substantial and significant differences in shoot growth and dry weights between treatments occurred during the second growing season, with better growth from seedlings overwintered outdoors. These differences are likely to remain for several years because of better establishment of seedlings stored outdoors.

These results do not suggest that long-term storage of seedlings at temperatures below 0°C is inadvisable, but they do indicate that there are reasons for improving long-term storage procedures as they are currently applied in Sweden. The importance of good establishment for avoiding mortality and poor growth in plantations cannot be overemphasized. With all the stresses at the planting site, such as moisture deficits, insects and competition it is essential that we produce forest seedlings that have good potential for establishing themselves and growing quickly after outplanting.

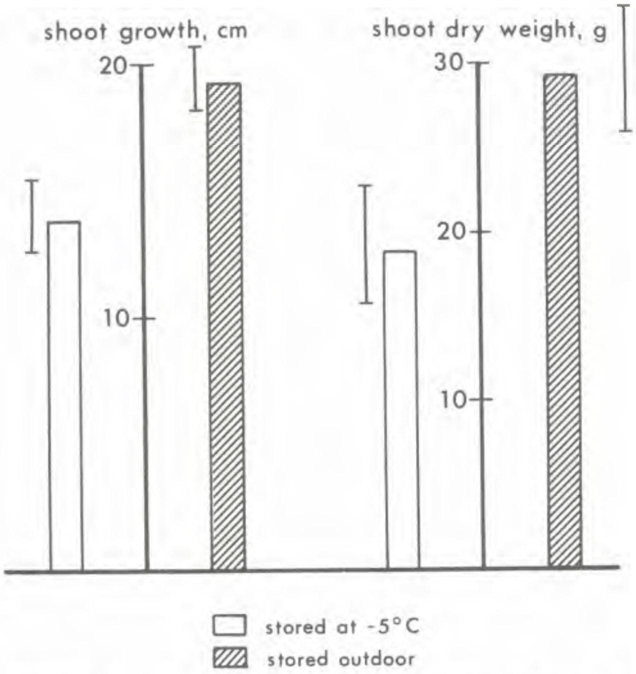


Figure 3. Shoot growth (n = 50) and dry weight (n = 25) at the end of the second growing season.

Work to investigate root growth capacity in relation to plantation establishment after cold storage is of great importance (Stone and Jenkinson 1971, Jenkinson and Nelson 1978, Burdett 1979, Stone and Norberg 1979, Jenkinson 1980, Sutton 1980). Some of these authors have worked out practical nursery regimes for obtaining a high root growth capacity after planting. These take into account planting location, species, seed source, nursery climate, lifting date, storage temperatures and planting date. The recommendations are based upon the seasonal pattern of root growth that has to be considered in long-term cold storage practice. Since root growth after planting is the key to good establishment, it is essential that practical nursery regimes which take account of local conditions and species requirements be introduced.

Time of planting during the growing season is also important for the establishment of long-term cold stored seedlings. As noted in the previous section, cold stored seedlings were also outplanted in early June and July so that the feasibility of using such stock to achieve a longer planting season could be examined.

Shoot growth and dry weight measurements during the first growing season after successive plantings of cold stored seedlings indicated no significant differences in shoot growth between the three plantings (Fig. 4). However, although shoot dry weights were the same for the May and June plantings they showed a significant decline for the July planting. Root dry weights declined progressively from May to July, an indication that very little root growth occurs in late-planted Scots pine stock which has undergone long-term cold storage.

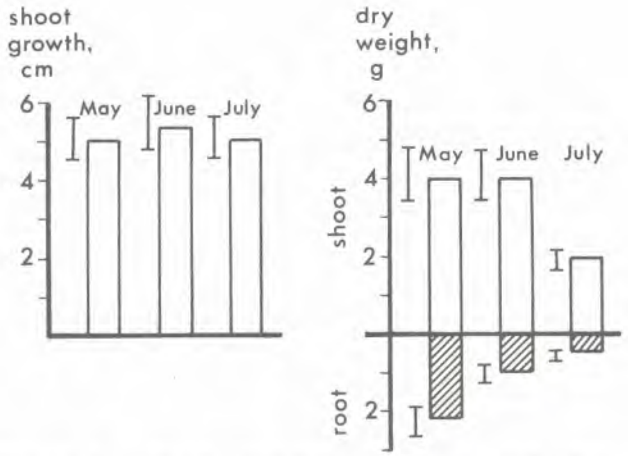


Figure 4. Shoot growth (n = 50) and dry weight (n = 25) at the end of the first year after planting for cold stored seedlings planted successively during the growing season.

As noted earlier, shoot growth of cold stored Scots pine seedlings began quickly after they were planted. Once shoot growth starts, the rate of root growth is reduced. The main period for seedling root growth in spring is therefore the time between the attainment of a soil temperature favorable to root growth and the time when shoot growth begins. For Ponderosa pine *(Pinus ponderosa*

Laws.) the soil temperature (at 8 cm depth) when significant root growth can begin is about 10°C (Jenkinson 1980). If Scots pine reacts in a similar manner, a relatively early planting of cold stored stock would be essential to ensure that some root growth has taken place before shoot growth begins.

The progression of shoot growth for cold stored seedlings planted at different times during the growing season is illustrated in Figure 5. Only the May planting had a two-week period after planting before shoot growth started: the June and July plantings required just one week. This suggests a longer period available for root growth in the May planting, a hypothesis borne out by the considerably higher root system dry weights of seedlings from this early planting (Fig. 4).

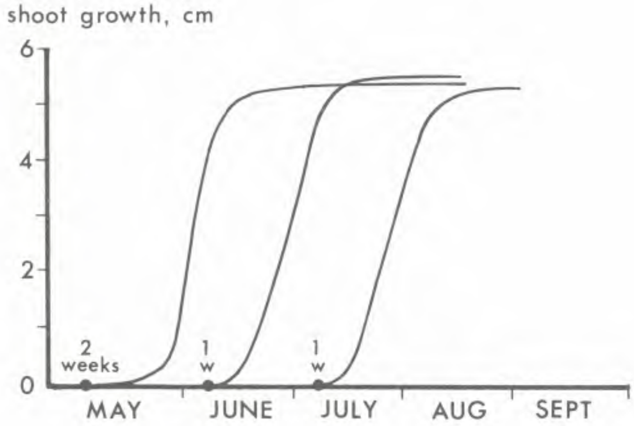


Figure 5. Height growth progression during the first growing season of cold stored seedlings planted successively during the growing season (n = 50).

The poor root growth and low shoot dry weights associated with late-planted cold stored seedlings during their first year after outplanting also showed up in poor shoot growth during the second growing season (Fig. 6).

These results indicate that when we extend the planting season in Sweden by using cold stored seedlings we can expect reduced performance. It can be concluded that cold stored Scots pine seedlings should not be planted later than the middle of June. However, this is based upon current cold storage techniques.

Despite these results, long-term cold storage still appears to hold promise for the future. In particular, cold storage facilitates the handling and shipping of large quantities of nursery stock. By considering root growth patterns and the possibility of pre-conditioning seedlings, and by careful choice of planting date, I am convinced that we can have high-quality cold stored seedlings that will give us the good establishment we need for economical reforestation.

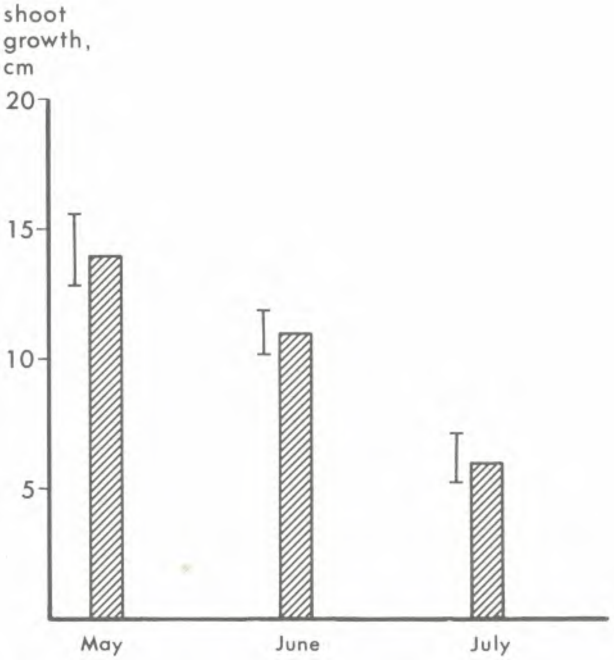


Figure 6. Shoot growth at the end of the second year after planting for cold stored seedlings planted successively during the growing season (n = 50).

CONCLUSIONS

When Scots pine is planted in early spring, before the onset of shoot growth, seedlings overwintered outdoors become established and grow better than does cold stored stock. This is evident from evaluations of shoot and root dry weights, secondary needle lengths and bud diameters at the end of the first growing season in the two stock types, where seedlings overwintered outdoors performed better than cold stored stock.

The results imply a stress situation resulting from low carbohydrate reserves, in the form of starch, during the period of intensive shoot growth in cold stored seedlings. This does not take into consideration other forms of carbohydrate reserve which might be present; other carbohydrates were undoubtedly present, but not in the starch form.

The better shoot growth and dry weight accumulation, during the first growing season, of outplanted seedlings overwintered outdoors was also reflected in superior second-year growth performance.

Cold-stored Scots pine planted late in the growing season does not perform well. Seedlings planted in May and June had better shoot and root dry weights at the end of the first growing season than did seedlings planted in July. This is attributed to the reduced amount of root growth in late-planted seedlings. The effects of late planting were also reflected in the poorer second-season shoot growth of seedlings planted in July.

LITERATURE CITED

Burdett, A.N.
1979. New methods for measuring root growth capacity: their value in assessing lodgepole pine stock quality. Can. J. For. Res. 9:63-67.

Hansen, J. and M$ller, I.
1975. Percolation of starch and soluble carbohydrates from plant tissue for quantitative determination with anthrone. Anal. Biochem. 68:87-94.

Hocking, D. and Nyland, R.D.
1971. Cold storage of coniferous seedlings. State Univ. Coll. For., Syracuse Univ., Appl. For. Res. Inst., AFRI Res. Rep. No. 6.

Jenkinson, J.L.
1980. Improving plantation establishment by optimizing growth capacity and planting time of western yellow pine. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif., Res. Pap. PSW-154.

Jenkinson, J.L. and Nelson, J.A.
1978. Seed source lifting windows for Douglas-fir in the Humboldt nursery. In Proc. Nurseryman's Conf. and Seed Processing Workshop, Eureka, Calif., Aug. 7-11, 1978, p. B-77 - B-95.

Sandvik, M.
1964. Refrigerated storage of coniferous plants during winter. First session of joint working party on techniques of forest extension and restoration.

Stone, E.C. and Jenkinson, J.L.
1971. Physiological grading of ponderosa pine. J. For. 69(1):31-33.

Stone, E.C. and Norberg, E.A.
1979. The effect of lifting dates and cold storage on the root growth capacity of bare-root coniferous seedlings. Paper presented at School of Forest Regeneration. Sacramento, California, July 19, 1979.

Sutton, R.F.
1980. Planting stock quality, root growth capacity, and field performance of three boreal conifers. N.Z. J. For. Sci. 10(1): 54-71.

Uhlig, S.K.
1977. Die Kaltlagerung von Koniferen. Tech. Univ. Dresden, Sekt. Forstwirtschaft Tharandt. Bereich Tropische Forst- und Holzwirtschaft. 1(1977):18-19.

Young, E.L.
1976. Forest research review. B.C. For. Serv., Res. Div., Victoria, B.C.

MONITORING CROP DEVELOPMENT DURING THE REARING OF CONTAINERIZED SEEDLINGS

R.D. Hallett[1]

Abstract.--Methods of monitoring important growth factors during the production of containerized tree seedlings are discussed. Experience has shown that crop scheduling requires the ability to predict how seedlings will grow. This can be facilitated by setting up a practical program following crop development and by controlling important influences such as soil water, soil fertility and greenhouse climate.

Résumé.--On discute des méthodes de contrôle des principaux facteurs de croissance durant la production des plants en mottes emballées. L'expérience a montré que, pour établir le calendrier des cultures, il faut être capable de prévoir de quelle façon les semis pousseront. On peut y parvenir plus facilement en mettant au point un programme pratique qui permet de suivre la croissance et en contrôlant des facteurs importants comme la teneur en eau et la fertilité du sol ainsi que le climat des serres.

INTRODUCTION

In the Maritimes, the development of greenhouse crops of tree seedlings is usually monitored regularly, by random sampling of seedlings, from each greenhouse. Seedling height and root-collar diameter are measured, and fresh and dry weights of roots and shoots are determined. Often a photocopy is made of a representative seedling on which data are recorded.

Records are also kept of cultural practices such as fertilization, irrigation, or the application of pesticides, and of weather and greenhouse conditions. In addition, the growing medium is routinely analyzed to indicate fertilizer and irrigation needs. Seedling foliage in particular is analyzed when problems arise.

In this paper, methods of monitoring the development of containerized seedlings are discussed. Because crop development and quality depend on effective greenhouse management, methods are also included for monitoring soil water, soil fertility and seedling nutrition.

SAMPLING REQUIREMENTS

To determine sample size, with statistical accuracy, for a practical monitoring program, several crops were evaluated. The variation in seedling height, diameter and dry weight, and the sample size required to estimate means within acceptable limits (± 10%), are given in Table 1 for a crop of white spruce (*Picea gZauca* [Moench] Voss) and black spruce (*P. mariana* [Mill.] B.S.P.) raised in FH 408 paperpots.

Sample size and number of samples were determined sequentially according to Day (1979) with the formula:

$$NO = \frac{S^2 t^2}{AE^2}$$

---

[1] Forestry Officer, Maritimes Forest Research Centre, Canadian Forestry Service, Fredericton, New Brunswick.

where NO = required number of seedlings
S = standard deviation
t = student's t ($P \leqslant 0.05$)
AE = allowable error (10%)

Three samples are sufficient for estimating total crop means between greenhouses or bays ($P < 0.05$, ±10%). Individual seedling dry weights vary greatly and too large a number of samples is required for this parameter to be a practical statistic. Root-collar diameter appears to be a useful statistical measure, but the measurement is not sufficiently sensitive for estimating required sample size accurately. Succulent seedlings must be measured carefully to avoid damage.

Height is the most practical measure for the statistical evaluation of crop size. It can be measured easily with simple equipment, and seedlings in containers are not damaged. A similar conclusion was reached by McClain (1975) for evaluations of bare-root stock in seedbeds.

If these data are obtained sequentially, unnecessary work is avoided. Day (1979, 1981) and the statistical section in the Ontario Nursery Manual (Armson and Sadreika 1979) are useful references for crop monitoring programs.

STANDARD CURVES AND THEIR INTERPRETATION

The ability to predict crop growth is essential for production planning both in the nursery and in field planting. Standard growth curves can be prepared for different species and conditions (Van Eerden 1974, Scarratt and Reese 1976, Tinus and McDonald 1979, Hallett 1980). For example, standard curves were drawn for height, root collar diameter, and dry weight of several black spruce containerized crops (Fig. 1). These are shown as exponential functions. Many crops produced in the Maritimes were outplanted in the year of production while still actively growing. Therefore, the upper curve values varied with the time of planting and total seedling dry weights ranged from a suggested minimum of 650 to 2,020 mg.

Curves for winter and summer crops show differences in growth equivalent to two months of growing time. Comparison with such standard curves can be used to determine if growth is on schedule to meet production or field planting dates, or to evaluate the success of cultural practices.

Regression equations for these exponential growth curves were calculated. Useful correlations exist between seedling dry weight and height and diameter (e.g., the

Table 1. Mean seedling heights, root-collar diameters, and total seedling dry weights with standard errors (SE), and required sample sizes with 10% allowable error at the 95% level of probability (Greenhouse N = 180; All N = 720)[a]

		Height		Root-collar diameter		Total seedling dry weight	
Species	Greenhouse	Mean ± SE (cm)	Required sample size	Mean ± SE (mm)	Required sample size	Mean ± SE (mg)	Required sample size
White spruce	9	10.3 ± 2.7	26	1.5 ± 0.3	16	378 ± 181	89
	10	11.6 ± 2.7	21	1.6 ± 0.3	16	465 ± 204	74
	11	10.9 ± 2.4	20	1.5 ± 0.3	17	406 ± 180	76
	12	10.8 ± 2.2	17	1.5 ± 0.3	16	398 ± 177	77
	All	10.9 ± 2.5	15	1.5 ± 0.3	16	412 ± 188	81
Black spruce	13	15.9 ± 3.5	20	1.5 ± 0.3	18	441 ± 203	82
	14	12.9 ± 2.9	21	1.4 ± 0.3	19	322 ± 147	81
	15	15.1 ± 2.6	12	1.6 ± 0.3	14	429 ± 171	61
	16	12.5 ± 2.6	16	1.4 ± 0.3	12	341 ± 155	79
	All	14.1 ± 3.3	21	1.5 ± 0.3	18	383 ± 178	83

[a] Data collected by S.I. Cameron and R.D. Hallett, Maritimes Forest Research Centre.

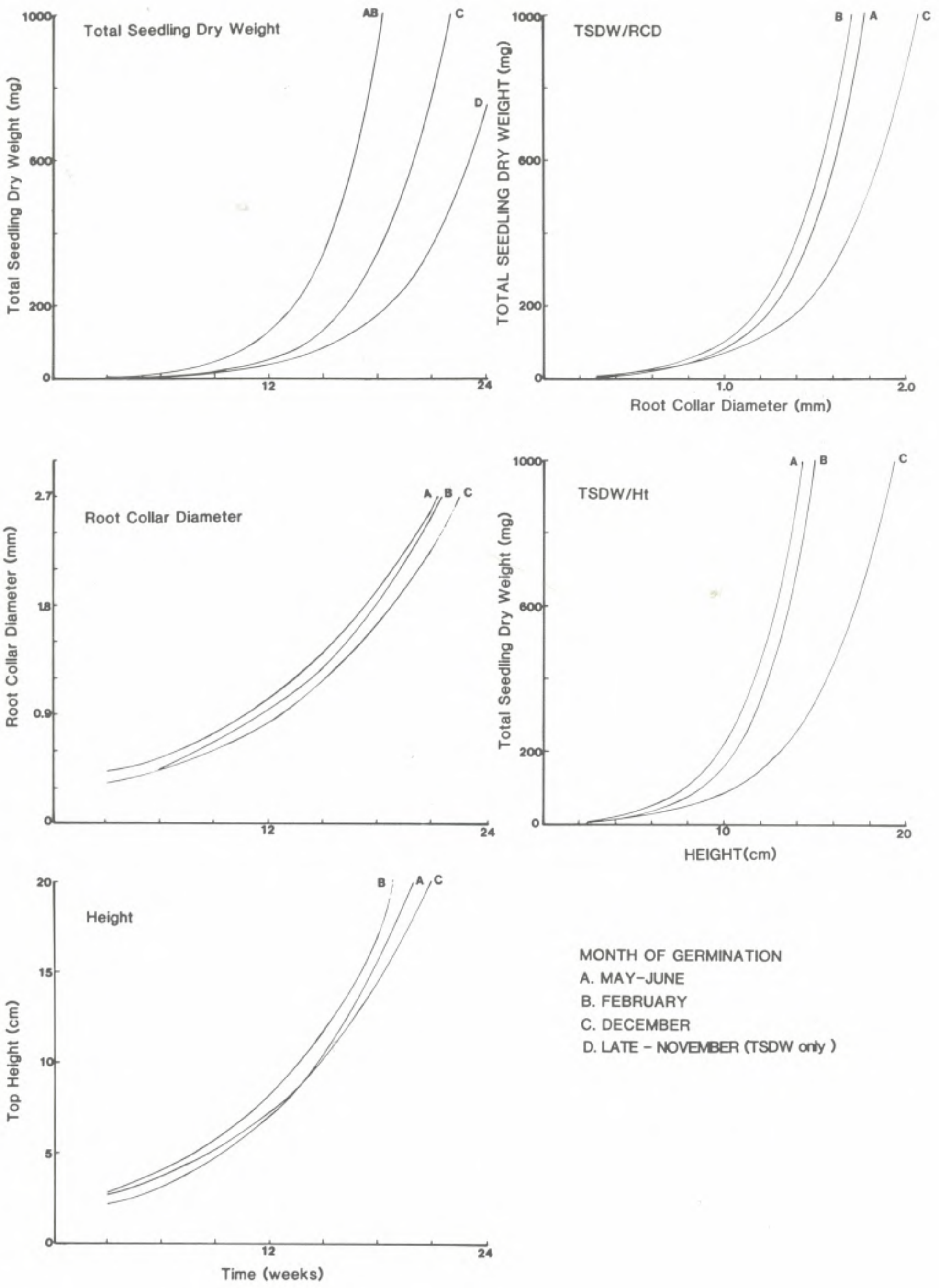


Figure 1. Standard curves showing seasonal patterns of growth of containerized black spruce seedlings raised in greenhouses.

equation for February dry weight vs height: $Y = 4.43e^{0.04x}$, $r^2 = 0.88$ where Y = dry weight, x = height). For convenient non-destructive sampling this relationship can be used to estimate dry weights from height (Armson and Sadreika 1979, Day 1979).

ROOT GROWTH

Root development is often ignored until it is time to ship the seedlings, when the plug or paperpot must be extractable and plantable. Root weights are commonly measured: what use can be made of the data? Shoot:root ratios may help to detect inferior root development. For example, with winter crops raised under poor natural light, greenhouse temperatures, soil moisture and nutrients must be managed carefully to prevent spindly shoots and weak root development.

Carlson (1979) states that, at shipping, the dry weight of roots per cm^3 of rooting volume should be greater than 4.0 mg; consequently, root dry weight may also be used to assess extractability of the plug. The root area index used in Ontario nurseries (Armson and Sadreika 1979) could also be used to assess quality.

MONITORING GREENHOUSE ENVIRONMENT

In the container nursery, the opportunity to maximize growth lies in the ability to control environmental factors. Often, differences in growth may be due simply to climatic factors. While the greenhouse climate may be sensed by those passing through and temperature and relative humidity are recorded by gauges, variation can be considerable. The use of hygrothermograph and weather data is most helpful in answering questions if growth is not as expected.

The nurseryman's greatest influence on crop development is usually through the use of water and fertilizers, although he may not have adequate knowledge of what is happening.

MONITORING SOIL WATER

Poor irrigation practices frequently cause trouble in the greenhouse. Water applications may be too heavy, too light, too often, too infrequent or too uneven, but whatever the problem, seedlings do not grow as well as they should.

Several methods are used to monitor soil water. The simplest is to weigh the containers. However, the seedling's need for water or the degree of moisture stress can be assessed through use of the pressure bomb (Carlson 1979, McDonald and Running 1979, Day 1980). (For a detailed description of the use of the pressure bomb see Day and Walsh 1980.)

Weight of Containers

Differences in soil moisture levels can be detected by weighing flats of seedlings. Several flats from various areas of the greenhouse should be marked for weighing because the weights may vary greatly on account of their proximity to heating or cooling equipment, walks, etc. Enough weights are needed to give a reliable assessment.

Growth of each species and in each type of container should be studied to determine optimal soil moisture levels, but first a safe approximation is needed for the commercial grower. McDonald and Running (1979) suggested that containers be allowed to dry to 75-80% of their saturated weight, then be rewatered to drip (near field capacity).

The reaction to different levels of soil water and fertility varies with species (Table 2). From studies such as these, a range in weight of 13.5 to 14.5 kg is suggested for FH 408 paperpot flats and the minimum weight for styroblock-4s and styroblock-8s is 5.8 kg (Table 3).

Day (1980) concludes that "the secret of effective nursery irrigation is to keep the interstices of the soil filled with both water at low matric potential (i.e. -0.1 to -0.5 Bar tension) *and* air in order to minimize plant water stress." Day (ibid.) and McDonald and Running (1979) prescribe soil moisture retention curves which show the relationship between the amount of water in the soil and the tension at which it is held. Puustjrvi et al. (1972) similarly developed moisture release curves for different grades

Table 2. Effects of fertilizer and water on growth (mean seedling total dry weight (mg) of several conifer species raised in styroblock containers).

Species	Normal fertilizer[a]		High fertilizer	
	Normal[b] water	High water	Normal water	High water
Black spruce	527	545	558	601
White spruce	579	540	550	600
White pine	610	625	597	633
Tamarack	747	752	738	751

[a] Fertilizer: Normal 1 kg/100 m^2; high 1.5 kg/100 m^2

[b] Water: Normal minimum 5.5 kg; high 2 extra passes.

Table 3. Recommended container weights and total soil moisture content (T.S.M.C.) by weight and by volume.

Container	Recommended weight (kg)	Weight of medium[a] in containers		Water weight (kg)	Total medium volume (L)	Pore vol of medium (%)	Weight pore vol filled water (kg)	T.S.M.C. by	
		Wet (kg)	Dry (kg)					wt (%)	vol (%)
Paperpot FH 408	13.5-14.5	11.5-12.5	1.50	10-11	24	96	23	660-730	43-48
Styroblock 4	min. 5.8	5.8	0.54	3.46	9.6	94	9.2	640	38

[a]Growing medium was peat in paperpots and peat plus vermiculite in styroblocks.

of peat (Fig. 2). Their optimal soil moisture range for a medium coarse peat was 42.5 to 46.1% by volume with an associated air capacity of 53.6 to 50%, and soil moisture tension less than -0.55 Bar (close to Day's [1980] recommendation). The soil water content at recommended container weights for local data is comparable (Table 3).

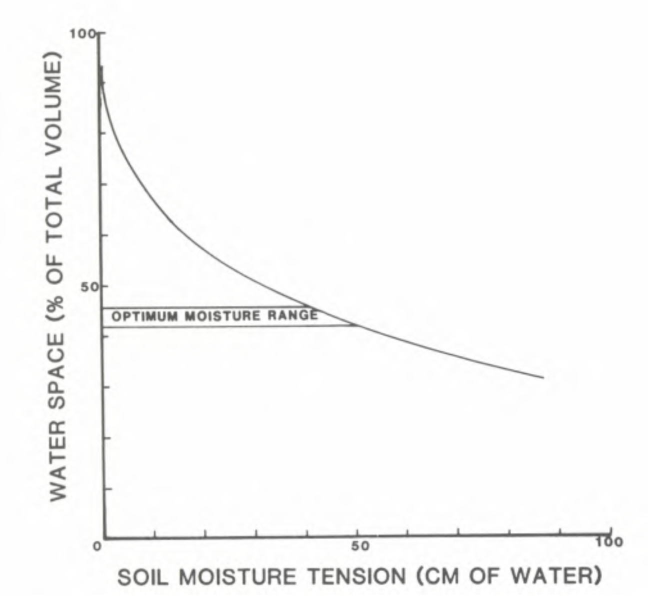


Figure 2. Soil water characteristic curve for medium coarse peat showing optimum moisture range (100 cm = 0.1 Bar). Adapted from Puustjarvi et al. (1972).

SOIL FERTILITY

Often, little is known about the level of soil fertility and how it changes with fertilization and irrigation. Several methods are used to fertilize containers: a once-weekly "shot" of concentrated fertilizer solution followed by irrigation; a once-weekly "soak" with a less concentrated fertilizer; "constant" application of a fertilizer of very low concentration with every irrigation; and "slow-release" fertilizers mixed in the medium at the start of production.

Nutrients are readily leached from peat or peat-vermiculite growing media, yet root and shoot injury from excessive concentrations of total salts or individual elements is still possible because of rapid changes in soil moisture. Management of the greenhouse soil and water is usually very intensive and changes can take place quickly. Frequent testing of soils for nutrient content is recommended.

Analysis of greenhouse soils

Soil test kits were developed in horticulture for rapid determination of pH, soluble salts, and the macroelements. Use of the kits and the interpretation of results requires experience and can take a lot of time. However, in most regions greenhouse soil testing is done as a service at various soil and plant testing laboratories. Fast service is needed for intensively fertilized greenhouse soils. Over five years, greenhouse managers in the Maritimes have submitted more than 4,000 samples for testing. Results have been monitored and an interpretation scheme developed for containerized tree seedling production (Table 4). The grower must become familiar with the results from the laboratory he uses because of variation in testing techniques (Hanan et al. 1978).

Table 4. Recommended greenhouse ranges of nutrients in peat and peat-vermiculite growing media fertilized with soluble fertilizers.

Salts mhos x 10^{-5}	pH	Available nutrients in ppm in soil extract[a]				
		N	P	K	Ca	Mg
Horticultural crops						
30	6.2	6	6	20	min	min
120	7.2	12	16	59	150	6
Tree seedlings						
25	4.0	6	8	15	min	min
50	6.0	12	16	30	5	3

[a] Specific recommendations are available for different stages of seedling development.

Samples must be collected and handled carefully for reliable results. Growers randomly select several locations in the greenhouse at which they collect a soil plug, remove the surface grit and soil, then combine the medium to make one sample. Self-addressed, wax-lined cardboard boxes or plastic-lined bags are provided by the laboratory for shipping.

At the Maritimes Forest Research Centre laboratory, the soil is mixed and a fixed volume is sub-sampled. Because the samples are not dried before analysis, they should not be shipped dry one week and saturated the next. Samples should be taken after the medium is irrigated or fertilized, and allowed to drain to field capacity. High readings result if the samples are delayed in the mail or collected a long time before analysis.

Greenhouse soil analysis is an effective tool for greenhouse managers, not only for those using periodic additions of soluble fertilizers but also for constant fertilization or for soils amended with slow-release fertilizers. Figure 3 shows the initial reduction in excessive fertility and the week-to-week variation in nutrient content at a nursery using weekly fertilization. Analyses from greenhouses using constant fertilization are less variable but are still required, particularly during phases of production when changes are required, such as hardening-off, or for crops grown outside when rainfall may cause considerable nutrient losses.

FOLIAR ANALYSIS

Soil analysis data can be used to compare concentrations of soil nutrients with predetermined levels of fertility. Seedlings should also be analyzed periodically for nutrient content to measure the response to the levels of fertility provided and to relate this to the growth achieved. The ranges in nutrient concentrations in the foliage of bare-root nursery stock in Ontario are presented by Armson and Sadreika (1979). Such published information is not yet available for container stock, although several sources give values or suggestions for interpretation (Brix and van den Driessche 1974, Owston 1974, Tinus 1974, Tinus and McDonald 1979).

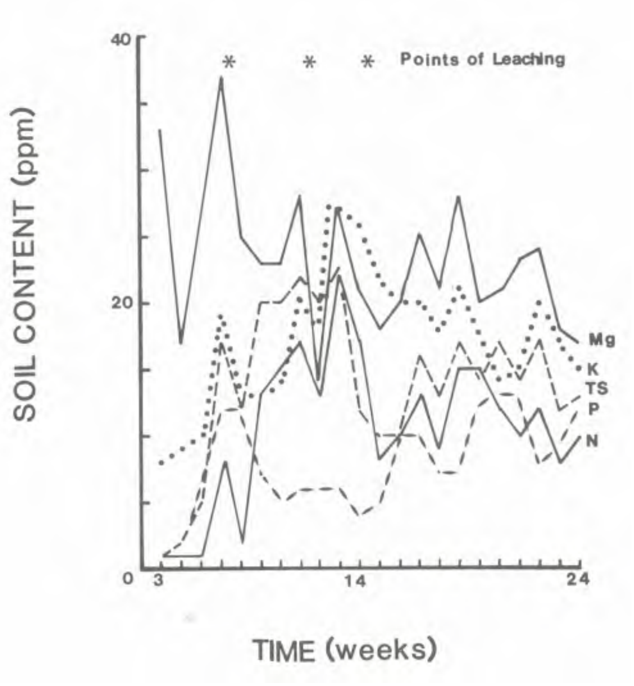


Figure 3. Trends in total salts (TS), nitrate nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) as determined weekly by laboratory analysis for a containerized black spruce crop raised in the greenhouse in a peat-vermiculite growing medium (December-May).

Foliar analysis data are difficult to interpret. To follow the advice of Tinus and McDonald (1979), the nurseryman can collect data at different stages of development of a satisfactory crop and use them for future comparisons.

Nitrogen concentrations

Probably the simplest way to use foliar analysis data would be to look first at the actual concentration of nitrogen and determine if it is adequate, deficient, or excessive. Guidelines for nitrogen content are given in Table 5 for local spruce and pine *(Pinus* spp.) at different stages of development.

Ingestad nutrient proportions

The second step in the evaluation of seedling nutrient concentration data would be to calculate the "Ingestad" nutrient proportions rather than attempting to evaluate the concentrations of the other elements in the foliage. These are the proportions of the other elements in relation to nitrogen (e.g., P/N x 100). Ingestad (1962, 1967) stated that "the proportions of elements in plants at optimum nutrition vary insignificantly with species or age of plant, although the absolute concentrations and quantities may vary." He considered the following nutrient proportions to be optimal: nitrogen 100; phosphorus 13; potassium 65; calcium 6; magnesium 8.5; sulfur 9; iron 0.7; manganese 0.4; boron 0.2; copper 0.03; zinc 0.03; chlorine 0.03 and molybdenum 0.003. In the Maritimes, macronutrients have been used successfully in the following proportions (nitrogen = 100); phosphorus 10 to 13; potassium 40 to 65; calcium minimum 6; and magnesium minimum 6. By using these proportions and the suggested nitrogen concentrations, one can readily assess the relative nutrient content of a sample. Foliar analysis data for several good crops of containerized black spruce are presented in Table 6.

USE OF MONITORING DATA

The use of monitoring data is illustrated in Table 7, where differences in total seedling dry weight, shoot:root ratio, soil nitrogen, and foliage nutrient concentrations are related to seasonal, fertilizer, or supplementary lighting treatments of black spruce crops.

Predicting growth reliably depends on the establishment of a good data base which includes seedling development, soil water and fertility and seedling nutrient content. By the use of such data, problems can be better assessed with confidence since it is soil water and fertility, combined with greenhouse climate and weather conditions, that determine the growth of a crop.

Table 5. Provisional guidelines for nitrogen concentration (%) in containerized seedlings at various ages and stages of development.

	Age (weeks)			
Species	3 - 10	10 - 16	Hardening	Overwintering
Spruce	2.8 - 3.0	2.5 - 2.8	2.2 - 2.5	1.9 - 2.2
Pine	3.2 - 3.6	2.5 - 3.0	2.5 - 2.8	1.9 - 2.2

Table 6. Foliage nutrient concentrations (% or ppm) and macronutrient proportions from satisfactory crops of containerized black spruce seedlings.

Age (weeks)	Nutrient concentrations										Nutrient proportions			
	N	P	K	Ca	Mg	B	Fe	Mn	Cu	Zn	P	K	Ca	Mg
	(%)					(ppm)					(Nitrogen = 100)			
10-14	2.73	0.44	1.39	0.23	0.16	28	99	306	15	47	16	51	8	6
15-18	2.44	0.38	1.34	0.24	0.17	89	68	200	9	33	16	55	10	7
19-26	2.50	0.36	1.15	0.37	0.22	37	127	107	16	45	14	46	15	9

Table 7. Dry weights and shoot:root ratios of containerized black spruce seedlings raised in peat or peat and vermiculite in winter and summer under different fertility or lighting regimes, with associated foliage nutrient concentrations and proportions.

	Month seeded	Treatment	Age (wk)	Total seedling dry weight (mg)	Shoot: root ratio	Soil nitrate nitrogen (ppm)	Foliage nitrogen content (%)	Ingestad nutrient proportions (Nitrogen = 100)				Comments
								P	K	Ca	Mg	
A.	Sept.	High nitrogen fertilizer	13	86	6.8	25	2.94	13	55	10	6	Excessive nitrogen, slow growth rate.
B.	Sept.	As in A but with HID lighting	13	699	5.8	7	1.74	15	61	11	6	Fast growth rate resulting in nitrogen deficiency.
C.	Nov.	High fertility	16	150	6.5	32	2.84	17	46	9	7	Excessive nutrients with seedling losses.
D.	Nov.	As in C but with modified fertility	16	200	3.4	7	2.51	14	56		6	Better growth without injury.
E.	Jan.	Reduced fertilizer levels	11	44	4.5	2	2.16	23	59	9	9	Slow growth and nitrogen deficiency.
F.	Jan.	Recommended fertilizer levels	16	585	5.5	10	2.65	14	42	6	6	Good growth.
G.	June	"Normal" rate 28-14-14	13	175	4.3	2	2.75	14	33	9	6	Acceptable growth.
H.	June	Increased rate 28-14-14	13	290	6.6	3	3.04	11	36	7	6	Better growth.
I.	June	Excessive rate 28-14-14	13	255	10.0	12	3.41	11	31	3	4	Inferior growth.

LITERATURE CITED

Armson, K.A. and Sadreika, V.
1979. Forest tree nursery soil management and related practices. (metric ed.) Ont. Min. Nat. Resour. 179 p.

Brix, H. and van den Driessche, R.
1974. Mineral nutrition of container-grown tree seedlings. p. 77-84 in R.W. Tinus, W.I. Stein and R.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium, Great Plains Agric. Counc. Publ. 68.

Carlson, L.W.
1979. Guidelines for rearing containerized conifer seedlings in the Prairie Provinces. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-214. 62 p.

Day, R.J.
1979. The development of a method for monitoring the growth of nursery stock. Lakehead Univ. Sch. For. Silvic. Rep. 1979-1. 28 p.

Day, R.J.
1980. Effective nursery irrigation depends on regulation of soil moisture and aeration. p. 52-71 in Proc. North. Am. For. Tree Nursery Soils Workshop, Coll. Environ. Sci. For., State Univ. New York, Syracuse.

Day, R.J.
1981. Programmable calculator (TI-59) programs for use on forest nurseries. Lakehead Univ., Sch. For. Silvic. Rep. 1981-1. 70 p.

Day, R.J. and Walsh, S.J.
1980. A manual for using the pressure chamber in nurseries and plantations. Lakehead Univ., Sch. For. Silvic. Rep. 1980-2. 49 p.

Hallett, R.D.
1980. Seasonal patterns of growth for black spruce container seedlings raised in the greenhouse. Dep. Environ., Can. For. Serv., Fredericton, N.B. Tech. Note No. 20. 4 p.

Hanan, J.J., Holley, W.D. and Goldsberry, K.
1978. Greenhouse Management. Springer-Verlag. 530 p.

Ingestad, T.
1962. Macroelement nutrition of pine, spruce and birch seedlings in nutrient solutions. Medd. Skogsforsk. Inst., Stockholm. 51(7). 133 p.

Ingestad, T.
1967. Methods for uniform optimum fertilization of forest tree plants. XIV. IUFRO Congress, Munich. III. p. 265-269.

McClain, K.M.
1975. Seedling height growth, a monitoring technique in nursery soil management. Tree Plant. Notes 26(2):23-25.

McDonald, S.E. and Running, S.W.
1979. Monitoring irrigation in western forest nurseries. USDA For. Serv., Gen. Tech. Rep. RM-61. 8 p.

Owston, P.W.
1974. Two-crop production of western conifers. p. 104-111 in R.W. Tinus, W.I. Stein and R.E. Balmer, *Ed.* Proc. North Am. Containerized For. Tree Seedling Symp., Great Plains Agric. Counc. Publ. 68.

Puustjdrvi, V.
1972. Physical properties of peat used in horticulture. p. 11-17 in V. Puustjärvi, D. Ratia and S. Vuovikallas, *Ed.* Peat and Plant Yearbook 1972.

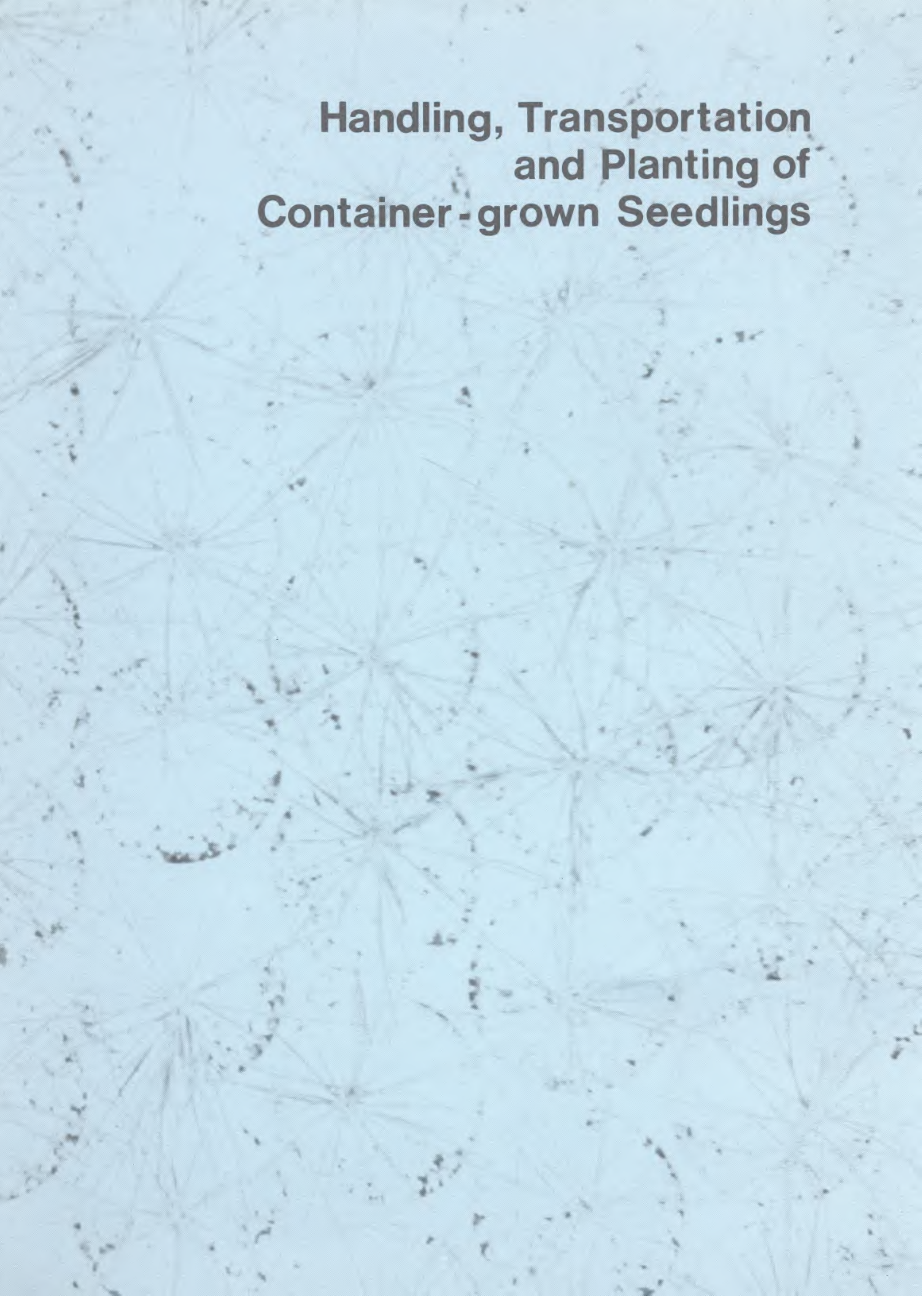
Scarratt, J.D. and Reese, K.H.
1976. Objectives and criteria for planting stock production in Ontario. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. O-X-253. 17 p.

Tinus, R.W.
1974. Large trees for the Rockies and Plains. p. 112-118 in R.W. Tinus, W.I. Stein and R.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium, Great Plains Agric. Counc. Publ. 68.

Tinus, R.W. and McDonald, S.E.
1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv., Gen. Tech. Rep. RM-60. 256 p.

Van Eerden, E.
1974. Growing season production of western conifers. p. 93-103 in R.W. Tinus, W.I. Stein and R.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium Great Plains Agric. Counc. Publ. 68.

Handling, Transportation and Planting of Container-grown Seedlings



BIOLOGICAL AND OPERATIONAL CONSIDERATIONS IN THE DEVELOPMENT OF INTEGRATED HANDLING AND TRANSPORTATION SYSTEMS

Hakan Hulteni

Abstract.--A number of the larger nurseries in Sweden have developed systems and hardware for integrating the handling, packaging and storage of containerized planting stock in the nursery with its delivery and distribution in the field. Biological and operational factors to be considered in the development of integrated handling systems are reviewed and discussed.

Résumé.--Un certain nombre des principales pépinières suédoises ont intégré l'équipement et les systèmes de manipulation, d'emballage et de stockage sur place du matériel de reproduction en mottes emballées puis de son transport et de sa distribution sur le terrain. On étudie les facteurs d'ordre biologique et opérationnel dont il faut tenir compte dans la mise au point des systèmes intégrés, et on présente une discussion sur ce sujet.

INTRODUCTION

The starting point for an integrated containerized system is the seed in the nursery, and the goal, or outcome, is the planted seedling in the field. The seedling should be firmly positioned or planted and should have good prospects for developing into a healthy tree in the future forest. The three important links in the chain--plant production, distribution and planting--should be interrelated and the whole process optimized. An important element in the distribution link that merits special attention is storage.

Various approaches can be used in designing a containerized system. Frequently, the pivotal feature of a system is a specific item such as container design or planting technique. With a little luck and skill, such systems will find specific situations to which they are well suited. An alternative approach is first to identify the basic characteristics of the situation at hand and to specify the demands they make on the production-distribution-planting system. The problem is then one of finding solutions that satisfy these demands.

The likelihood of finding the "right" system for specific situations is probably greater if the latter approach is used. However, it is crucial that the characteristics of a given situation be accurately identified.

ASSESSING THE SITUATION

The setting under which our system is to function must be clearly specified in terms of critical characteristics. For example, the size of the tract to be planted will determine the volume of trees to be transported to the planting site. Smallhold forests in southern Sweden average 1 to 3 ha, whereas industrial tracts in northern Sweden range from 15 to 20 ha. These two extreme cases call for entirely different modes of transportation (types of vehicles, etc.). Similarly, the infrastructure in the form of

---

[1] Professor, College of Forestry, Swedish University of Agricultural Sciences, Garpenberg, Sweden.

roads and available manpower will influence the types of transport that can be used. The timing and duration of the planting season are a function of manpower supply and climate, and these also have a decisive effect on the length and intensity of the transport season, as well as upon the need for storage facilities.

The scale of operations influences the length of supply lines. A company with vast forest holdings and centralized plant production will have long supply lines. The type of forestry operations also influences the length of supply lines as well as the total area over which the plants have to be distributed. Patterns of ownership (socio-economic structures) also exert considerable influence on the organization of transportation. For a heterogeneous group of forest owners who draw their plants from the same nursery a system of considerable adaptability will be required. A single, flexible system will be more economical than several rigid ones.

Totally integrated systems are most easily achieved when the forest owner is in a position to plan and steer plant production, distribution and planting. Independent plant-producing companies or organizations may put too much priority on plant production. Furthermore, efforts to effect changes in such systems often take a long time. A typical example of this is the situation in Sweden, where practically the entire forest industry, which accounts for roughly 50% of the total forest area, utilizes containerized systems and has developed appropriate and well practised routines. On the other hand, smallhold forest owners in southern Sweden lack systems specially adapted to their conditions. It is unlikely that this group will be able simply to copy industrial systems. The forest industry has been able to analyze its situation and identify its needs; the corresponding process among smallholders started only recently.

VIEWS ON DISTRIBUTION

As suggested earlier, many of the needs in a given system are dictated by field conditions. Therefore, in examining the handling and transport link of the overall system one must start in the field.

Planting concludes the distribution process. It can be achieved in two fundamentally different ways: by inserting the seedling into the soil, or by placing the seedling on the surface of the soil. The latter technique, which is discussed elsewhere in this symposium (Lindstriim and Wigberg 1982), has had only limited application to date. The technique used to fix or anchor the seedling dictates features of container design, container function and handling.

By examining the chain of events leading from nursery to planted seedling, we can identify a series of critical points in the transportation process: terminal, roadside depot, edge of the cleared site, strategic placement on the site and the location of

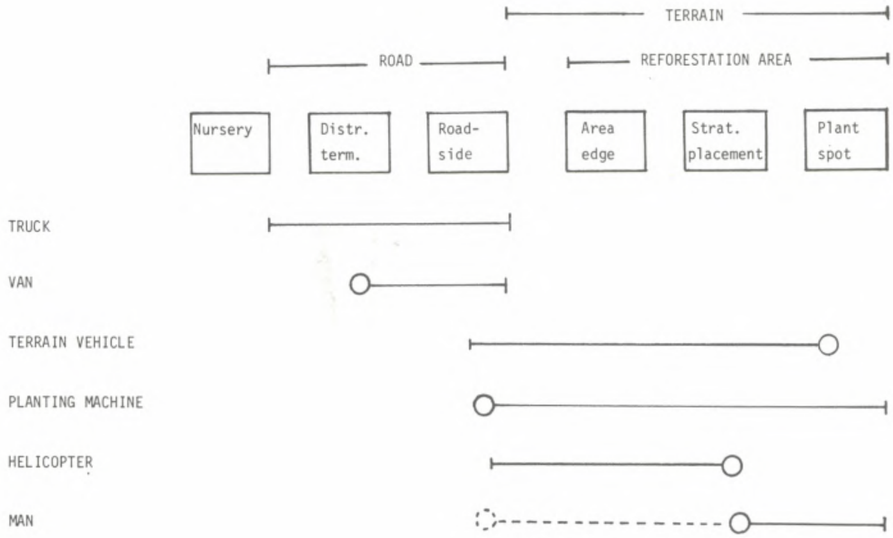


Figure 1. Schematic diagram of stock distribution and various means of transportation.

each individual plant. Various means of transport may be used, depending on the types of roads, volumes of trees and length of the supply line. The application of various types of vehicle to different transportation situations is illustrated in Figure 1.

The transportation of seedlings from the nursery to the planting site may be looked upon as a flow in which the volume to be transported is progressively broken down, ultimately to the individual seedling. Figure 1 indicates the most natural points for such subdivisions. It is important that the weight or volume of the transport unit (e.g., box, pallet, etc.) be matched to the vehicle capacity. In the case of small planting tracts, the strategic placement of seedlings on the site is unnecessary. The only feasible means of transport here, in terms of costs, is to carry the seedlings on foot to the site, so that the transport unit at the edge of the site must break down into units suitable for manual transport.

In the case of hand planting the planter performs the final act of distribution on the site. Volumes and packaging should therefore be adapted to the human body. Such packaging characteristics can be built into the nursery operation, e.g., in the form of tear-away segmented cartons.

In large-scale operations helicopters have proven especially effective vehicles for transportation of seedlings from roadside depots to strategic points on the cleared site. Terrain vehicles can bring the plants in unbroken packages practically to the point at which they are to be planted. Planting machines carry the process through to the point of fixing the seedling in the soil, although the machines' feeding mechanisms generally require that transport packages be broken down when the machine is loaded. Normally, the distance between roadside depot and the edge of the cleared site is short or negligible, especially in large-scale operations where access roads were constructed when the former stand was felled.

Generally, large trucks transport the seedlings from the nursery to the roadside depot. When planting sites are small and widely scattered, it may be appropriate to establish a distribution terminal, where the transport unit can be broken down into cartons which can be transported by hand in smaller vehicles. The successive breakdown of the transport unit after leaving the nursery is illustrated in Figure 2. Packaging should protect the plants against mechanical and biological abuse, such as excessive wind, dehydration and less than optimal temperatures. The package should also be designed so that it can be handled and transported easily through the various distribution links. It may be necessary to establish a buffer storage depot somewhere along the distribution chain. The need for such a depot varies, and will depend on administrative and organizational factors. Transfer points in the chain are the most logical places for buffer storage. The earlier in the chain that storage takes place the easier it will be to monitor and maintain an adequate storage environment because of the greater volumes involved.

In the case of small, scattered sites, with labor-intensive operations, return transport of packaging materials for reuse in the nursery can prove expensive. In such cases disposable, single-use packaging is preferable, although it may entail special handling (burning, burying, etc.) of the refuse. The decision as to whether or not to assume the cost of return transport will influence the choice of container type.

HANDLING IN THE NURSERY

Containerized nurseries nearly always use stationary facilities, sowing machines and packaging units. The seedlings are transported between these installations and the places of cultivation, storage areas, etc. Transport and handling are thus dominant features in the nursery routines. Cultivation takes place on "surfaces", whereas transportation involves "volumes". Many other nursery activities, such as peat filling, sowing, and packing, also take place on surfaces. Recurrent transportation in the nursery phase thus demands rational internal transport units that can easily be converted to surfaces and back into volumes again, as illustrated in Figure 3.

The smallest unit is the container, numbers of which may be aggregated into a "surface", often into a unit suitable for manual handling (a container set). It is this unit which passes through the peat-filling machine and sowing machine. If these units are stacked in frames which can be used for mechanized distribution and collection in the nursery they may be called "cultivation units". To achieve rational transportation between various locations, these units may be combined into internal transport units (ITU). Use of these various units in the nursery is illustrated in Figure 4.

In situations where the seedlings are packaged, the packing phase marks an important breaking point in the chain of events

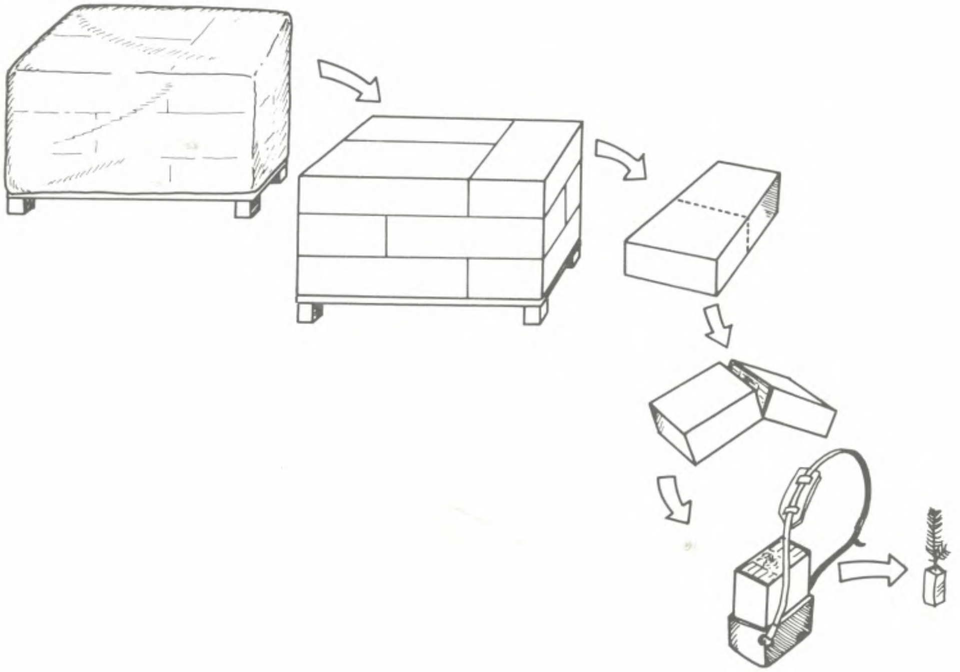


Figure 2. Example of progressive breakdown of an External Transport Unit (ETU).

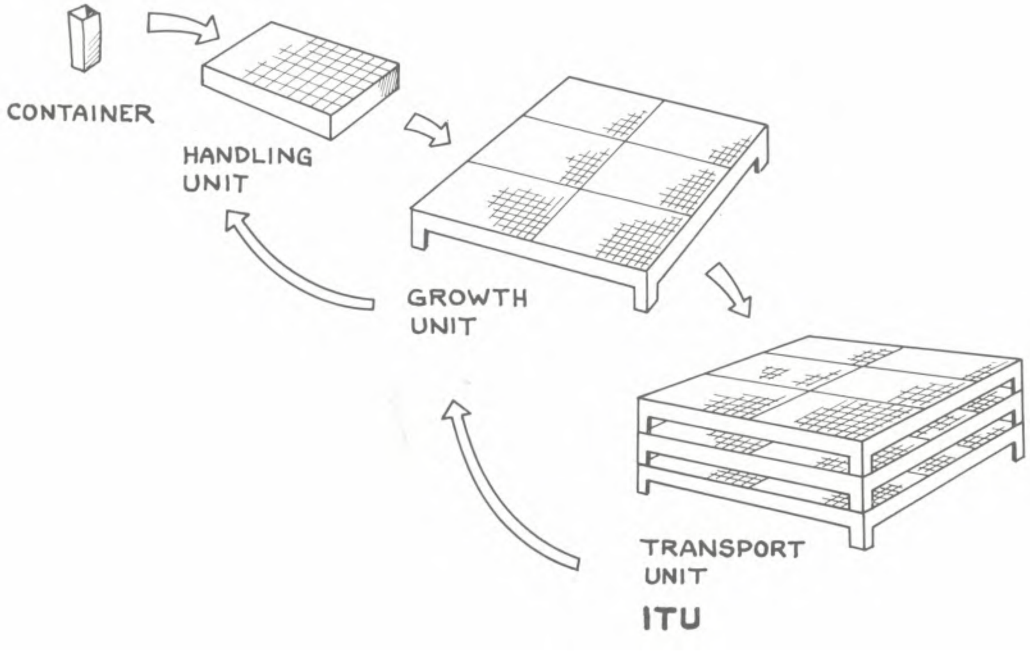


Figure 3. Examples of different handling levels in the nursery.

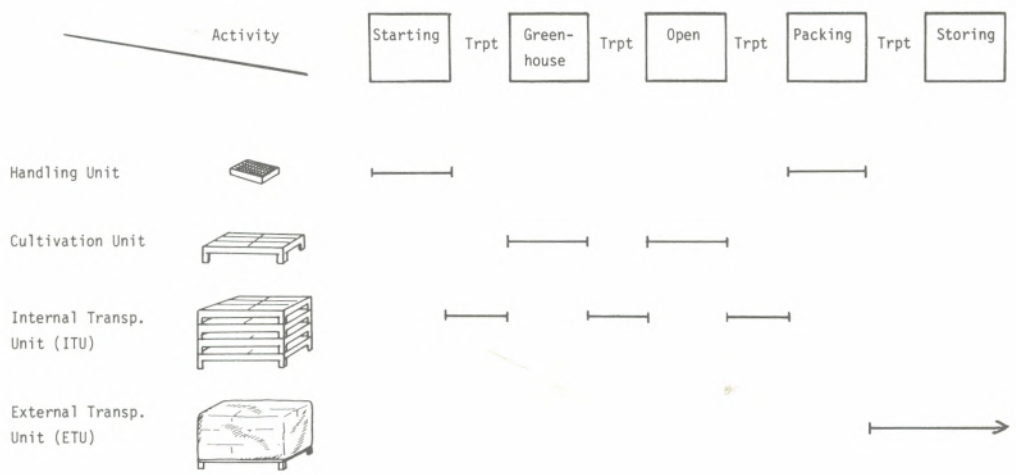


Figure 4. Handling in the nursery.

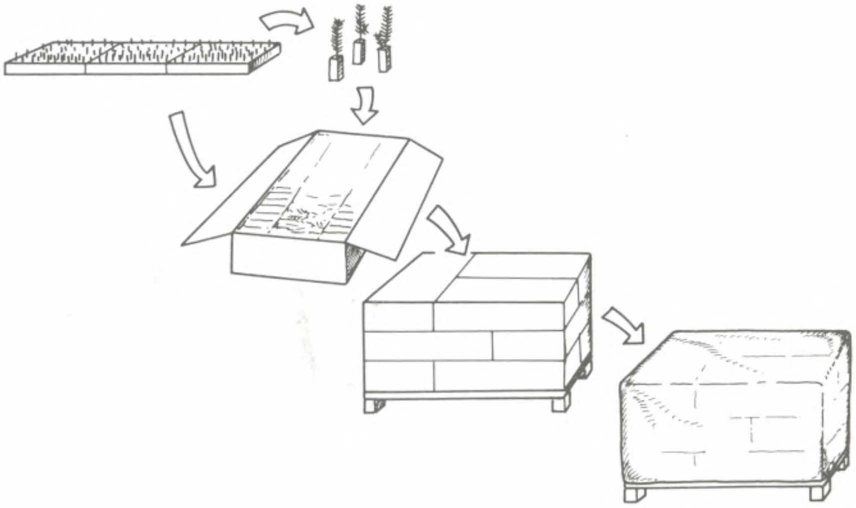


Figure 5. Composition of an External Transport Unit (ETU).

from seed to planted seedling. Demands on handling and transport in the nursery may be more easily satisfied if the nurseryman is free to ignore all the demands posed in the subsequent distribution phase outside the nursery, and vice versa. In the simplest case, ITUs will be broken down into units that may be packed by hand in cartons to constitute the elementary units in external transport units (ETU). If the container is removed in the packing process (as in the case of plug seedlings), the container set will be broken down into individual seedlings. Handling is thus intimately associated with container characteristics and the mode of aggregation. The situation is somewhat simpler when the container stays with the plant (as in the case of paperpots), leaving only the handling tray behind.

Figure 5 illustrates the composition of an ETU. Properly designed, an ETU will accommodate many plants per cubic metre and is therefore well suited to refrigerated storage, provided that the packaging material shields the plants against dehydration.

Other functions besides handling may also be accommodated in the cultivation unit, including air pruning of the roots. This generally works well during the growing season, but is risky for winter storage at the cultivation site--especially on elevated racks--even for such hardy species as Scots pine *(Pinus sylvestris* L.) and Norway spruce *(Picea abies* Karst.).

Where there is no packaging of seedlings, but the ITU is identical with the ETU, the requirements of the distribution process must be completed in the nursery phase. Long-term refrigerated storage is made more difficult, but certain advantages are gained in the event of buffer storage in the field inasmuch as the plants can be set out in a single layer to resume growth. However, this entails special care and attention. Such a system is relatively simple, with few components, but it is a typical return transport system.

CRITICAL POINTS IN HANDLING

The need for culling and sorting of seedlings in the nursery is well known from bare-root production. This need probably cannot be neglected much longer in containerized stock production. This requirement necessarily implies individual handling, which is a key problem that requires the development of fully automated technical solutions. First of all, empty containers must be discarded. This is not too great a problem, but more difficult is the removal and discarding of substandard plants. Intensive research and development efforts are required to solve this problem.

Thinning to make sure that each container contains only one plant, and replacing empty cavities, are problems familiar to all of us which call for a radical solution. Thinning is extremely hard to mechanize. One way of getting around the problem is to sow in preliminary containers (precontainers) and then transfer the seedlings to the final container. This would also solve the problem of refilling empty cavities, since all the containers would be filled at time of transplanting. This is a potentially interesting line of development, which may also afford opportunities to sort or segregate seedling populations without sacrificing the benefits of surface or belt aggregation when planting stock is delivered to the planting machine.

STANDARDIZATION

Finally, a word about standardization is in order. It is essential to adopt generally accepted standard measures in all phases of production. Standardization will facilitate adaptation to existing technology and equipment, particularly in the realm of handling and transportation. Tailor-made is luxury indeed.

LITERATURE CITED

Lindstrom, Anders and Hogberg, Karl-Anders 1982. Surface planting systems. p 397-400 in J.B. Scarratt, C. Glerum and C.A. Plexman, *Ed.* Proceedings of the Canadian Containerized Tree Seedling Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. O-P-10.

ALBERTA'S APPROACH TO CONTAINERIZED SEEDLING HANDLING

S.A. Luchkow[1]

Abstract.--The Alberta Forest Service has developed a system of handling Spencer-Lemaire containerized seedlings which is both efficient and economical. Details of nursery, transportation, and planting site handling with this modern, palletized system are discussed.

Résumé.--Le Service des forêts de l'Alberta a mis au point un dispositif pour manutentionner de façon efficace et économique les plants en contenants Spencer-Lemaire. Les détails de la manutention en pépinières, sur les lieux de la plantation et en transit avec ce système palettisé moderne font l'objet d'une discussion.

INTRODUCTION

The purpose of this paper is to describe the containerized seedling handling system used by the Alberta Forest Service in its reforestation program. Information is presented on three distinct phases involved in growing and planting containerized seedlings.

1. Production - includes all handling practices at the nursery during seedling growth and storage.
2. Transportation - includes all handling involved in moving containerized seedlings from nursery to planting site.
3. Planting - includes all handling practices at the planting site.

A brief description of the nursery facility and the container system used is essential for an understanding of the containerized seedling handling system.

The Pine Ridge Forest Nursery, located 19 km east of Smoky Lake, Alberta, is one of the largest, most modern forest tree nurseries in North America. The nursery was designed for four major activities:

1) seed extraction, cleaning and storage
2) containerized seedling production
3) bare-root seedling production
4) research and investigations program.

This paper will consider only the container production program, which is currently capable of producing 10 million seedlings per crop.

The nursery employs the Spencer-Lemaire (Ferdinand) Container System manufactured by Spencer-Lemaire Industries Limited, an Edmonton-based company. The basic unit of this container system is the folding book planter. It is a vacuum-formed plastic sheet containing both halves of the container. When folded, the sheet forms rectangular cavities with open bottoms. Each folding book planter forms six cavities. Each 10-cm-deep cavity, measuring 3 cm x 2 cm, is capable of accommodating 41.0 cm^3 of growing medium. Seventeen books, forming 102 cavities, are held in a tray measuring 22 cm x 37 cm. The uniformity and inherent strength of this system facilitate mechanization of seedling production, transportation and distribution in the field.

---

[1] Forester, Reforestation and Reclamation Branch, Department of Energy and Natural Resources, Edmonton, Alberta.

PRODUCTION PHASE

Pine Ridge Forest Nursery's container seedling program utilizes both used and new containers. Used containers arrive at the nursery assembled. Before the containers are sent to the filling and seeding line, all broken components are replaced; then the containers are thoroughly washed and disinfected. The container washing machine consists of a chain conveyer carrying the containers through a pressurized water wash followed by a spray of dilute commercial bleach (disinfectant). New containers arrive at the nursery unassembled. Before filling and seeding, the containers are assembled by local residents on a piecework basis.

The filling and seeding line is designed as a continuous flow system. When the nursery was built, machinery that could fill and seed one million cavities per day was not available commercially. Therefore, it was necessary to construct the entire filling and seeding line for this particular container. The design, fabrication, and development of this production line has cost $141,000 to date.

Production starts with mixing of the growing medium which is composed of peat moss and vermiculite in a 2 to 1 ratio. First the peat moss and vermiculite are blended dry in a 4.6 m^3 hopper, then the blend is transferred to a wet mixer where water (approximately 160 L/m^3) and other additives (for wetting purposes or pH adjustment) are incorporated into the mix. When the proper moisture content is reached, the mixture is moved into the two holding hoppers located directly above the conveyor belts which transport the assembled trays through the filling, tamping, seeding and gritting operation in a continuous motion (Fig. 1). Each holding hopper is equipped with a vibrating agitator which prevents the medium from bridging and lodging in the hopper. The growing medium passes through an adjustable gate onto a reciprocating coarse sieve located at the bottom of the holding hoppers (used for removing unwanted debris and breaking up lumps) and then into the tray moving over the vibrating table. Here a worker brushes any surplus growing medium evenly over the tray of containers to ensure even filling of all cavities. As the tray leaves the vibrating table a revolving brush removes any excess medium and returns it to the holding hopper. The tray then moves under a pneumatic packer where the growth medium in the cavities is compressed to a uniform density. Once the growth medium is compressed, the tray proceeds through a drum-type vacuum seeder capable of sowing 2, 3 or 4 seeds per cavity on demand. The tray then moves through the gritter where grit is applied over the cavities to hold the seed in place during germination.The trays are then taken off the filling and seeding line and placed in specially designed plastic pallets, each of which holds 16 trays (1632 trees). Once filled, the pallets are stacked five high and forwarded by forklift or wagon to one of 20 greenhouses where the pallets are unstacked and placed on elevated wheeled dollies, each holding one pallet. The pallets remain on the dollies during the 12- to 17-week greenhouse growing period, after which they are moved to shade frames where the trees are hardened off and/or stored over winter. This completes the production phase of the containerized seedling handling process.

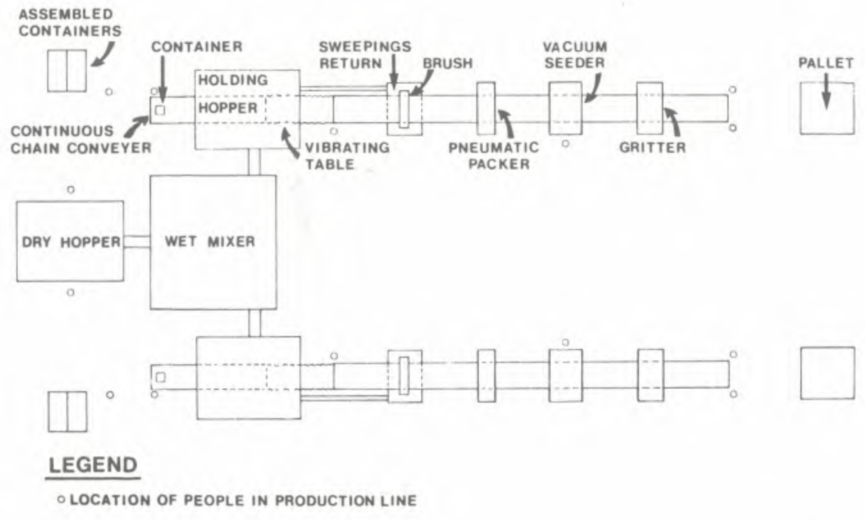


Figure 1. Pine Ridge Forest Nursery Container Production Line

TRANSPORTATION PHASE

Transportation handling involves the movement of palletized trees from nursery to planting site. This is achieved by the use of one of two specially modified cattle liners 15.25 m long, each capable of hauling 250,000 trees per load. The pallets are stacked seven high, loaded onto the trailer deck and moved into position by means of a pallet jack. The last four rows of pallet stacks placed in the trailer are strapped together to prevent movement during the trip to the field.

Upon arrival in the field the pallets are unloaded by one of two systems:

1) the reverse of the loading procedure used at the nursery

2) a swivelling crane on the hydraulic tailgate of the trailer.

If the access permits, pallets are unloaded at a central storage area at or near the planting site. However, in most cases poor access does not permit movement of semi-trailers onto the planting site. In such cases the pallets are unloaded as close to the planting site as possible. Tree planting in Alberta is done primarily on a contract basis. Movement and care of the seedlings after they have been unloaded from the semi-trailers is generally the responsibility of the planting contractor.

As trees are required in the more poorly accessed areas, they are moved to central locations within the planting site by all-terrain vehicles (ATVs) and/or helicopters. In the case of ATVs, the pallets are stacked, tarped, strapped and loaded onto the deck of these vehicles and are forwarded to the planting site. The size and type of the vehicle dictate the number of trees that make up a load. With helicopters, pallet slings designed and built by the Alberta Forest Service are used. These are designed for a helicopter with a 540 kg minimum sling capacity. The sling is assembled around the bottom pallet in a stack of seven pallets. Cables run the height of the pallet stack on all four sides, then through an adjustable top clamp which holds the stack together, and finally to the cargo hook of the helicopter. Each sling kit consists of three complete slings. This is to ensure continuous loading and unloading of pallets, thereby minimizing non-productive flight time. Once the trees have been centrally located within the planting site they are forwarded, usually with ATVs, to seedling cache sites within the blocks scheduled for planting. This completes the transportation phase of the containerized seedling handling process.

PLANTING PHASE

The movement of trees within the planting site is usually by one of two methods. The method most commonly used in Alberta is one in which the trees are removed from the Spencer-Lemaire containers at the seedling cache sites and placed in bare-root planting bags. From this point on, the seedlings are handled as bare-root stock. In the second method individual seedling trays are transported by the planters in wire-framed carriers. With this method the trees remain in the containers right up to the moment of planting.

Once planting has been completed all containers and pallets are returned to the nursery for re-use. This is done in reverse of the handling system used for getting the seedlings to the planting blocks.

Costs incurred during the production and transportation phases up to the unloading of the semi-trailers at the planting site are presented in Table 1. Further costs are borne by the tree planting contractor: the Alberta Forest Service does not have information about these costs.

Table 1. Containerized seedling production and transportation costs

Materials	Total spent ($)	Cost/'000 ($)	
A. Production phase[a]			
Trays	17,486.66	1.543	1/3 of purchase cost (3-yr life)
Filler books	135,954.86	12.000	7.2 /6 cavities
Propane for CO_2	550.10	0.048	
Grit, fertilizer, peat moss, vermiculite, other chem., and materials	25,067.97	2.213	
Misc. small equipment	5,946.23	0.525	
	185,005.82	16.329	
Labor			
Seeding	14,529.77	1.282	
Moving trays	7,337.85	0.648	
Thinning	53,205.08	4.696	
Crop maintenance	21,882.09	1.931	
Crop protection	7,438.33	0.656	
Container handling	6,864.44	0.606	
Tray assembly	11,993.70	1.059	
Misc. labor	36,082.74	3.185	
Benefits - labor	25,239.00	2.228	
	184,573.00	16.291	
Government service charges			
Natural gas (heating)	40,423.78	3.568	
Power, water + maintenance of facilities	107,695.73	9.505	
	148,119.51	13.073	
Depreciation			
Equipment (pallets, dollies, etc.)	57,302.04	5.057	7-yr use, 15% residual
Greenhouses	153,233.53	13.525	$4,597,006 ÷ 30 yr
Seeding line	4,689.24	0.414	30-yr depreciation period
	215,224.81	18.996	
Total cost of production phase before over-wintering	732,923.14	64.69	
B. Transportation phase[b]			
Transportation (average of 800 km round trip)	24,988.00	2.00	
Labor	4,781.43	0.38	
Depreciation	3,873.35	0.31	7-yr use, 15% residual
Total cost of transportation phase	33,642.78	2.69	

[a] Based on 11.33 million trees produced in 1980

[b] Based on 12.495 million trees shipped in 1980

PLANNING AND ORGANIZING THE PLANTING PROJECT

R. Brown[1]

Abstract.--Ecological interpretations are used in British Columbia to determine the most suitable site preparation methods and the preferred species for planting. Planting is usually done by contract, and this has allowed Ministry staff to spend more time on planting inspections rather than on administrative details. As a result, the quality of planting has improved.

Résumé.--En Colombie-Britannique, on utilise des interprétations écologiques pour déterminer les meilleures méthodes de préparation de la station et les essences les plus convenables à la plantation. La plantation se fait habituellement par des entrepreneurs, ce qui donne plus de temps au personnel du ministère pour inspecter les plantations au lieu de s'occuper des détails administratifs. Il en est résulté une amélioration de la qualité des plantations.

INTRODUCTION

Fully stocked plantations of vigorous and fast-growing seedlings of the correct species result from careful preplanning and the application of sound economic and biological principles. This paper describes the approach to tree planting taken in British Columbia.

ECOLOGICAL CLASSIFICATION OF FOREST LAND

Forest management, particularly in the field of silviculture, is site-specific. Forest ecosystem identification provides a framework for selecting different management practices and for prescribing particular regeneration techniques on a site-specific basis.

In British Columbia, ecological classification is based on the extensive research of Krajina (1973) and, more recently, Klinka (1977) and others. Ecosystem classifications now exist for all sites in the Vancouver, Kamloops, Nelson, Cariboo and part of the Prince Rupert forest regions. In essence, the system classifies plant associations by characterizing forest sites according to two major soil gradients on an edatopic grid: soil moisture and soil nutrient status (Fig. 1).

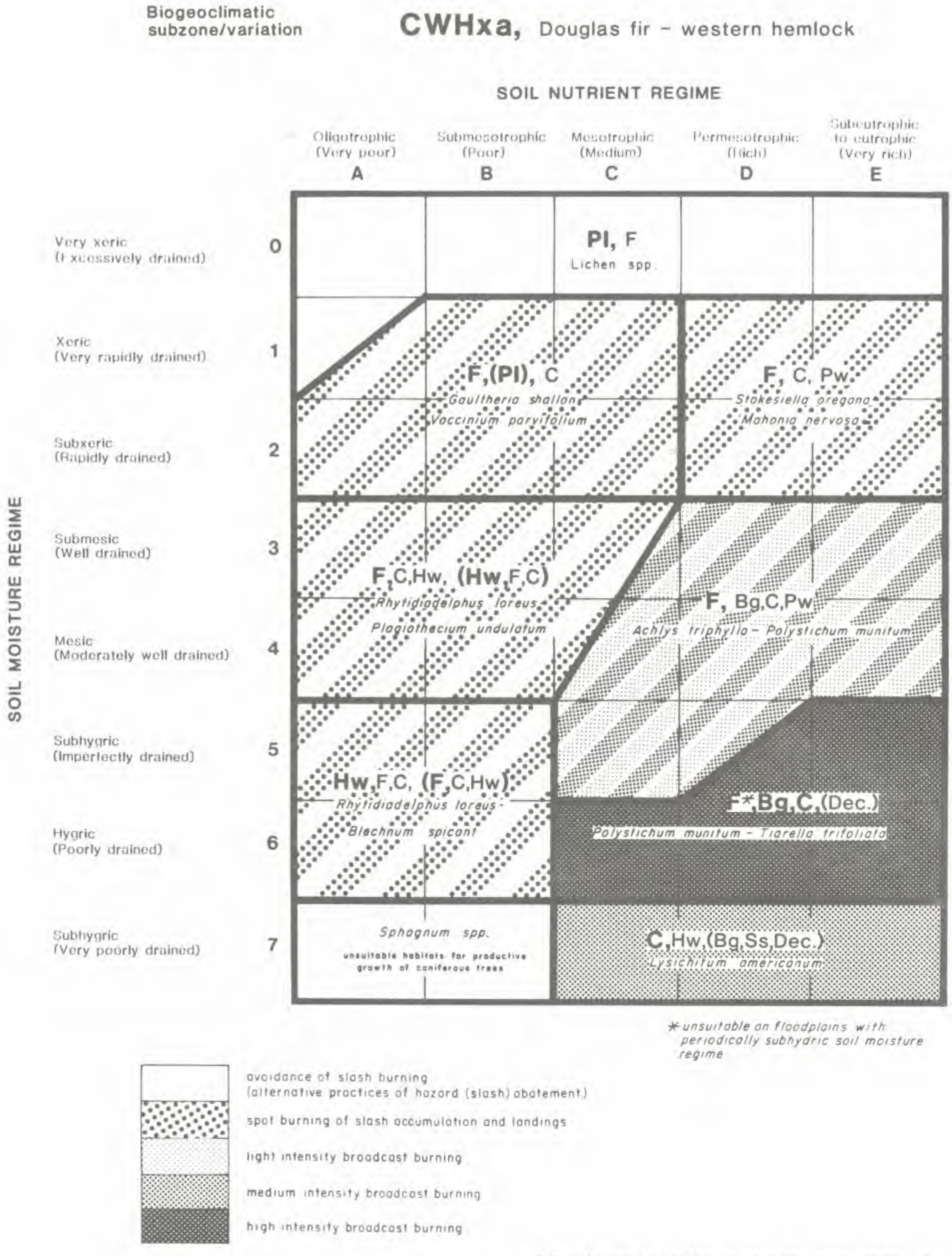
This edatopic classification system facilitates selection of suitable tree species and evaluation of the suitability of prescribed burning. More recently, stocking standards have been superimposed on the edatopic grid. It is expected that stock types and stock size standards will be added in future.

The selection of the most suitable tree species for reforestation must be based on both ecological and productivity considerations. The grid, therefore, identifies the most appropriate species, or mixture of species, for the particular forest site on the basis of plant associations and site index (m/100 years). For a complete description of the development and use of the edatopic grid, see Klinka (1977).

Prior to harvesting, a silvicultural field assessment is completed. This assessment identifies the factors which have to be taken into account in determining subsequent

---

[1] Forester-in-Charge, Reforestation Planning and Technical Development, Silviculture Branch, Ministry of Forests, Victoria, British Columbia.



*unsuitable on floodplains with periodically subhydric soil moisture regime

BRITISH COLUMBIA FOREST SERVICE, VANCOUVER FOREST DISTRICT, 1977

Figure 1. Guide for tree species selection and prescribed burning in the Vancouver Forest Region.

actions. For example, for each ecosystem association within each biogeoclimatic subzone there are management recommendations with regard to prescribed burning, grass seeding, tree species selection, stocking levels, etc. Information on the amount, composition, distribution and vigor of the understory may be used to predict its ability to respond to a partial or total removal of the overstory, and to restock the site fully or partially to produce a satisfactory future stand. Examination of the shrub species and percent cover will allow evaluation of the effects of partial or total cuts on stand structure and possible regeneration problems.

The underlying principle is to ensure that harvesting, site preparation, regeneration and other uses of forest land are compatible with the overall management objective.

SITE PREPARATION

Immediately after cutting, a suitable site treatment on a site-specific basis has to be prescribed. This treatment should be consistent with the management objectives for the area, and must give consideration to site productivity, fire hazard and risk, reforestation objectives and the feasibility of treatment.

PLANTING PRESCRIPTION

Satisfactory plantation establishment depends to a large degree on the recommendations of the examiner. Prescriptions must therefore be made by the most experienced personnel available.

The purpose of the Planting Site Prescription form (Fig. 2) is to ensure that all site factors influencing survival and growth of planted trees are taken into account when the planting program is developed. It also provides a means of recording all the administrative details that must be completed before planting begins. The front of the form becomes part of the planting contract information to assist contractors in their submission of tenders.

The field examiner completes parts A to D which describe the location, site factors, access and recommendations for species, stock type, age class and numbers of trees. Part E is completed by the Regional Office staff when the planting program is finalized and planting stock is allocated.

Province of British Columbia
Ministry of Forests
Forest Service

PLANTING SITE PRESCRIPTION

A. IDENTIFICATION

1. Forest Region V 2. Dist. No. and name 11. CAMPBELL R.(N)
3. Location HEAD OF BUTE INLET 4. S.Z. 1080
5. PSYU/Other QUADRA 6. UTM grid 10·395·5632
7. Tenure C.P.5, T.S.H.L. A00515, RAYONIER
8. Project number and name 92 K16-5, SOUTH GATE R.

B. SITE FACTORS

1. Planting unit	A		B		C
2. Former stand: Spp.	FCH		HF		FC
3. Biogeoclimatic subzone	CWHa		CWHa		CWHa
4. Ecosystem					
5. General soil texture: Clay, sand, loam, silt, gravel	S-G		C-G		C-G
6. Moisture: Dry, medium, wet	D		M		M
7. Soil nutrients: Poor, med., rich	M		P		P
8. Veget. compet.: N.L.M.H.	L		L		M
9. Grazing use: N.L.M.H.	N		N		N
10. Slash: % cover and height	15-50		5-20		25-40
11. Organic layer(s): cm	5		7		25
12. Disturbance symbol/year	L74		L75		L75
13. Site prep.: Method/year	B75		B75		B75
14. Aspect and % slope	S20		SE20		E45
15. Elevation: m	140		210		240
16. Planting diffic. class	MOD.		MOD		DIFF.
17. Existing regen. per ha	210		150		330
18. Spacing: m	2.5		2.5		2.5
19. Plantable spots per ha	1280		1310		1220
20. Net area to be planted: ha	68.1		42.0		30.3

C. ACCESS AND ACCOMMODATION

1. Access: Distances and means 105 Km by air from Campbell R. to dock at camp, thence 26 Km on mainline and 9 Km on secondary road to area.
2. Access problems Vehicles to be barged from Campbell R. Spur roads in poor condition.
3. 4 W.D. is required 4. Accommodation None available - Camp on area.
5. Other Heel-in site at junction of mainline and Spur road in standing timber - see map.
6. Date prescribed 20.6.77 By C. KENDALL

F.S. 739

F.S. 739 (Revised May, 1979)—c

D. EXAMINER'S RECOMMENDATIONS

1. Planting unit	A		B		C
2. Species	FC		H		F
3. Type of stock	BR		PLUGS		BR
4. Age or size class	2+0		1+0		2+1
5. Type of planting tool	MATT.		DIBBLE		SHOVEL
6. Order of planting	1		3		2
7. 000's of trees	87		55		37

8. Season and year S78 9. Priority and reason High: secondary roads due to washout.
10. Access improvement and cost $750 for minor road repair - D6 available from Logging Camp. also show on map
11. Stock supplied to planters at Company dock, head of Bute Inlet.
12. To be planted by:
F.S. ☐ Contract ☒ Type Advertised.
Licensee ☐ Name. Other ☐
13. Supervisor(s) Forestry Crew No. 6
14. Crew Contract: minimum of 15 planters.
15. Vehicles n/a
16. Estim. cost: Total $ 26,490 Per tree 14.8 ¢
17. Duration 18 days. 18. Start-up time 7 days
19. Mandatory viewing? No Leaving
at on 20. Special clauses:
Screefing in Unit C. Heeling-in of bareroot stock.
21. Advertise in Campbell R. Upper Islands Vancouver Province.

E. STOCK ALLOCATED (by Regional Office)

Unit	Spp.	Seed Lot	Stock Type	Age/Size Class	Nursery	000's of Trees
A	F	1646	BR	2+0	C.R.	87
B	H	2781	PLUGS	P4	K.	56
C	F F	1646 1345	BR	2+0 2+1	C.R. G.T.	20 17

Approved H. Hohn Date Jan. 3/79 Total 180

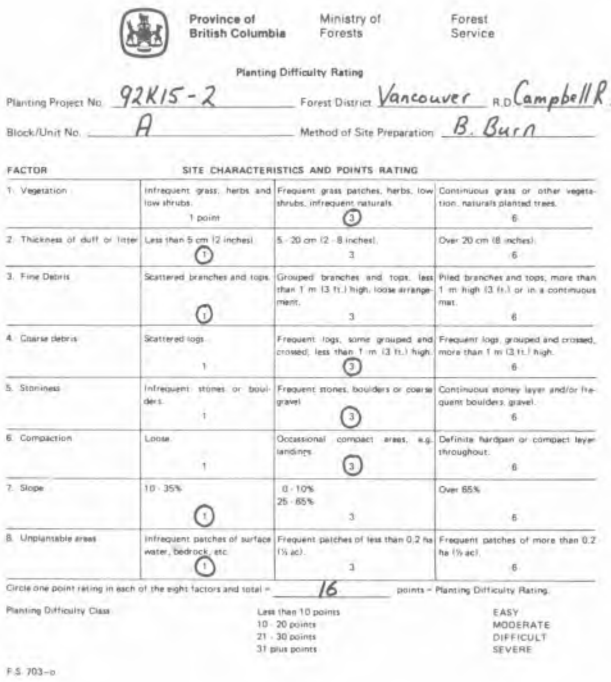
Figure 2. Planting site prescription.

An accurate map is an integral part of the prescription. This map can also be used to record information for which there may be insufficient space on the prescription form, including the identification of various ecological units.

Prescriptions may become out of date rapidly. If there has been an appreciable delay between prescription and planting, there must be a further ground check to note any changes in items such as natural regeneration, brush competition, access, and so on.

Planting Difficulty Rating

An important consideration in the planting prescription is an assessment of the difficulty of planting. This assessment will assist in the choice of suitable planting stock types and will provide an indication of planting productivity and, therefore, expected costs in relation to site conditions and classes of stock (Fig. 3). The point rating obtained from an assessment of the factors is applied to the production table to establish the number of trees that should be planted per man-day for the class or classes of stock assigned to the project (Table 1).



Province of British Columbia Ministry of Forests Forest Service

Planting Difficulty Rating

Planting Project No. 92K15-2 Forest District Vancouver R.D. Campbell R.

Block/Unit No. A Method of Site Preparation B. Burn

FACTOR	SITE CHARACTERISTICS AND POINTS RATING		
1. Vegetation	Infrequent grass, herbs and low shrubs. 1 point	Frequent grass patches, herbs, low shrubs, infrequent naturals. ③	Continuous grass or other vegetation, naturals planted trees. 6
2. Thickness of duff or litter	Less than 5 cm (2 inches) ①	5 - 20 cm (2 - 8 inches). 3	Over 20 cm (8 inches). 6
3. Fine Debris	Scattered branches and tops. ①	Grouped branches and tops, less than 1 m (3 ft.) high, loose arrangement. 3	Piled branches and tops, more than 1 m high (3 ft.) or in a continuous mat. 6
4. Coarse debris	Scattered logs. 1	Frequent logs, some grouped and crossed, less than 1 m (3 ft.) high. ③	Frequent logs, grouped and crossed, more than 1 m (3 ft.) high. 6
5. Stoniness	Infrequent stones or boulders. 1	Frequent stones, boulders or coarse gravel ③	Continuous stoney layer and/or frequent boulders, gravel. 6
6. Compaction	Loose. 1	Occassional compact areas, e.g. landings ③	Definite hardpan or compact layer throughout. 6
7. Slope	10 - 35% ①	0 - 10% 25 - 65% 3	Over 65% 6
8. Unplantable areas	Infrequent patches of surface water, bedrock, etc. ①	Frequent patches of less than 0.2 ha (½ ac). 3	Frequent patches of more than 0.2 ha (½ ac). 6

Circle one point rating in each of the eight factors and total = 16 points = Planting Difficulty Rating.

Planting Difficulty Class		
	Less than 10 points	EASY
	10 - 20 points	MODERATE
	21 - 30 points	DIFFICULT
	31 plus points	SEVERE

F.S. 703–o

Figure 3. Planting difficulty rating.

Table 1. Expected tree planting production per 8-hour day.

	Class of stock and planting tool						
Difficulty rating class	Small B/R[a] mattock	Regular B/R[a] mattock	Large transplants (shovel)	Large transplants (mattock)	Styro-2 dibble	5"[b] M.P.[c] dibble	7"[b] M.P.[c] dibble
Easy: less than 10 points	800–1,000	650–800	350–700	450–600	1,300–1,600	1,100–1,400	950–1,200
Moderate: 10-20 points	600–800	450–650	400–550	300–450	1,000–1,300	800–1,100	700–950
Difficult: 21-30 points	400–600	300–450	250–400	200–300	700–1,000	600–800	500–700
Severe: 31 + points	less than 400	less than 300	less than 250	less than 200	less than 700	less than 600	less than 500

[a] 2-yr-old bare-root seedling
[b] 1 in. = 2.54 cm
[c] Mud-packed seedling

Selection of Planting Stock Type

Where less than optimum site conditions exist the selection of stock type is based on the limiting factors shown in Table 2. In addition, a comparison of establishment costs is made for various site preparation and planting alternatives based on observed field performance and estimated costs (Table 3). Although the costs shown in this table are provided as examples only, the methodology allows individual regions to conduct their own cost comparisons, based on current and local costs and survival rates.

Recently, the British Columbia Ministry of Forests commissioned B.C. Research to refine this method of cost comparison, to investigate the factors which affect the selection of planting stock type, and to provide a methodology for comparing alternatives (Anon. 1979). The methodology developed by B.C. Research is described elsewhere in these Proceedings (Tunner 1982).

Sowing Request

In British Columbia, the Regional Manager is responsible for collating and submitting sowing requests for all agencies that will plant on Crown lands in the region. These requests are submitted to the Silviculture Branch by 15 September of the year preceding the spring sowing.

The submission of a sowing request constitutes a commitment by the Region to undertake the necessary preparation to ensure that sites will be ready for seedlings and that funds will be budgeted at the appropriate time. The Regions are advised of the approximate sowing capability in Ministry and private nurseries in July preceding the sowing request submission.

Because of the lead time required to produce most bare-root stock types, container-grown stock is increasingly becoming the preferred stock type. The demand for container-grown stock currently exceeds production capacity. The additional time required to produce bare-root stock types often means that a revised planting prescription is necessary.

CONTRACT PLANTING

Contract planting developed in British Columbia in the late 1960s and increased during the 1970s; today the majority of planting is done by contract. Contracts are awarded by both the forest industry and the Ministry. Although this paper deals exclusively with Ministry contracts, the contract document used by the Ministry is similar to those used by the private forest companies.

Pre-award Procedure

The pre-award procedure, up to award, takes at least one month from receipt of a contract proposal at the Regional Office. Whenever possible, information on spring contracts should be prepared the preceding fall to allow the prospective bidder to conduct a ground assessment of the planting site prior to the onset of winter.

The Regional staff must ensure that a current Planting Site Prescription is in effect, and that any areas which are satisfactorily restocked are blocked out or avoided when the arrangement of planting units is being drawn up. Each planting unit should have approximately 20 randomly established planting inspection plots (see section on Planting Quality Inspection) to determine the average number of plantable spots per hectare at the required spacing standard and, consequently, the number of seedlings to be assigned to the contract.

At this point, the ground must be in a plantable condition. It is unwise to anticipate that site preparation will be done prior to the planting date; one should wait until it has been done before proceeding with any contract proposals. It should also have been confirmed that the area is unencumbered by any reserves such as rights-of-way, grazing, recreation, gravel pits, etc.

It is important as well to ensure that the area will be accessible during the planting season. If road improvements are required, these should be made well in advance of the proposed contract period. Where road conditions or on-site conditions are unpredictable it may be advisable to specify a requirement for four-wheel drive or all-terrain vehicles on the contract particulars.

A check with the nursery is required to ensure that adequate and suitable planting stock can be allocated to the contract. It is probably unwise to allocate an entire seedlot to a contract, particularly with bare-root planting stock. Abnormal losses or extra-heavy culling may reduce the plantable inventory when lifting has been completed. This problem is much less severe with container-grown stock and is a further reason it is preferred over bare-root stock in many situations.

Table 2. Preferred type of stock for sites with less than optimum conditions.

Limiting factors	Bare-root			Plugs[a]			Container[b]
	2-0	1-1 2-1	1-2 2-2	PSB 211	PSB 313	PSB 415	CBW 210
Limited moisture	-	X	-	X	-	-	X
Heavy veg. competition	-	X	X	-	X	X	-
Heavy slash	-	-	-	X	X	-	X
Organic layer 15+ cm	X	X	X	-	X	X	-
Soils: shallow	-	-	-	X	-	-	X
Soils: rocky	-	-	-	X	X	-	-
Soils: loose	X	X	X	-	-	-	X
Soils: compacted	X	X	X	-	-	-	-

[a] 1-yr-old seedlings grown in styroblock containers
[b] 1-yr-old seedlings grown in Walters' plastic bullet containers

Table 3. Example: comparison of establishment costs for various site preparation/planting alternatives on the basis of observed field performance and estimated costs.

Stock type	Nurs. cost ($/1000)	Site Preparation				Contract ($/tree)	Survival (%)	No. of trees for 1000 live trees/ha at 5 years	Planting ($/ha)	Nurs. costs ($/ha)	Total establ. costs ($/ha)
		None	Burn ($/ha)	Strip clearing[a] ($/ha)	Piling ($/ha)						
BR 2-0	130	0				0.28	50	2000	560	260	820
			90			0.20	65	1538	308	200	598
				120		0.18	75	1333	240	173	533
					160	0.15	60	1667	250	217	627
BR 2-1	250	0				0.30	75	1333	400	333	733
			90			0.25	80	1250	313	313	716
				120		0.20	80	1250	250	313	683
					160	0.18	75	1333	240	333	733
PSB 211	130	0				0.23	75	1333	307	173	480
			90			0.15	80	1250	188	163	441
				120		0.13	80	1250	163	163	446
					160	0.12	75	1333	160	173	493
PSB 415	325	0				0.26	75	1333	347	433	780
			90			0.18	80	1250	225	406	721
				120		0.16	80	1250	200	406	726
					160	0.14	75	1333	187	433	780

[a] Clearing by a 'V' plow in continuous strips

Finally, a small amount of extra plantable area should be available in the event that there is stock left over after the contract area, as mapped, has been completed. (The contract administered by the British Columbia Ministry of Forests is for a specific number of trees, not hectares.) A map, clearly outlining the proposed planting area, must be submitted with the contract proposal.

Advertising and Award

Government policy dictates that all interested parties should have the opportunity to bid on contracts. Therefore, all planting contracts must be advertised.

The Regional Office prepares the advertising for all contracts. Advertisements are placed in the British Columbia Gazette (a weekly government publication), in a Vancouver daily paper (usually the Saturday edition), in a regional headquarters daily paper, and in a local paper serving the community nearest the planting project. Thus, contractors throughout the province are advised of potential work.

Tenders must be submitted on the proper form and must be accompanied by a bid deposit fee, currently $50. Certain qualifications are necessary to undertake planting contracts. Bids will be considered only from those who are qualified by planting experience and citizenship (including landed immigrants or persons who hold an employment visa), and from those contractors who have viewed the planting site where that requirement has been specified in the advertisement.

Government policy is to accept the low bid on a contract unless there are extenuating circumstances. For example, a contractor may already have received a substantial number of trees from other contracts and it may be felt that additional trees would tax the contractor's resources and ability to complete the contract. In cases where the bid appears excessively low for the known site conditions, the contractor is consulted and is given the opportunity to withdraw his bid.

When the contract has been awarded the contractor is given a date by which the security deposit, amounting to 5% of the total value of the contract, is to be submitted.

Pre-work Conference

It is essential that both the Forest Officer who will be in charge of the contract and the contractor meet before planting begins. The purpose of this meeting is to review the contract requirements and develop a work progress plan for the contract. Details are specified on the Work Progress Plan form and become an integral part of the contract.

Many misunderstandings that could arise during the contract may be prevented by taking care during the pre-work conference to ensure that the contractor knows the ground rules for his performance and the manner in which his work will be inspected and evaluated.

Points that must be covered are:

a) appointment by the contractor of a representative who will act on his behalf during his absence;

b) confirmation of the starting date for the contract;

c) arrangements and schedule for delivery of planting stock to the contractor;

d) arrangements for field storage (locations and field facilities should be approved);

e) determination of the number of planters required and the foreman to be employed by the contractor, and the order of planting by unit;

f) the address to which correspondence and payments in connection with the contract should be sent during the period of the contract, the need for early reply or action being kept in mind;

g) an explanation of the planting quality inspection procedure.

Planting Quality Inspection

The introduction of a rigorous planting evaluation procedure has resulted in a substantial improvement in the quality of planting in British Columbia.

The purpose of the inspection is to estimate the total number of trees planted on the project to ensure that the stock is used properly. It is a useful check against trees issued to determine if seedlings are being buried or otherwise destroyed. In addition, the inspection provides an estimate of the planting quality percent (ratio of the number of trees judged to be satisfactorily planted to the ideal number of trees for that area). The ideal number of trees is determined through an estimate of plantable spots for the required tree spacing, and this ratio, or percentage, is a measure of how well the trees have been planted.

Details of the planting quality inspection procedure are contained in the B.C. Ministry of Forests Silviculture Manual and in a publication by the Ministry entitled "Planting Quality Inspection" (Anon. 1980). Briefly, inspections are based on a statistical sampling of 50 m^2 plots with the inspector assessing the number of trees planted and the number of trees judged to be planted satisfactorily.

In assessing plantable spots, the inspector checks the number of trees planted within the plot. Where spacing has been maintained, the number of plantable spots (allowing for areas that are unplantable because of slash, rock or other obstructions) equals the number of trees planted, up to the maximum allowable number. However, if spacing is wider or closer than specified in the contract, the estimate of plantable spots is adjusted upward or downward, respectively. Table 4 shows the relationship between spacing and plantable spots.

Table 4. Relationship between inter-tree spacing and plantable spots.

Inter-tree spacing (contract spec.) (m)	Density (trees per ha)	Maximum allowable number of plantable spots per 50 m^2 plot
2.29	2200	11
2.40	2000	10
2.53	1800	9
3.10	1200	6
3.40	800	4
4.39	600	3

In determining the number of plantable spots within the plot, the inspector must consider the growing space occupied by any naturals (or previously planted trees) either just outside the boundary of the plot or inside the plot. This space, which is unavailable for planting, is a circle around the tree with a radius equal to the prescribed spacing less 0.5 m. It is important that inspectors understand this concept and the influence which a tree just outside the plot has on the number of allowable plantable spots within the plot.

Trees are then assessed for planting quality on the basis of the usual factors: planting spot selection; screefing, scalping or clearing; preparation of a suitable planting hole; tree placement within the hole; firmness; and the position of the crown and stem.

Contract Planting Payments

The first contract payment is made as soon as the inspection of a pay area is completed. Payment is based on the numbers of trees and on the quality of planting. Because this is a statistical sampling of the actual work done, a tolerance is added to the calculations to arrive at the pay rate.

In 1980, from a total of 500 payment certificates processed, 62% received no penalty for poor planting quality, while only 1% failed to receive any payment because planting quality was less than 85% (the minimum acceptable planting quality for payment).

CONCLUSIONS

Contract planting has proven to be a suitable method for carrying out the annual planting program. Government forest officers are able to concentrate on the monitoring of planting quality rather than spending their time on the many administrative and organizational aspects of planting projects. Plantation survival and growth performance are often dependent upon making the best use of a limited planting season; flexibility and speed are required in arranging the planting project. Contract planting has provided this flexibility and has been widely accepted by Ministry and industry staff as a means of meeting planting objectives.

LITERATURE CITED

Anon.
1979. Comparison of alternatives in planting seedlings. Unpubl. Rep. for B.C. Min. For., Victoria, B.C.

Anon.
1980. Planting quality inspection. B.C. Min. For., Victoria, B.C. 16 p.

Klinka, K.
1977. Guide for the tree species selection and prescribed burning in the Vancouver Forest District. B.C. Min. For., Victoria, B.C. 40 p., Appendices.

Krajina, V.J.
1973. Biogeoclimatic subzones of British Columbia. B.C. Ecol. Reserve Comm., Dep. Lands, For. Water Resour., Victoria, B.C. (map).

Tunner, A.
1982. A procedure for comparing alternatives in planting tree seedlings. p 407-418 in J.B. Scarratt, C. Glerum and C.A. Plexman, *Ed.* Proceedings of the Canadian Containerized Tree Seedling Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. 0-P-10.

THE OPTIMIZATION OF PLANTATION ESTABLISHMENT BY POT PLANTING

John Walters'

Abstract.--The optimization of plantation establishment depends on the mechanical efficiency of the planting technique and on the subsequent growth of the trees. The technique should accommodate the biological characteristics of the species throughout its life as a unit of the plantation. Pot planting offers the greatest promise of achieving these mechanical and biological objectives.

Résumé.--L'optimisation de l'établissement d'une plantation dépend de l'efficacité mécanique de la méthode utilisée ainsi que de la croissance subséquente des arbres. La méthode de plantation doit convenir aux caractéristiques biologiques de l'essence pendant toute sa vie au sein de la plantation. Les plants en pots semblent offrir les meilleures chances d'atteindre ces objectifs biomécaniques.

INTRODUCTION

There is an increasing awareness that the Canadian forest industry may be unable to maintain its present economic importance unless plantations are established on a scale and at a rate unprecedented in the history of any nation. This awareness of the magnitude and urgency of reforestation projects facing Canada and other countries has provided impetus to the mechanization of tree planting. Much of the interest in mechanization is associated with the increasing cost and decreasing supply of manual planters. Although this is an important reason for mechanization, additional reasons can be offered which are of greater significance to plantation establishment in the context of the inevitable mechanization of all the main silvicultural treatments. As we replant our forests we should do so in ways which anticipate and prepare for this inevitability. The mechanization of tree planting is a first and vital element in the sequence of mechanized silvicultural practices necessary for modern plantation establishment. I believe that mechanization of tree planting can be greatly facilitated by exploiting the mechanical and biological properties of rigid plant pots.

SOCIO-ECONOMIC REASONS FOR MECHANIZING PLANTATION ESTABLISHMENT

The increasing cost and decreasing supply of manual planters are well recognized factors which have stimulated interest in mechanized planting. The shortness of the planting season compounds the problem of labor supply. Another factor which will influence the design of tree-planting machines relates to the comfort of the operators. Air conditioning, sound-proofing, and musical entertainment will soon be a part of the silviculture industry in the same way that they are a part of other industries. Eventually, comfort becomes an important reason for machine development.

SILVICULTURAL ENGINEERING REASON

A less obvious reason for machine development, but one, I believe, of greater importance, is the need to establish plantations in a systematic configuration. Seedlings should be planted precisely in rows and at uniform spacing to facilitate mechanized weeding, cleaning, thinning, and harvesting

---

[1] Director, University of British Columbia Research Forest, Maple Ridge, British Columbia and Professor, Faculty of Forestry, University of British Columbia, Vancouver.

operations. In my opinion, systematic plantation configuration is a crucial prelude to the efficient mechanization of all silvicultural practices subsequent to planting. The optimization of mechanized weeding, cleaning, thinning, and harvesting practices is contingent on the system of plantation establishment. A reforestation program already suffering from labor shortages would be further constrained if, to the manual work of planting, the manual work of plantation layout were added. Indeed, the latter is usually more laborious than the former.

The fact that tree-planting machines plant in a systematic configuration is an incidental, but nevertheless important, benefit of mechanization. As silvicultural practices are mechanized they, too, will traverse the terrain in straight lines. Only trees in rows will be cultivated efficiently; trees of valuable species may well be weeds if growing between, rather than in, rows. Systematic plantation configuration can significantly increase the efficiency with which subsequent silvicultural practices can be mechanized.

Hence, in addition to the use of tree-planting machines to reduce the cost of reforestation (something that has not yet been accomplished) and their ability to accelerate the rate of planting, machines have an important role in what can and should be called "silvicultural engineering".

The systematic establishment of plantations is vital to Canada's reforestation objectives and it alone is reason enough to mechanize tree planting. For both socio-economic and engineering reasons, the development of tree-planting machines deserves far greater emphasis in Canada than it receives at present.

BIOLOGICAL REASONS

Bare-root seedlings are the most commonly used type of nursery stock. Many foresters believe that bare-root seedlings have advantages over balled and pot seedlings. Many foresters also believe that the silviculture industry will always be dependent on the planting of bare-root seedlings with mattock and shovel. Yet there are serious and chronic problems associated with the planting of bare-root seedlings and with the use of those tools. Lifting, sorting, packaging, transporting, storing, and planting all contribute to physiological deterioration. Moreover, the factors involved in physiological deterioration of seedlings remain largely unknown. For example, an examination of plantations established in the Kamloops Forest District from 1960 to 1975 revealed that survival averaged only 51% two years after planting (Anon. 1977). The report stated: "The reasons for the poor average survival were unknown but planting quality and quality of planting stock were suspected as having contributed to a major portion of the mortality".

A year earlier a study of lodgepole pine plantations in British Columbia revealed significant mortality shortly after out-planting and poor growth over a period of several years (Anon. 1976). In addition it was reported that a major problem was mechanical instability, possibly leading to toppling and the formation of basal sweep. This problem, related to morphological development of root systems, is of increasing concern.

A planting trial in the Nelson Forest District in 1973 using three methods of manual planting showed that by 1976 "no method produced satisfactory rooting on lodgepole pine". Similar results were obtained in the Cariboo Forest District. Another study in the same report (Anon. 1977) concluded: "The great majority of mattock-planted trees exhibited hockey-stick or bunched roots. It appears that proper positioning of roots of bare-root lodgepole pine seedlings in the planting hole is very difficult if not impossible when the mattock is used as a planting tool".

One of the most important studies of plantation performance made anywhere in the world surely must be that of Mullin (1974) who found that planting can exert a considerable long-term effect on growth. His study of red pine *(Pinus resinosa* Ait.) showed that two crews produced a 14% difference in volume growth 20 years after planting. As in many other studies no significant differences in growth were apparent 5 years after planting. Hence, the large volume difference occurred in only 15 years and there seems reason to expect an even greater difference in the future.

Balled seedlings, such as those produced by the Kopparfors multipot, styroblock, and "Rootrainer" systems, avoid most of the physiological problems of bare-root plants. However, there is concern that the pot binding of the roots, *inherent in these systems,* may retard growth and reduce stability. Evidence of these problems was presented by several speakers at the Symposium on the Root Form of Planted Trees in Victoria (Van Eerden and Kinghorn 1978). Moreover, while root deformation of seedlings in poor physiological condition, such as that common to bare-root plants, may disappear as new roots are formed, root deformation of plants in good physiological condition, such as that of some balled plants, may persist. The long-term consequences for the stability of the new plantations are uncertain.

Setting out seedlings in pot-shaped receptacles has long been recognized as a successful means of achieving high survival rates. Seedlings can be transferred to the planting site with a minimum of physiological deterioration. For this reason, it is a method much used in semi-arid countries. However, the pot-binding of roots, common to modern balled seedlings, is, of course, also common to pot plants. Seedlings in soft-walled pots must have pot-bound roots, as must balled plants, to be transportable as a unit. Rigid pots, on the other hand, are fundamentally different in that the seedlings in them do not affect the efficiency of transportation and metering techniques. It is true that seedlings can be grown in rigid pots until pot-bound but it is true also that rigid pots can carry seedlings in any stage of development *before* pot-binding occurs. *It is only through the use of rigid pots that seedlings can be planted with root systems undisturbed by nursery or planting practices, while developing in accordance with their* natural *silvical habits.* The literature describes enough growth and stability problems associated with planting to make foresters uncertain of the future of their plantations. They have good reason to be uncertain, but no reason to accept uncertainty. Nursery stock should not suffer physiological or morphological disturbance in the nursery or during planting. The principle of the rigid plant pot offers the best promise of achieving this objective. Moreover, rigid pots of suitable composition and design offer important post-planting benefits to seedlings. I disagree with those who have stated that containers are of no benefit to seedlings after outplanting (Arnott 1973 and 1974, Van Eerden 1972). The work of Day and Skoupy (1971) and Day and Cary (1974) shows that containers can have a beneficial influence because their root masses lose moisture slowly and remain moist for. longer periods than do those of balled plants. Seedlings planted in biodegradable rigid plant pots now under development also benefit from the supply of nutrients released by the process of degradation.

To these biological advantages can be added mechanical advantages which are unique to plants grown and planted in rigid pots. The use of rigid pots maximizes efficient mechanical handling and planting and optimizes the establishment of the plantations so important to Canada's economic future.

LITERATURE CITED

Anon.
1976. Forest research review. B.C. Min. For., Victoria, B.C. 71 p.

Anon.
1977. Forest research review. B.C. Min. For., Victoria, B.C. 78 p.

Arnott, J.T.
1974. Performance in British Columbia. p. 283-290 *in* R.W. Tinus, W.I. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Day, R.J. and Cary, J.R.
1974. Differences in post-planting soil-moisture relations of container-grown tube and plug stock affect the field survival and growth of black spruce. p. 388-392 *in* R.W. Tinus, W.I. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Day, R.J. and Skoupy, J.
1971. Moisture storage capacity and post planting patterns of moisture movement from seedling containers. Can. J. For. Res. 1:151-158.

Mullin, R.E.
1974. Some planting effects still significant after 20 years. For. Chron. 50:191-193.

Van Eerden, E.
1972. Influences affecting container seedling performances near Prince George. p. 92 in Waldron, R.M., *Ed.* Proceedings of a Workshop on Container Planting in Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. DPC-X-2.

Van Eerden, E. and Kinghorn, J.M., *Ed.*
1978. Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./ Can. For. Serv. Joint Rep. No. 8. 357 p.

ENGINEERING CONSTRAINTS ON PLANTING MACHINE DEVELOPMENT

B.J. Sutherland'

Abstract.--Design problems involved in the development of mechanical planters and limitations on such development from an engineering viewpoint are discussed. A major concern is the definition of field requirements for planting machines and the translation of these requirements into engineering specifications suitable for equipment design.

Résumé.--Les difficultés de conception ainsi que les entraves techniques associées à la mise au point de planteuses mécaniques sont discutés. Par exemple, il faut déterminer les conditions d'emploi sur le terrain, puis les traduire en spécifications techniques qui conviendront à la conception de l'équipement.

INTRODUCTION

The development of tree-planting equipment is a specialized engineering problem. Historically in North America, tree-planting machines have evolved from agricultural equipment. Continuous furrow transplanters were strengthened and modified for rough ground conditions in untitled soils. The relatively low demand for mechanical planters was one of the main reasons for the slow advancement of planting machine technology. Consequently, planting machines on the market today, whether bare-root or container stock planters, are still relatively simple in design. In addition, detailed information on site preparation requirements is lacking for the various species of trees planted. Failure to translate such field requirements into engineering specifications useful to designers has resulted in a lack of understanding among equipment manufacturers of what is really needed.

This paper will outline information that is important for planting machine design and define some of the limits to technological development.

WHY DEVELOP EQUIPMENT?

Field personnel who are having problems with existing equipment will find this an easy question to answer. A case can be made for developing planting machines to alleviate a shortage of labor for manual planting, to maintain a consistent level of acceptably planted seedlings, and to reduce or minimize the cost of planting. Why do equipment manufacturers attempt to develop a new product? Primarily to receive a fair return on money invested. This is usually in the form of profits through the sale of large quantities of machines. The benefits are shared by both user and manufacturer. If customers are happy with equipment performance then more equipment will be sold and the development costs will be justified.

How do equipment manufacturers decide when to develop a new product? In the case of tree planters, a potential user will sometimes approach a manufacturer directly, and state why such a machine is needed. Sometimes the manufacturer himself will see a need for mechanized planting and will try to interest field personnel in his ideas. In either situation a market study is required to determine the potential for equipment sales. If a company can predict potential sales that will cover development costs and

---

[1] Forestry Officer, Great Lakes Forest Research Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario.

bring a reasonable return on investments then it will proceed with development.

In any development program funded solely by the manufacturer, the user stands to gain the most while the manufacturer bears most of the risk. In the past it was difficult to interest equipment manufacturers in mechanical planters. Potential sales were low and the planting season was short, so that costs had to be written off on the basis of very few machines. Consequently, the selling price of a planter could be as high as that of a logging skidder, for example, and was therefore less attractive to the manufacturer. To overcome this high risk deterrent and to stimulate planting machine development it may be necessary for the users, whether government or private industry, to share the development costs.

LIMITS TO TECHNOLOGY

In view of the biological constraints imposed by species requirements and the limits imposed by extremely variable terrain, the development of equipment suitable for handling and successfully planting seedlings may require very sophisticated technology. Lawyer (1978) describes several planting machine concepts that are now on the market or are being tested. These are: injection or spot, intermittent furrow, continuous furrow, and ridge or hill planting.

Continuous furrow planting is the most common machine planting technique and the simplest in design. It is best suited to relatively stone-free and stump-free areas. The intermittent furrow concept, though more complex, is better suited to handling obstructions such as stumps or boulders because the planting dibble enters the ground only occasionally. The spot or injection planting concept encounters even less ground interference because the planting dibble enters the ground vertically until the seedling is injected and then is retracted from the same location. Spot planters are currently being tested as prototypes but are not yet commercially available.

The design problems increase substantially as one moves from continuous furrow planters through to the true spot planters. Some prototypes incorporate scarification and planting into one planting machine, or even into a single planting head. As machines become more complex, costs rise and mechanical availability tends to decrease. To justify such costs, productivity must be correspondingly high (Hatfield and McKenzie 1981).

Productivity on manually loaded planters is limited by operator comfort and safety. In the future, automatic loading may eliminate the ergonomic problems of manual loading and permit productivity increases that will help justify high equipment costs. Productivity is also affected by variable-sized and deformed planting stock from the nursery. Better quality control in the nursery will reduce this problem.

Containerization of seedlings holds the most promise for automation as it eliminates the problem of variability in seedling size. Some of the most sophisticated fully automatic planters currently being tested in Scandinavian countries, and to a lesser extent in Canada and the United States, use container-grown stock.

A major problem in the development of handling mechanisms for containerized seedlings is the wide variety of container designs that are available. Some equipment manufacturers hesitate to embark on a development program when they cannot get a clear consensus on which container is the most commonly accepted. One solution would be a planting system which accommodates a range of sizes. The problem of container planting can best be solved by a total systems approach, in which all aspects of nursery production, containerization and handling are considered as well as field equipment to plant the seedlings.

New technology in various fields of engineering is being made available to equipment manufacturers. To derive the most benefit from these new concepts a designer relies on detailed specifications from the field as to what is required in a tree planter.

DEFINING THE PROBLEM

In defining the requirements of a planting task for an equipment designer it is not sufficient to speak in generalities. Silvicultural prescriptions for various species on a range of sites are necessary for proper definition of the planting requirement. Site variability is common, especially in the boreal forest region of Canada. Numerous site characteristics can affect machine design and operation. Some of the more important questions to be answered are:

- How will soil texture vary on the sites to be planted?
- What will be the range of penetrative forces required to plant the seedling?

- What type of ground pressure and clearance limits exist for the carrier?
- If the sites contain rock, what degree of stoniness and size classes might be expected?
- How much logging debris and how many residuals and stumps will be present?
- What is the proper microsite in which to plant?
- Will the scarification required to produce an ideal planting site be incorporated into the planter or be carried out in a separate operation?
- Should the equipment be designed to incorporate attachments for herbicide sprayers or fertilizer spreaders?
- If container-grown stock is to be planted, how much deformation of the container is acceptable during handling, planting and subsequent packing?
- What spacing is required for planted seedlings and what angle and depth of planting?

Once the details of site and biological requirements have been defined, such information should be made available to the equipment designer.

INFORMATION TRANSFER

All too often the field requirements for planting seedlings are not clearly defined or understood and the translation of these requirements into engineering specifications is based only partly on experience while the remainder is based on judgment. It is also necessary to translate the requirements into a form that equipment designers can work with. For example, a specification for planting depth should be given as a range above and below an optimum figure. This permits the designer to design around a target value and includes acceptable limits as well. Every detail which could affect machine function or performance should be brought to a designer's attention at the outset. Changes in concepts or thinking are relatively easy and inexpensive to incorporate at this time. It is advisable that a request for a planting machine be made with a good understanding of the range of conditions in which it will be expected to work. Variability in terrain or drainage problems can limit the use of equipment. To develop a planting machine flexible enough to handle a wide variety of ground and moisture conditions is usually impractical and often impossible. For example, a planter designed to penetrate dense clay soils may end up being too heavy for moist sites on which light-weight equipment and little soil compaction are desired. Spot planting in heavy soils may create problems for root egress from the container unless a localized area around the seed spot is tilled or a furrow planting concept is used. Designers need to know how much tilling of the microsite is required for a particular soil type.

Another consideration not related to site is the power source for the proposed planting machine. If the power to operate the planter is supplied by the prime mover then the selling price of such a machine will be lower. However, it may be difficult to find a prime mover with the proper hydraulic or electric hookups. A good understanding of machine capability by both field staff and equipment designers will help promote the use of equipment only where it is most suitable.

SUMMARY

Silvicultural equipment development is a high-risk proposition for equipment manufacturers. In the past, low market potential has resulted in minimal development of equipment such as tree planters. Research efforts have been isolated and to some extent based on judgment rather than experience. To initiate a development program, foresters and other field personnel must familiarize themselves with all requirements and conditions for planting trees of various species and be able to present this information to equipment designers in a form the latter can understand. This is the best way to ensure that the resulting equipment stands a good chance of success.

A recent survey of agencies across Canada indicates that machine planting is one of the most pressing needs for improved or increased mechanized silvicultural treatment (Riley 1981). To achieve the goal of better equipment, successful machine development programs depend heavily upon effective communications between equipment manufacturers and users.

LITERATURE CITED

Hatfield, D.C. and McKenzie, D.W.
1981. Tree-planting machine--How much can you afford to pay for one? USDA For. Serv., Equip. Devel. Center, San Dimas, Calif. (Unpubl.)

Lawyer, J.N.
1978. Analysis of mechanized systems for planting trees for reforestation. Univ. Calif., Dep. Agric. Eng., Davis. 244 p.

Riley, L.F.
1981. Mechanization of silviculture research and development in Canada. Pap. prepared for Pulp Pap. Res. Inst. Can. Survey of For. Res. Workshop. 12 p. (Unpubl.)

SPECIFICATIONS FOR A CONTAINER PLANTING MACHINE: A FIELD VIEWPOINT

J.K.K. Heikurinen[1]

Abstract.--Desirable characteristics of a container planting machine suitable for northern Ontario are discussed. A brief description of the working conditions for the hypothetical planter and reasons for its need are presented. Biological and economic constraints on design and ergonomic considerations are used as the basis for the specifications.

Résumé.--On examine les caractéristiques qu'une planteuse de plants en mottes emballées devrait posséder pour son utilisation dans le nord de l'Ontario. On donne une brève description des conditions d'utilisation ainsi que les raisons pour lesquelles on aurait besoin de la planteuse hypothétique. Pour déterminer ses caractéristiques, on s'est basé sur des contraintes biologiques et économiques et sur des considérations ergonomiques.

INTRODUCTION

A container planting machine can be anything from a simple, manually operated dibble to a complex, machine powered, computer controlled, automated machine which site prepares and plants in one operation. The planter we require is one that will do the whole job in a biologically acceptable manner and at a reasonable cost.

The principal factors influencing the choice between the simple and the complex will undoubtedly be related to a number of local conditions. In this paper I will be dealing with those conditions which we find in the Ontario portions of the Canadian Shield, most of which lie in the transition zone between the Great Lakes-St. Lawrence and the Boreal Forest regions. The factors which dictate the design of the machine are i) the species to be planted, ii) the type of container, iii) the labor force available, iv) the terrain and site conditions, v) the scale and duration of the operation, vi) market conditions and available capital. On the basis of these factors, I will attempt to draw up a set of specifications for a hypothetical container planting machine. Unfortunately, my experience is limited mainly to northeastern Ontario.

WORKING CONDITIONS

Northern Ontario is a vast area of mostly forested land (approx. 892,400 km^2), occupied by relatively few people. In the four northern regions of the Ontario Ministry of Natural Resources (OMNR), approximately 42,000 ha of forested land are harvested annually, of which 23,000 ha are replanted. We have a full range of soil conditions from very shallow, coarse tills to deep deposits of sandy outwash to lacustrine silts and clays. Current estimates for the Northeastern Region indicate that of the 5,944 ha planted annually, 3,320 ha will be planted with containerized stock (paperpots). This is approximately 56% of the total area planted. If we were to extrapolate these figures to northern Ontario as a whole, at current rates, approximately 13,000 ha (35 million seedlings) of cutover area would potentially be planted with container-grown stock of one type or another.

---

[1] Forestry Specialist, Northeastern Region, Ontario Ministry of Natural Resources, Sudbury, Ontario.

In the Northeastern Region, about 80% of the land area comprises shallow to moderately shallow, gravelly tills. The bulk of the remaining 20% is either lacustrine deposits of finer textured soils which are mostly under agricultural cultivation or deeper outwash deposits of sands and gravel. It is our current opinion that the upland till deposits must be planted by hand, largely because of the stoney, shallow nature of the soil deposits and the generally steep topography. We can visualize the possibilities of using planting machines on up to 10% of the total plantable area over the region. This amounts to 332 ha per year. Again, if we extrapolate this figure to northern Ontario as a whole, it amounts to 1,300 ha of machine-plantable land per year for containerized stock.

The growing season is rather short, averaging about 160-180 days with a possible frost-free period from 10 June to the end of August (80 days). On the basis of outplanting experiments (Scarratt 1974), the maximum recommended period for planting container-grown seedlings is from 1 May to 15 August (107 days). Our current growing regime for containers (FH 408 paperpots) limits the period of shipping, particularly of pines, to a period from 1 May to 15 June for the overwintered crop and from 15 June to 15 July for the spring-grown crop. This limitation is due primarily to the intergrowth of roots from one container to the next. Hence, if we assume that the container to be used for mechanized planting is the paperpot, our planting season would be only about 76 days long.

The labor supply in remote areas of the province tends to be poor. Potential workers demand better social amenities than those offered at "bush camps". These facilities can be found only in the larger towns, at some distance from the planting site. As the planting program lasts only 4-8 weeks, it does not attract highly skilled labor. Generally, OMNR employs unskilled labor for the planting job. Few, if any, of these people are trained in the operation of complex machinery.

The species most commonly planted as containerized stock in the Boreal Forest are jack pine (*Pinus banksiana* Lamb.), white spruce (*Picea glauca* [Moench] Voss) and black spruce (*P. mariana* [Mill.] B.S.P.). In the Northeastern Region sizeable quantities of red pine (*P. resinosa* Ait.) and white pine (*P. strobus* L.) are also planted.

Jack pine can be grown in paperpots under a 14-week growing regime, on a two-crop-per-year basis. The spruces should be produced under a greenhouse regime of at least 18 weeks' duration, starting in late February or early March, to be grown on outside during the frost-free summer period and overwintered. They should be planted the following spring or early summer.

Red pine and white pine are best grown as summer crops in the greenhouse, beginning in early June, for overwintering until the following spring. They should be planted prior to 15 June.

The hard pines (jack and red) are perhaps better suited to container planting than to bare-root planting, largely because of their rooting habit. These species do not put out adventitious roots and therefore are extremely prone to deformities resulting from poor planting practices. The use of containerized seedlings can reduce, to some degree, the severe deformities found in planted bare-root stock (Heikurinen and Wilson 1980).

The spruces are capable of adventitious root development; consequently, the deformation of the original root system is not as critical as that of the hard pines. However, factors which affect root regeneration potential, such as planting depth, planting microsite, and moisture stress in the tree, seem to be more critical for spruces than for pines. The containerized seedling can, if handled properly, alleviate some of these potential problems.

THE NEED

Do we need a mechanized planter? The answer to this question undoubtedly depends on whether the planter helps to resolve some of our regeneration problems.

Some of the problems we face in Ontario are related directly to shortages in the labor force in remote areas. The arduous and highly seasonal nature of the planting program will not attract workers from the more populated areas. One of the greatest concerns of our field staff relative to the doubling of our planting program by 1984 (Scott 1975) is the question of who will plant the trees. Existing labor is thought to be barely sufficient for the current program. One of the answers to this problem could be greater use of containerized planting stock, together with a mechanized planter capable of greater rates of planting than would otherwise be achieved with manual labor.

Machines will consistently duplicate a task with very little variation. If a machine can be made to plant a seedling well, it should do this consistently. We are plagued with the problem of planting error in our hand planting operation. Poorly planted trees account for at least 50% of the mortality in our plantations. A machine planter might aid in this respect, by providing a better working environment and at the same time increasing the worker's capability. However, mechanization will undoubtedly involve some loss of capability in terms of microsite selection in order to achieve consistency and speed of operation.

SPECIFICATIONS

I will now attempt to elucidate a set of general machine specifications based on the working conditions outlined in Table 1. These specifications are intended solely as guidelines for designing a machine which will plant containerized stock in northern Ontario.

Biological Considerations

The planting machine must be capable of delivering the tree, without mechanical or physiological damage, into the soil, in as natural a position as possible.

To prevent physiological damage, the tree should be held in a suitable receptacle until placed in the soil so as to protect the roots from exposure to air. The vibration and bouncing of the machine must not loosen soil, as this might lead to loss of growing medium from the container or plug. The integrity of the container must be protected throughout the planting process.

The machine should be designed to permit the maintenance of adequate moisture conditions in the growing medium within the container during the planting operation. This generally will mean a watering capability if more than a 4-hour supply of seedlings is carried on the machine. For shorter periods, protection from direct sunlight and moving air must be provided.

Table 1. Factors to be considered in the design of a container planting machine.

<u>Species</u>	-	jack pine, red pine, white pine, black spruce and white spruce.
<u>Size of stock</u>	-	10 to 15 cm top with a 1 to 3 mm root collar diameter, and weighing 250 to 1,500 mg.
<u>Container</u>	-	any biodegradable, flexible paper container or plug ranging in size from 3 cm to 6 cm in diameter and 8 cm to 12 cm in depth.
<u>Site conditions</u>		
Soils	-	Lacustrine deposits of silts and clays.
	-	Fluvial deposits of fine to coarse sands with varying degrees of gravel.
	-	Aeolian deposits of very fine to fine sands.
Stoniness	-	ranging from nil to plentiful, but not excessive. Mostly pebbles and cobbles with few boulders.
Soil depths	-	minimum depth of 30 cm.
Slash	-	less than 9 m^3/ha (about 25 tonnes/ha) well distributed, ranging up to 7 cm in diameter.
Stumps	-	750/ha, with average diameter of 40 cm and maximum height of 50 cm.
Slopes	-	less than 15% on a sustained slope.
<u>Job duration</u>	-	1 May to 15 July.
<u>Job size</u>	-	varies from 10 to 200 ha per location.
<u>Market size</u>	-	enough machines to plant 1,300 ha in Ontario (3.5 million seedlings).

The temperature of the stock should be kept above 5°C and below 33°C during the planting process. The trees should be protected from exhaust fumes, oil drips, and other toxic elements which are normally present during machine operations.

Physical or mechanical damage to seedlings must be minimized in the handling and planting process. During machine loading operations, the original growing tray should be used for handling or, alternatively, the containers should be transferred carefully to a cassette or tray from which the container can be transferred to the planting head. It is important to minimize handling of the individual container, to avoid loss of growing medium. At no time should the seedling shoot be used as a handle in the moving process. Generally, the seedling is not sturdy enough to support the relatively heavy root ball. The container should always be firmly supported, yet not squeezed or otherwise mutilated. In the case of paperpots, separation of containers should be delayed as long as possible and should never be done more than 4 hours in advance. The paperpot must always be soaked thoroughly prior to separation; otherwise, damage in the form of torn pots, loss of growing medium, etc., will result.

During the planting process, a planting hole should be made similar in size to the container. The container should be planted slightly below the surface of the soil. In the case of paper containers, the paper should be buried to a depth of about 0.5 cm. Root disturbance should be minimized by placing the container in the hole gently. The impact of the container falling to the bottom of the hole should be no greater than that of the container falling from a height of 60 cm down a tube, with a cross-sectional area not greater than 125% of the cross-sectional area of the container. At no time should the container be injected into the hole by pneumatics or other means, or with anything greater than gravitational force. Pneumatic injection may cause loss of growing medium or enlargement of the hole to the extent that compaction may be hindered.

Roots protruding from the container side walls or the bottom, to the extent that they will be swept upward during the planting process, should be pruned mechanically. Both live and dead roots have a tendency to catch on the side of the planting hole, and turn up. In hard pines, this will result in the worst possible type of deformity, i.e., deep vertical roots will not develop. For hard pines, rapid development of vertical roots is required for growth on the driest sites on which these species are prescribed for planting (Fayle 1978).

In the process of creating the planting hole, minimal compaction of the walls of the hole is sought. A blunt dibble should never be used for this purpose. An auger or a punch which removes the material from the hole is the preferred tool. Something similar to the jaws of a Pottiputki, which forms an appropriate hole configuration by splitting the ground and compacting two sides of the planting hole, is acceptable. A continuous shoe or an intermittent shoe which creates a slit is not desirable.

Compaction of the earth around the container after planting should not be excessive. The compaction process should not bend, flatten or otherwise mutilate the container or the tree. Light tamping around the tree is preferred to compacting wheels which tamp on two sides only. Never use heavy pressure from one side of the container.

Operational Considerations

The planting machine must be both efficient and effective from an operational point of view.

In the first place, it must be cost-efficient. The cost per unit planted is a function of the operating cost, the cost of the machine, its planting rate capability and its availability.

At the risk of oversimplification, I have attempted to estimate the cost of such a machine by assuming that the total cost of planting with the machine should not exceed that of manual planting. A current estimate of the cost of manual planting is $125.00 per 1,000 seedlings, including direct and indirect costs. In a machine planting operation, the prime mover will cost $50.00/hr, including operator. The cost of labor to service and operate a planting machine is about $30.00/hr (based on a requirement of two operators and one service person at $10.00/hr each). In most projects of this nature, overhead costs constitute up to 25% of the total cost. I have assumed $20.00/hr; therefore, the total cost, excluding the planting machine, is $100.00/hr. In Table I, I have outlined the allowable cost of the machine for three assumed planting rates.

On the basis of this example, a machine planting 1,000 seedlings/hr can have an operating cost of $25/hr while a machine with triple the productivity at 3000/hr can have an hourly cost 11 times that of the slower machine. Conversely, a machine that is expensive to own and operate must have high production rates.

The cost of "downtime" will offset some of the advantages of the high production/high cost models over the low production/low cost models. Trees not planted will not produce much wood fibre, despite the cost of planting. Therefore, the planting machine must be very reliable and not be prone to breakdown. In the more remote parts of northern Ontario, skilled mechanics and supplies of spare parts are few and far between. The day to day maintenance and repairs quite often must be carried out by local staff. Even simple machine parts must often by shipped from Toronto or other large centres. It is very important that machines be durable and as simple as possible to operate and maintain, and that parts used in the construction of the machine be readily available. Sophisticated electronic and hydraulic components are generally prone to failure because of the rugged environment and are difficult to replace. Such components should be minimized or totally eliminated.

If we are to replace people with machines, then machine productivity must be higher. If we assume that a planting machine requires four people to operate it, then what must be its productivity? One person can plant on an average about 1,350 containerized seedlings in one 8-hr day, i.e., 168.75 seedlings/man hour. To break even on labor requirements, a machine must average 675 seedlings/machine hour. An acceptable machine availability is 80%. Hence, during the available time, the machine must be capable of planting 843.75 seedlings/hr. If we include the lost time such as coffee breaks, travelling time, etc., it would appear that a reasonable minimum rate of production to break even on the labor requirements would be 1,000 seedlings/hr. As determined in Table 2, the maximum operating cost of this machine should be $25/hr or less. In order to achieve average production rates of 1,000 seedlings/hr, and planting at 2 m intervals, a single row machine would have to travel at a calculated average speed of 2 km/hr. To increase production capacity to the point at which the planting machine would be of benefit, i.e., 2,000 seedlings/hr or better, rates of travel would have to be 4 km/hr or greater. Average speeds of this nature are not feasible in the Ontario cutover. Hence, it would seem that a single row planter would be of little or no use on a large-scale planting operation. A two- or three-row machine is necessary.

Spacing in forest stands is important for optimizing wood production. Therefore, the machine should be capable of spacing plants within and between rows with only minimal variation. To do this, we have found that crawler tractors are most suitable as prime movers. Conventional wheeled tractors have not proven successful in the past, primarily because of their inability to maintain constant speeds. If wheeled prime movers are contemplated, then the planting mechanism must be designed so that it is not dependant on constant forward rates of travel. A wide variety of prime movers are used in Ontario forests: no standard machine is available. The planting machine must, therefore, be highly adaptable to a variety of makes and models or must be self-propelled. The terrain, even in the better soil conditions, is very often uneven, hummocky and littered with stones and debris. Many unsuitable microsites are encountered in unpredictable locations. The planting machine must be able to sense whether or not to plant in a specific location in order to avoid planting on stumps, rocks, or slash piles. If a planting chance is missed, the machine must be able to recycle quickly and pick out the next plantable location without loss of average spacing.

Prior to designing a machine, the designers must have a thorough understanding of the site conditions the machine will traverse. It is our experience that service factors in current use in the design of ma-

Table 2. Allowable machine cost relative to production rates

Planting rate 1,000s/hr	Cost (excluding planting machine) Cost/hr	Cost/1000	Allowable cost of planting machine Cost/hr	Cost/1000	Total cost Cost/hr	Cost/1000
1.0	$100.00	$100.00	$ 25.00	$ 25.00	$125.00	$125.00
2.0	100.00	50.00	150.00	75.00	250.00	125.00
3.0	100.00	33.33	275.00	91.67	375.00	125.00

chinery do not adequately reflect the harsh conditions found in the forest.

SAFETY

The effect on human comfort and safety of problems created by the harsh site conditions in our forests, particularly when planting machines are being operated, cannot be overstressed. In order to function efficiently, the machine must be operated efficiently. The operator must be adequately protected from the hazards of the site and at the same time be free to do the task at hand. The person feeding stock into the machine should be placed well away from the operating planting head because of the hazards created by moving machine parts and the difficulty of providing personal protection from flying debris. The feed to the planting head should be done by mechanical components.

Since the terrain tends to be rough, the machines often rock severely. This movement hampers the operator's ability to work. Either the tossing about of the operator must be greatly reduced or the task at hand must be simplified to allow for the movement of the machine. The bouncing or tossing action may be minimized by using modern, low pressure tires which engulf obstacles. The task of loading container seedlings could be semiautomated so that the operator loads the seedling into some type of cassette rather than directly into the ground or the planting head. The cassette would also allow for the irregular loading rates which result from unsteady working conditions.

The operator must also be protected from undue machine noise and from sharp machine components. If possible, he should be protected from wind, heat, rain and pests such as mosquitos and blackflies. A totally enclosed, climate controlled cab may become necessary for a high speed machine that requires a high degree of efficiency from the operator.

SUMMARY

The design of a container planting machine must be such that it will successfully transport and plant a container-grown seedling without damage, at an affordable cost.

The conditions under which it must operate dictate that the machine be simple to operate and maintain, be built from standard and rugged machine components and yet be cheap enough to operate on a three-to-four-months-per-year basis. The scale of operations shows a potential need for six to ten machines in northern Ontario.

The need for a planting machine can be justified only if it will solve one or all of the problems associated with labor shortages, poor planting quality, and high planting costs.

How complex or how simple the machine will be is left to the designers and manufacturers. Ultimately, they must decide on the configuration of the machine we use on the basis of sales and profits resulting from its manufacture.

The designers of the machine are urged to become very familiar with the ground and terrain conditions and related engineering service factors prior to design.

LITERATURE CITED

Fayle, D.C.
1978. Poor vertical root development may contribute to suppression in a red pine plantation. For. Chron. 54(2):99-103.

Heikurinen, J.K. and Wilson, W.R.
1980. Root development of plantation grown jack pine and red pine in northeastern Ontario. Ont. Min. Nat. Resour. (unpubl.)

Scarratt, J.B.
1974. Performance of tubed seedlings in Ontario. p. 70-85 in R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Scott, J.D.
1975. Recent developments in mechanized planting and the future for Ontario. p. 70-85 in Mechanization of silviculture in northern Ontario. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Symp. Proc. 0-P-3.

SITE PREPARATION AND AUTOMATIC MACHINE PLANTING OF CONTAINERIZED STOCK

Martti Kohonen[1]

Abstract.--An automatic planting machine has been developed for the planting of peat pots and paperpots. Planting and site preparation are carried out simultaneously, the latter by integral hydraulically driven double-blade scarifiers. The machine automatically selects the best planting spot and adjusts row spacing to maintain the required plant density. Different types of planting machine can be produced depending on the desired scarification method and planting conditions.

Resume.--Une planteuse mécanique a été mise au point pour le plantage des pots en tourbe et des pots en papier. Le plantage et la scarification, faite par des scarificateurs hydrauliques intégraux à deux lames, se font simultanément. La machine choisit automatiquement le meilleur endroit pour le plantage et corrige l'espacement des rangées pour maintenir la densité de plantage requise. On peut fabriquer différents types de planteuses selon la méthode de scarification désirée et les conditions de plantage.

INTRODUCTION

In recent years the G.A. Serlachius Corporation has developed an automatic planting machine which combines the site preparation and planting functions into a single mobile unit (Kohonen 1981). The machine is modular, and is normally mounted on a Valmet forwarder. Although different combinations are possible, the planting machine comprises five main elements, which perform the following functions: 1. mechanical/chemical site clearance; 2. site preparation; 3. plant feeding; 4. planting; 5. herbicide application. After the planting period is finished, all components are easily removable so that the prime mover can be used for other purposes.

The five machine functions will be described separately.

1. MECHANICAL/CHEMICAL SITE CLEARANCE

A blade is attached to the front of the prime mover for mechanical clearance of slash and other debris from the planting path. The height of the blade can be varied, and it may be set to cut any residual trees. In the case of hardwoods the driver may spray herbicides from nozzles positioned inside the blade.

2. SITE PREPARATION

In 1975, when development work on the planting machine project began, we recognized that the site preparation requirements for automatic, mechanized planting are far more stringent than those for manual planting. To insure good survival of machine-planted stock the site must be well prepared. The planting bed must be even, and must not contain any slash or air-pockets. Also, because we plant immediately after scarification, provision must be made for compressing the planting bed before planting. To fulfill these requirements we constructed hydraulically driven double-blade scarifiers, which will be described later.

The most commonly used site preparation equipment in Scandinavia today falls into one of three categories, viz.: i) spot scari-

---

[1] General Manager, Planting Technics, G.A. Serlachius Corporation, Mänttä, Finland.

fiers, ii) continuous scarifiers, or iii) various types of plow. The application of these three operating principles in the development of a single-unit site preparation/planting machine is discussed briefly below.

i) Spot scarifier - The first prototype planting machine used spot scarifiers, but the results were unsatisfactory. The main fault was that the scarified spot was too short for more than one planting attempt, so that on a second attempt the planting head frequently landed outside the spot. Consequently, with spot scarifiers the planting density is usually too low. The advantage of spot scarification is low cost, relative simplicity of operation and low energy requirements.

ii) Continuous scarifier - The earliest type used was a freely rotating single-blade scarifier. In difficult conditions the results were poor. In general, there were too many interruptions in the planting bed, with the result that trees were often planted into slash or unscarified spots. In the second stage of development the scarifier was kept in contact with the forest floor by hydraulic pressure. The results were better, and the equipment was further improved by powering the scarifier through the addition of a hydraulic motor. While this has improved the quality of site preparation, energy requirements have increased.

The main disadvantage of these scarifiers for single-pass site preparation and planting is that the planting bed has no opportunity to settle. Normally, in Scandinavia, site preparation is carried out in summer, allowing time for the ground to settle before planting the following spring. With simultaneous scarification and planting, provision must therefore be made to compress the planting bed before planting.

iii) Plows - In general, plows are too heavy to be combined with a planting unit. Also, the speed and capacity of the planting machine would be reduced too much.

As noted earlier, the present Serlachius planting machine incorporates hydraulically driven double-blade scarifiers. The working principle is illustrated in Figure 1. The blades are placed in front of the rear wheels of the prime-mover in such a way that the front blade removes slash while the rear blade forms the planting bed on the cleared area. The planting bed is compressed by the rear wheels of the prime-mover, and the planting heads are situated just behind the rear wheels.

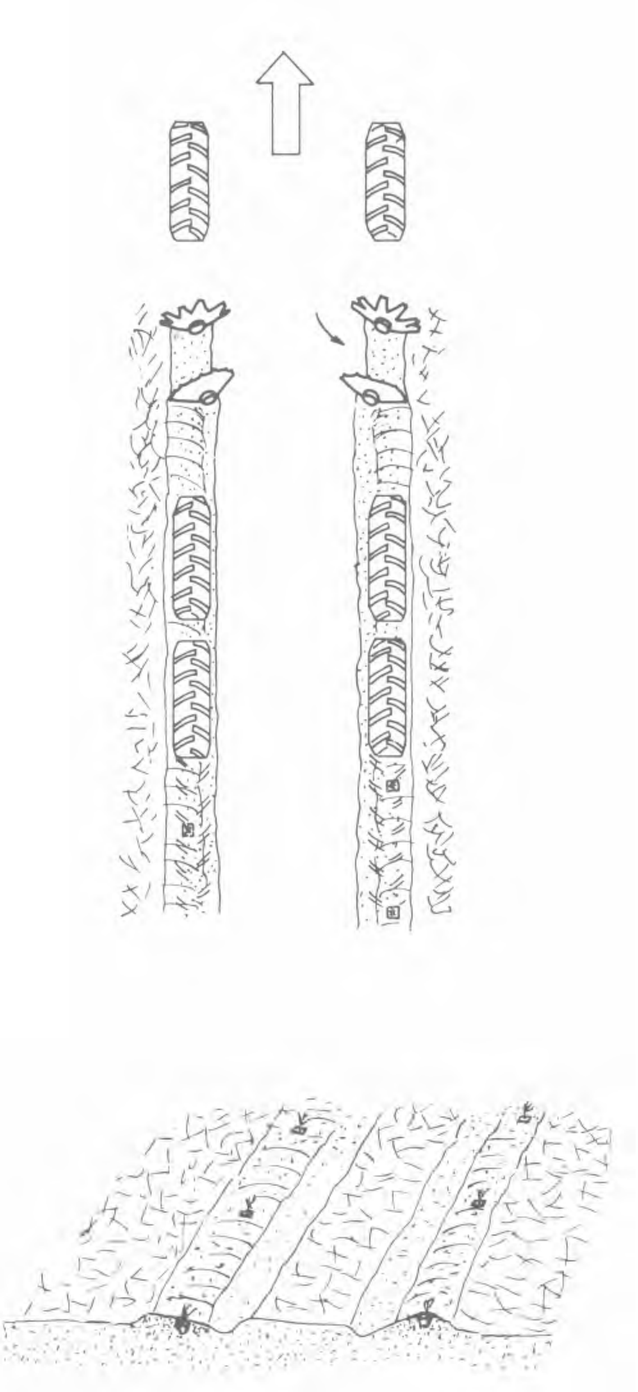


Figure 1. Working principle of double-blade scarifiers on Serlachius Planting Machine.

The scarifiers can readily roll over stumps and stones, and the driver can control the speed and direction of the blades.

Preliminary results of a study carried out by the Metsteho, the Forest Work Study Section of the Central Association of Finnish Forest Industries (Kaila 1982), show that planting beds formed in the above manner produce better planting conditions than do those formed by the regular methods. However, it must be kept in mind that such scarifiers are not intended to compete with forest plows.

This type of site preparation is expensive, but our tests have shown that the superior planting results will compensate for the extra costs. Spot scarifiers may be a viable alternative to the double-blade scarifiers for easier site conditions.

3. PLANT FEEDING

A European standard-size plastic pallet (100 cm x 120 cm) is used as the basic unit for growing and transporting the containerized seedlings (Fig. 2). It is also used as the basic unit in our planting machine (Fig. 3).

Figure 2. Standard pallets used for growing, transporting and loading seedlings onto planting machine.

The feeding system is loaded with five pallets, giving a planting capacity of 2,000 peat pot seedlings. The pallet is opened automatically and the seedlings are fed to the planting heads. The empty pallets are stacked on a separate frame. About once every hour the driver must feed in a new set of five pallets. The machine can carry planting stock for up to four hours of operation.

Figure 3. Serlachius Planting Machine.

The machine is designed to plant either peat pots or paperpots. Seedlings may be fed completely automatically, semi-automatically or manually.

4. PLANTING

The machine scarifies and plants two rows simultaneously. The planting heads (Fig. 4) remain stationary in relation to the planting spot during the actual planting cycle, while the machine continues to move forward. After the planting cycle is completed the planting heads are drawn forward to their starting position to receive a new seedling. The two planting heads operate independently, and automatically maintain the required plant density, select a suitable spot and adjust the planting depth.

When equipped with a planting spot sensor device, the planting heads are able to reject stones, stumps, slash and water as candidate planting spots. On wet sites, where the rear wheels of the prime-mover might sink, the driver can move the planting heads outside the wheel track and plant in suitable non-scarified positions.

5. HERBICIDE APPLICATION

Nozzles for applying herbicides are attached to the planting heads. They can spray so-called slow-release herbicides to enable small seedlings to be used on sites with potentially heavy weed competition. Such herbicides are inactive during the first year after site preparation, hut are released in the second year and keep out weed competition for two or three years after planting.

Figure 4. Planting head of Serlachius Planting Machine.

MACHINE CAPACITY AND APPLICATION

The production capacity of the machine varies between 1,500 and 3,000 seedlings per hour, depending upon site conditions, size of planting stock and the required planting density. The quality of planting is high, averaging 90% correctly planted seedlings.

Site restrictions on operation of the planting machine depend mainly on the ability of the prime-mover to negotiate difficult site conditions. The planting unit itself can operate under relatively difficult conditions. Depending upon the chosen combination of machine options and ground conditions, different prime-movers may be used. In Scandinavia, the forwarder is the most commonly used prime-mover.

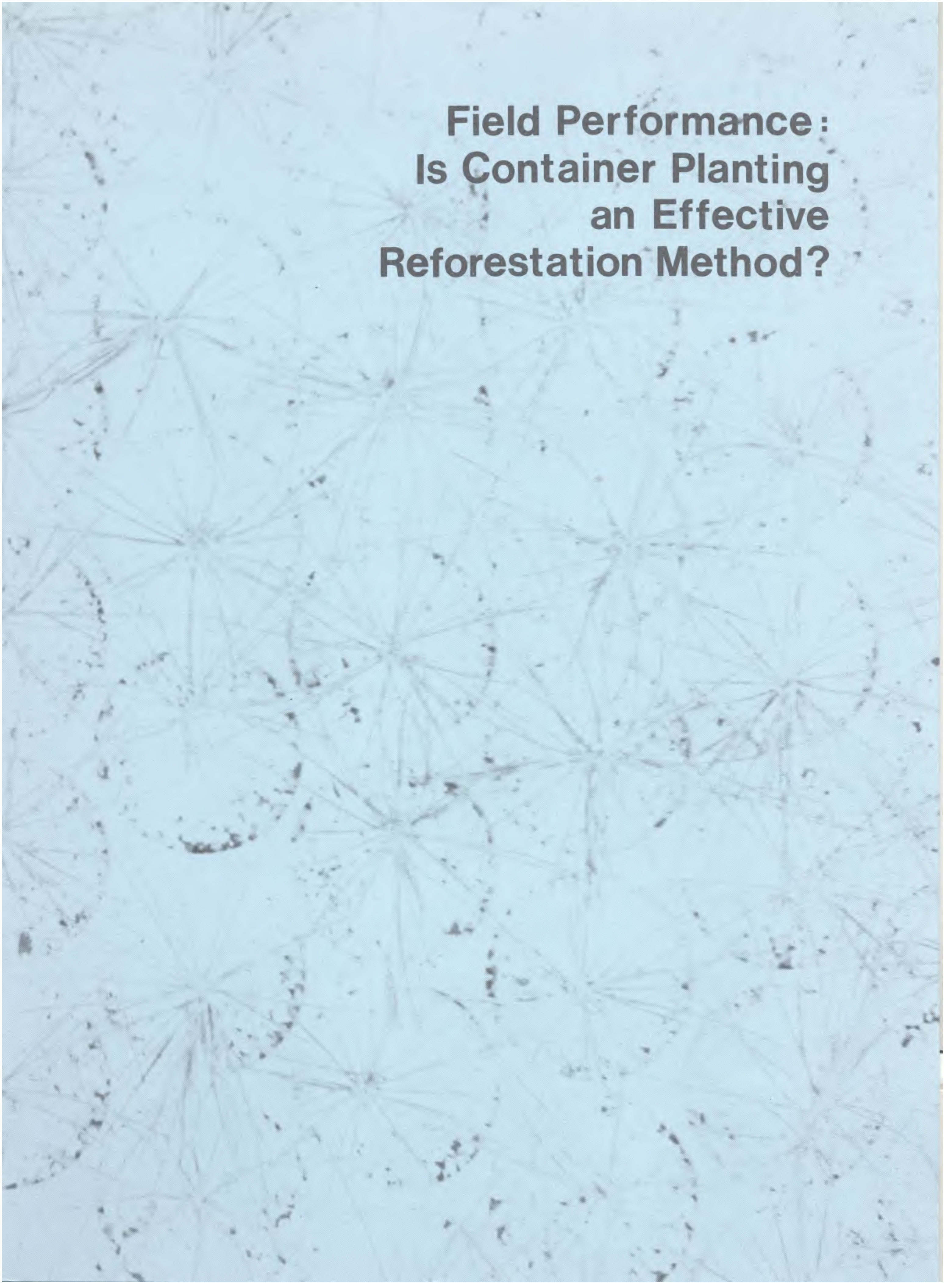
It is very difficult to give an exact cost for the machine because, inasmuch as the design is modular, the cost will depend on the components selected.

LITERATURE CITED

Kaila, S.
1982. Quality of soil cultivation in forest regeneration. Metsäteho Review (in press).

Kohonen, Martti.
1981. Automatic multifunction treeplanter and plantproduction system. p. 139-143 in Proc. Symposium on Engineering Systems for Forest Regeneration, A.S.A.E. Publ. 10-81.

Field Performance: Is Container Planting an Effective Reforestation Method?



FIELD PERFORMANCE OF SMALL-VOLUME CONTAINER-GROWN SEEDLINGS IN THE CENTRAL INTERIOR OF BRITISH COLUMBIA

Alan Vysel

Abstract.--Operational plantations of interior spruce *(Picea glauca* [Moench] Voss, *Picea engelmannii* Parry), lodgepole pine *(Pines contorta* var. *latifolia* Engelm.), and interior Douglas-fir *(Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) in the central interior of British Columbia were examined to compare field performance of small-volume container-grown seedlings and bare-root seedlings and transplants. The performance of interior spruce container-grown seedlings was judged superior to that of bare-root seedlings and transplants. Lodgepole pine container-grown seedlings survived and grew as well as bare-root seedlings. The performance of a limited number of Douglas-fir plantations was less than satisfactory for both stock types.

Résumé.--On a examiné des plantations d'épinettes *(Picea glauca* [Moench] Voss, *P. engelmannii* Parry), de pin tordu latifolié *(Pinus contorta* var. *latifolia* Engelm.) et de Douglas taxifolié *(Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) établies dans le centre de la Colombie-Britannique continentale en vue de comparer la performance en plein champ des semis en récipents de faible volume, des semis à racines nues et des semis repiqués. On a jugé que les semis d'épinettes en tubes ont présenté une meilleure performance que les semis à racines nues ou les semis repiqués. La survie et la croissance des semis en tubes de pin tordu latifolié ont été semblables à celles des semis à racines nues. Dans certaines plantations établies avec l'un et l'autre type de semis, la performance du Douglas taxifolié n'a pas été satisfaisante.

INTRODUCTION

Field performance assessments are an essential ingredient in the evaluation of any reforestation system. To adapt an old saying, "the proof of the system is in the growing". If the trees do not survive and grow, considerations such as low cost, manpower savings or technological innovations are irrelevant.

In the past the biological performance of container systems in British Columbia has been evaluated on the basis of experimental field trials or small-scale operational trials (Arnott 1974). The early results of such trials were sufficiently encouraging that, despite their limitations in terms of site coverage and favored treatment (e.g., quality nursery care, limited stock handling, and planting by research crews), the province embarked on a substantial program of containerization. Some 230 million "plug" seedlings grown in small-volume (40 cm^3) BC/CFS styroblock containers have been planted to date, and the number planted is currently increasing at a rate of 66 million per year. Therefore, it is now possible to rectify some of the problems associated with field performance assessments of experimental trials by examining performance of seedlings planted under more demanding operational conditions.

---

[1] Research Forester, Cariboo Region, Ministry of Forests, Williams Lake, British Columbia.

The purpose of this paper is to present the results from 38 plantations of one-year-old container-grown seedlings of interior spruce (*Picea glauca* [Moench] Voss, *Picea engelmannii* Parry or a naturally occurring hybrid of the two species), lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), and interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) established across a range of sites in the central interior of British Columbia (Fig. 1). The plantations were established between 1972 and 1978 as part of the British Columbia Ministry of Forests' reforestation program in the Cariboo Region. The performance of container-grown plug seedlings will be compared with results from 214 plantations of two-year-old bare-root seedlings (2-0) and three-year-old transplants (2-1) of the same species established across a similar range of sites.

PLANTATION PERFORMANCE CRITERIA

Most authors examining the performance of seedlings and plantations use one or more of the following biological criteria:

1) mortality (usually expressed as survival)
2) relative condition (e.g., good or poor)
3) absolute size (height, diameter, weight)
4) size increment (height, diameter, weight)
5) indices which are products of 1) and 3).

Each has its own peculiarities and problems. Percent survival, for example, can be misleading because it is a snapshot of a dynamic process; many seedlings might be in poor condition and on the verge of death at the time of assessment. Experimental investigation usually includes seedling condition as a second measure of performance in an attempt to assess probability of mortality, but this is a subjective measure and difficult to apply on a large scale. Absolute size is an objective criterion, and integrates all previous effects until time of measurement. However, a small seedling that is growing fast in relation to its size could be judged inferior to a large seedling growing slowly in relation to its size. Increment measures made over several years are more satisfactory because they permit reconstruction of the growth curve for individual seedlings without precluding use of the absolute size criterion. Performance indices are intuitively attractive because they permit a summary of two or more factors. For example, height and survival are combined in the concept of aggregate height proposed by Mullin and Howard (1973). However, such indices can also be very misleading because they exhibit the faults of the combined factors, while hiding their absolute values (e.g., an aggregate height of 2,000 cm can be achieved if all the trees in a plot of 100 reach 20 cm, or if half of them reach 40 cm). When costs are added in an attempt to provide an economic tool for decision making (Mullin and Howard 1973, Ball 1980), the potential for serious misjudgments is increased further.

Figure 1. Map of British Columbia showing location of Cariboo Region and general location of the operational plantations sampled for this study.

In this study, three criteria will be used: survival, height increment expressed in the form of a growth curve from the time of plantation establishment, and relative height growth rate. Relative growth rate (RGR) is not a new concept but it has been used only occasionally in studies of forest seedling growth (e.g., Sweet and Wareing 1966). Defined precisely, RGR is the amount of growth per unit of plant material at the beginning of the growth period, per unit of time over which growth takes place. Agricultural crop physiologists first used the concept 60 years ago and its application has been vastly expanded since then (Hunt 1978). RGR is useful in the context of tree seedling performance because it allows an investigator to assess the *efficiency* of growth in relation to size. Since container-grown seedlings are often compared with bare-root seedlings that are much larger at the time of planting, the use of RGR is particularly appropriate in this study.

Expressed in mathematical terms, final plant size is related to initial plant size in the following way:

$$W_2 = W_1 . e^{R(T_2 - T_1)}$$

$$\text{thus } R(T_2 - T_1) = \frac{\log_e W_2 - \log_e W_1}{T2 - T1}$$

where W_1 and W_2 are plant size at time T1 and T2, and R is relative growth rate.

PLANTATION ASSESSMENT METHOD

Height growth of 252 plantations was measured for three seasons according to the method outlined by Vyse (1981). Details of a slightly revised method are available from the Silviculture Branch, B.C. Ministry of Forests.

Second or third season survival data for most of the plantations that were measured for height growth and for additional lodgepole pine plantations (a total of 193) were extracted from Ministry of Forests records. Almost all the plantations measured were located in the moist eastern half of the region (Fig. 1) where annual precipitation ranges from 600 mm to 1,200 mm. They were distributed among three biogeoclimatic zones: sub-boreal spruce; interior cedar-hemlock; and Engelmann spruce-subalpine fir (Annas and Coupe 1979). The distribution of plantations by species and stock type is shown in Table 1, and represents approximately 90% of those planted with interior spruce and interior Douglas-fir between 1972 and 1978. The low number of lodgepole pine plantations is due to insufficient operational survey work, but the low number of Douglas-fir container plantations reflects the limited scale of planting with that species and stock type.

Most of the plantations assessed were established on areas treated by prescribed burning or mechanical means to remove slash, and rarely suffered from severe brush competition.

The analysis of plantation assessment data is based on means of sample tree internode lengths, and the growth curves and relative growth rate are based on means of plantation means.

Table 1. Number of plantations assessed for height growth by species and stock type.

	No. of plantations per stock type[a]			
Species	1-0 P	2-0 BR	2-1 BR	Total
Interior spruce	27	115	74	216
Interior Douglas-fir[b]	4	17	2	23
Lodgepole pine	7	6	0	13
Total	38	138	76	252

[a] P = plugs or container seedlings; BR = bare-root

[b] All plantations located in interior cedar-hemlock zone

RESULTS AND DISCUSSION

Survival

The survival records for operational plantations (Table 2) show that plug seedlings of all three species examined perform at least as well as conventional bare-root stock. In the case of interior spruce and lodgepole pine the probability of high rates of survival (>90%) is, in fact, considerably greater for plugs than for either seedlings or transplant bare-root stock, a result which is supported by work in the southern interior (Clark and Elmes 1980) and by the opinions of local foresters. An examination of the survival records also indicates that the performance of spruce plug stock has improved over time (performances below 80% in Table 2 date back to 1974), whereas bare-root spruce performance has remained quite variable. Conversely, bare-root pine performance has improved in recent years. Some poor performances at an early stage were the result of low root growth capacity of seedlings before planting (Burdett 1979).

There were insufficient interior Douglas-fir plug plantations to allow a comparison with bare-root plantations. The growing of fir plug stock has been restricted because the standard low cost techniques used in British Columbia container nurseries have failed to produce fir seedlings with a .satisfactory root plug[2]. However, bare-root survival of interior Douglas-fir varies as it

---

[2] E. Van Eerden, 1981 (Personal communication)

Table 2. Distribution of plantation survival by percentile classes for species and stock type.

		No. of plantations per survival class[a]						
Species	Stock type	90	80	70	60	50	40	30
Interior spruce	1-0 P	17	-	3	1	2	-	-
	2-0 BR	15	16	11	10	6	3	3
	2-1 BR	19	8	5	4	1	1	1
Interior Douglas-fir[b]	1-0 P	1	1	1	-	-	-	-
	2-0 BR	7	6	2	1	1	3	-
Lodgepole pine	1-0 P	12	2	2	-	-	-	-
	1-0 BR	6	6	6	3	5	2	-

[a] 10 percentile classes (e.g. 80%-89%); 90 percentile class includes plantations with 100% survival.

[b] All plantations located in interior cedar-hemlock zone.

does with the other species, a factor which gives rise to the possibility that extensive use of plug stock might lead to improved survival, provided that nursery problems can be solved and large numbers of satisfactory seedlings can be produced.

Height Growth and Relative Growth Rate

Figure 2 presents the height-age and relative growth-age curves for each species and stock type. Performance of the 2-1 spruce stock type is not recorded because it is very similar to that of 2-0 stock. The initial height advantage of bare-root stock was maintained and, in the case of lodgepole pine and interior Douglas-fir, actually increased. The differential in absolute size amounted to less than one year of growth after six years in the case of pine, and two years of growth after five years in the case of fir. However, with interior spruce the initial size differential was not maintained and after five seasons of growth the mean height of plug stock plantations surpassed that of bare-root plantations.

The relative growth rate curves (Fig. 2 d, e, f) in effect measure the slope of the height-growth curve, and permit closer examination and partial explanation of the growth pattern. For spruce the eventual superiority in absolute size of plug stock is attributable to higher RGR in each year following planting, and thus a steeper height-age curve, despite a precipitous drop in RGR after one year. Possible explanations for this marked second year "decline" have been examined by Vyse (1981). The early growth of pine plug stock growth in relation to size was higher than for spruce and reduced some of the initial advantage held by bare-root stock. But after three years the RGR of both stock types went into decline also and there was no further reduction in the size gap.

The initial size difference between stock types was largest for Douglas-fir. Consequently, the small advantage in RGR of the smaller plug stock did not have much effect on the height advantage of the bare-root stock.

Figure 3 provides some further explanation of the growth trends. The curve of RGR against mean seedling size at the beginning of each growing season shows that, for each species, plug stock grew faster than bare-root seedlings of the same size up to about 30 cm in initial height.

Only for spruce was there any indication that the superior performance continues beyond the initial years. This apparent trend must, however, be treated with some caution. At least one plantation on a good growing site (93B16-15) with a side by side comparison of plug and 2-0 stock types showed superior early RGR of plug stock (Table 3), but unlike the aggregate plantation trend, the superiority did not continue beyond 30 cm initial height. It is possible that the combined data for spruce plug stock plantations contain a bias which elevates the mean performance of that stock type in later years. Alternatively, the early advantage of plug stock may be accentuated and extended on poorer sites.

CONCLUSIONS

A comparison of survival and growth records obtained from operational plug and bare-root plantations established on prepared sites in the Cariboo Region of British Columbia permits several conclusions of practical significance:

1. Valuable information on the comparative performance of stock types can be gleaned from operational survival and growth assessments despite the problems associated with analyzing data collected from heterogenous plantations by staff with little interest in research.
2. Plug seedlings from small-volume containers suffer less mortality than bare-root seedlings or transplants established on similar sites. For lodgepole pine and interior spruce plug plantations the probability of any plantation suffering

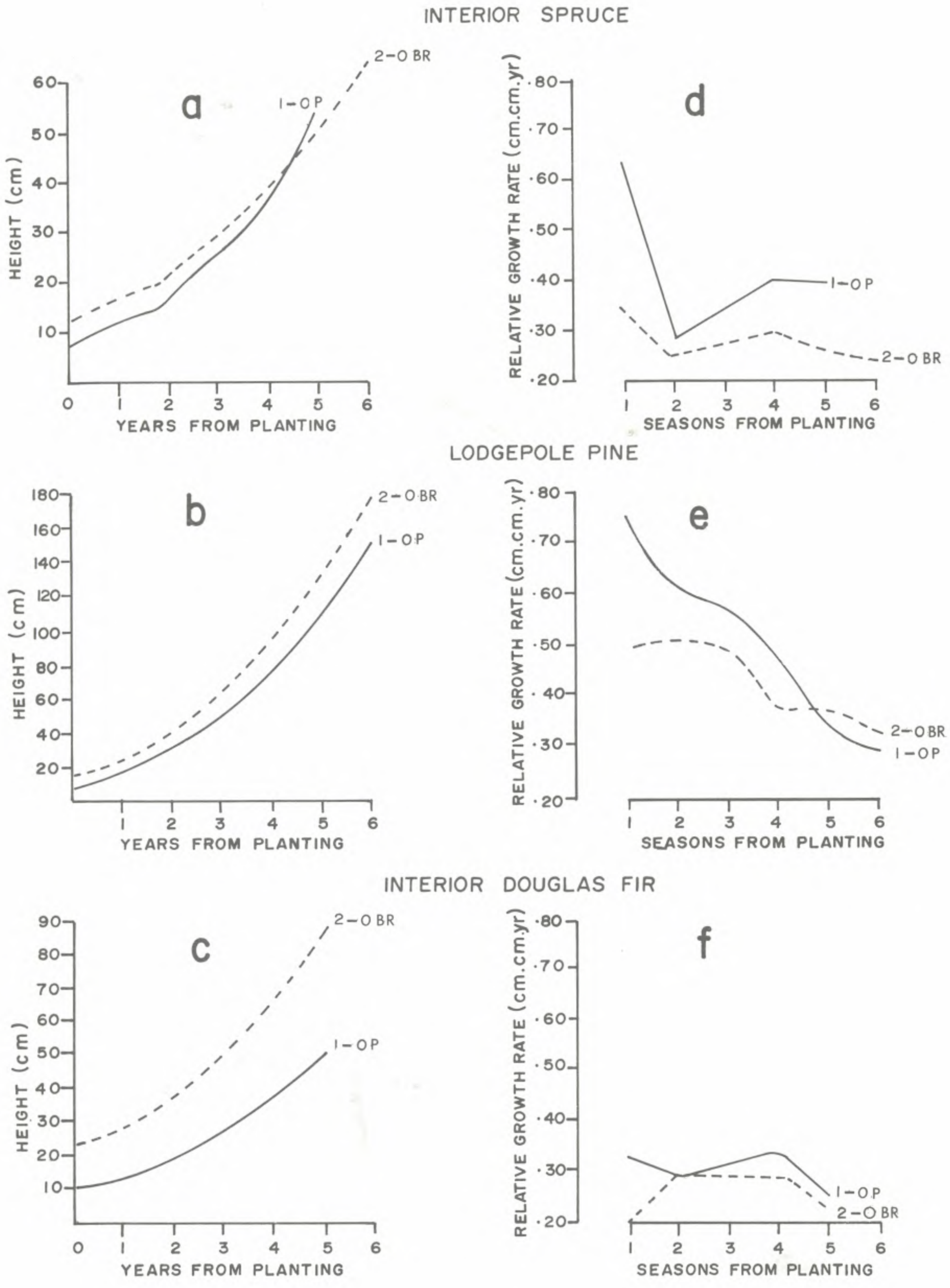


Figure 2. Height growth and relative growth rate of interior spruce, interior Douglas—fir and lodgepole pine 1-0 plug and 2-0 bare—root seedlings in operational plantations.

losses of less than 10% after two years is very high. And it seems probable that Douglas-fir plug plantations will match this record once nursery production problems are resolved.

3. The early growth performance of small plug stock is superior to that of standard sized bare-root stock. Within a height range of 15 to 30 cm, plug seedlings of all three species examined outgrew bare-root plants of the *same size* established on a similar range of sites, and beyond that range, growth rates were similar except for interior spruce. However, the continued superior growth of spruce plug stock should be treated with considerable caution until more detailed supporting evidence is available.

4. According to widely held views about stock type performance, the bare-root stock should have outperformed the plug stock because it was larger at the time of planting. The results do not provide any evidence to support this influential "bigger is better" dogma. Indeed, some of the results clearly contradict it. And even though the bare-root stock of fir and pine was larger than equivalent plug stock after five or six years of growth, the similarity in *growth rate* of both stock types suggests that the present absolute size differential will change with the increment pattern of the species, and that the relative size differential will decrease substantially. As it is doubtful if a mean difference of one or two years of increment will be detectable after 60 or 70 years of growth, claims of superiority on this basis are of dubious practical significance. Although the results of the study are not sufficient to relegate the "bigness" fixation to the status of an unsubstantiated slogan, they do indicate that some reformulation of ideas is necessary before British Columbia foresters have a useful theory with which to predict stock type performance. Such a task is beyond the scope of this paper. In the meantime the practitioner should take full advantage of the fact that vigorous seedlings, grown in and extracted from small-volume containers, are capable of matching and even exceeding the performance of larger bare-root plants on a wide range of prepared sites in the central interior of British Columbia.

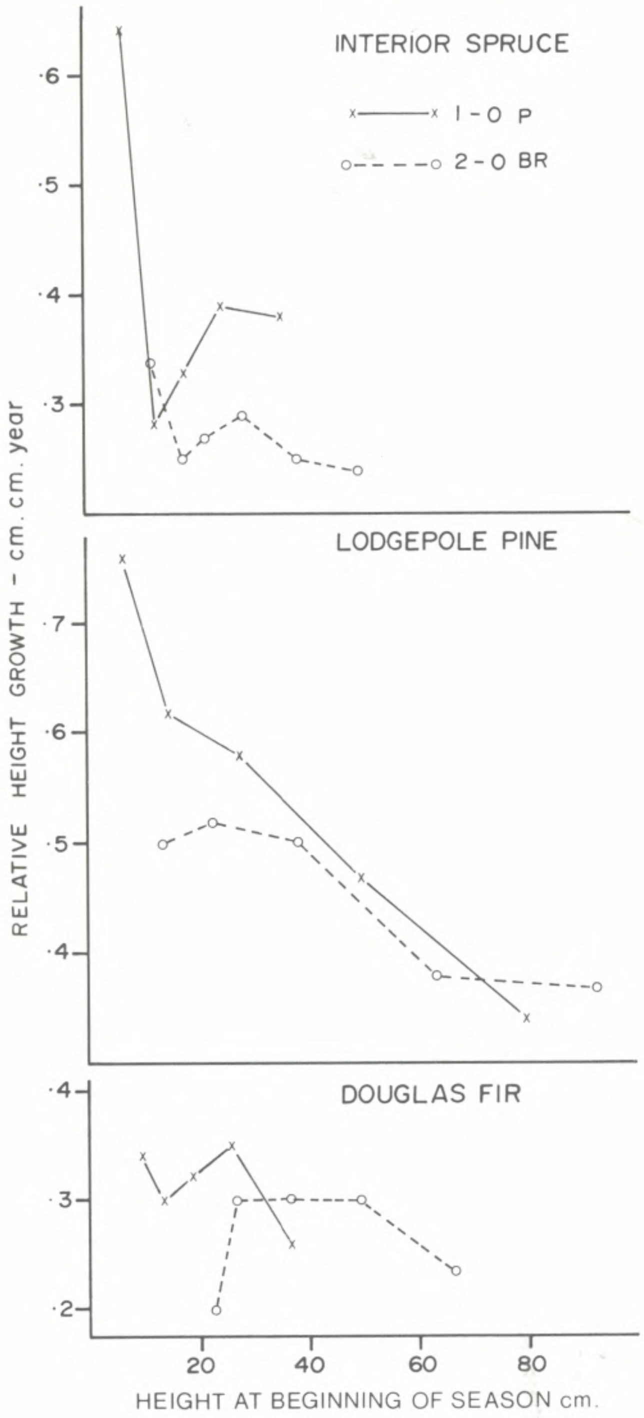


Figure 3. The relationship between RGR and mean seedling size at the beginning of each growing season.

Table 3. Height growth and RGR for selected superior plantations with 1-0 plug and 2-0 bare-root of same species planted on similar sites.

Species	Plantation	Stock type	Performance criterion[a]	Seasons following planting 0	1	2	3	4	5	6
				(cm or cm/cm/yr)						
Spruce	93B16-15	1-0 P	H	5	9	18	31	48	67	86
			RGR		.59	.69	.54	.44	.33	.25
Spruce	93B16-15	2-0 BR	H	13	19	27	43	64	83	102
			RGR		.38	.36	.46	.38	.28	.20
Douglas-fir	93A11-6	1-0 P	H	8	12	18	29	41	57	79
			RGR		.40	.41	.48	.34	.33	.33
Douglas-fir	93A11-3	2-0 BR	H	19	24	30	42	61	84	110
			RGR		.24	.22	.34	.37	.32	.27
Lodgepole pine	93G1-47	1-0 P	H	5	9	21	43	69	97	132
			RGR		.59	.84	.72	.47	.32	.31
Lodgepole pine	93G1-49	2-0 BR	H	13	20	36	60	86	114	151
			RGR		.44	.58	.51	.36	.29	.29

[a] H = Height growth measured in cm; RGR = Relative growth rate measured in cm per cm of initial height per year or season.

LITERATURE CITED

Annas, R., and Coupe, R.
1979. Biogeoclimatic zones and subzones of the Cariboo Region. B.C. Min. For., Res. Br. 103 p.

Arnott, J.T.
1974. Performance in British Columbia. p. 283-290 in R.W. Tinus, W.I. Stein, and W.E. Balmer, Ed. Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Ball, W.J.
1980. Plantation performance in perspective. Dep. Environ., Can. For. Serv., Edmonton, Alta. For. Manage. Note No. 4.

Burdett, A.N.
1979. New methods for measuring root growth capacity; their value in assessing lodgepole pine stock quality. Can. J. For. Res. 9:63-67.

Clark, M.B., and Elmes, E.
1980. Determination of the causes of mortality in young plantations (E.P. 790). B.C. Min. For., Kamloops Region, Res. Sec. Unpubl. Rep. 35 p.

Hunt, R.
1978. Plant growth analysis. In The Institute of Biology's Studies in Biology Series. No. 96. Edward Arnold, London. 67 p.

Mullin, R.E., and Howard, E.P.
1973. Transplants do better than seedlings... For. Chron. 49:213-218.

Sweet, G.B. and Wareing, P.F.
1966. The relative growth rates of large and small seedlings in forest tree species. p. 100-117 in Physiology in Forestry. For. Supplement 1966.

Vyse, A.
1981. Growth of young spruce plantations in Interior British Columbia. For. Chron. 57:174-180.

FIELD PERFORMANCE OF CONTAINERIZED SEEDLINGS IN INTERIOR BRITISH COLUMBIA

A.C. Gardner[1]

Abstract.--Seedlings of white spruce *(Picea glauca* [Moench] Voss), lodgepole pine *(Pinus contorta* var. l Engelm.) and Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) were grown in Walters bullets and BC/CFS styroblocks and outplanted in 1970 in the bullets, as bullet plugs, and as styroplugs. Bare-root seedlings of each species were planted as controls. Plantings were carried out in June, July, August and September of the same year to test the effect of extending the planting season. Survival and height growth results 10 years after planting are presented.

Résumé.--On a cultivé des semis d'épinette blanche *(Picea glauca* [Moench] Voss), de pin tordu latifolié *(Pinus contorta* var. *latifolia* Engelm.) et de Douglas taxifolié *(Pseudotsuga menziesii* [Mirb.] Franco) dans des cartouches de Walters et des BC/CFS styroblocks et on les a transplantés en 1970, dans leurs contenants. À titre de témoins, on a planté des semis 2-0 à racines nues de chacune des essences. Afin de vérifier les effets de la prolongation de la saison de plantation, on a réparti les dates de plantation en juin, juillet, août et septembre de la même année. On présente les résultats obtenus en dix ans après la plantation relativement à la survie et à la croissance en hauteur.

INTRODUCTION

Field testing of container reforestation systems over a wide range of site types in coastal and interior British Columbia began in 1967 with the initiation of the cooperative container planting research and development program of the Pacific Forest Research Centre (PFRC) and the British Columbia Forest Service (Kinghorn 1972). The trial reported here was established in 1970 near Prince George in the central interior of British Columbia and formed part of the second phase of the container program, which involved continued development of container systems and pilot production. The objectives of the trial were to study height growth and survival of seedlings grown in two container types, the Walters bullet (Walters 1969) and the BC/CFS styroblock (Sjoberg 1974), and to investigate the feasibility of extending the planting season throughout the June to September growing period.

SEEDLING PRODUCTION

All container stock for the trial was grown at the Pacific Forest Research Centre in Victoria, B.C. Seed of Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco), white spruce *(Picea glauca* [Moench] Voss) and lodgepole pine *(Pinus contorta* var. l Engelm.), obtained from provenances local to the test area, were sown into 11-cm Walters bullets (22 cm^3) and BC/CFS styroblock-2 (40 cm^3) containers in early March 1969. The growing medium consisted of a peat-vermiculite mix (3:1 by volume) to which 3 kg of dolomitic limestone (12 mesh and finer) had been added. The seeds were covered with #2 granite grit and misted daily. Seedlings were retained in the greenhouse for approximately 12 weeks after germination was com-

---

[1] Forestry Officer, Pacific Forest Research Centre, Canadian Forestry Service, Victoria, British Columbia.

pleted and were transferred to outdoor shadehouses which provided 30% shade for lodgepole pine and Douglas-fir and 46% shade for white spruce.

Fertilization consisted principally of biweekly applications of 28-14-14 at 187-374 g/kl throughout the peak height growth period (late March to mid-July). This was supplemented with three applications of 21-0-0 (lodgepole pine and white spruce) and 34-0-0 (Douglas-fir) at 374 g/kl. Thereafter each crop received two applications of 0-0-60 at 78-94 g/kl, one application of 15-15-30 at 312 g/kl, followed by a single application of 34-0-0 at 312 g/kl. All fertilizers were water soluble and applied concurrently with irrigation, using fixed sprinklers.

Bare-root stock, used for controls in the trial, was obtained from the British Columbia Forest Service nursery at Red Rock, B.C. Morphological characteristics of all planting stock are given in Table 1.

PLANTATION ESTABLISHMENT AND ASSESSMENT

Study Area

The study area is located approximately 120 km north of Prince George near the south end of McLeod Lake (lat. 54°52', long. 122°58') in the central interior of British Columbia, at an elevation of 855 m. The site falls within the SA.2 interior subalpine forest section (Rowe 1972) and previously supported a mixed stand of white spruce, subalpine fir *(Abies lasiocarpa* [Hook.] Nutt.) and lodgepole pine. The area was logged between 1964 and 1966 and slash was burned in 1967.

Predominant vegetation includes thimbleberry *(Rebus parviflora* Nutt.), black twinberry *(Lonicera involucrata* [Richards] Banks), *Vaccinium* spp., red elderberry *(Sambucus pubens* Michx.), pine grass *(Calamagrostis rubescens* Buckl.), *SaZix* spp. and trembling aspen *(Populus tremuloides* Michx.). Soils are variable, ranging from a coarse textured, well drained, degraded, dystric brunisol over glacial outwash to fine textured, moderately well drained to poorly drained orthic gray and bisqua gray luvisols[2]. The climate consists of relatively cool, moist summers and long, cold winters. The mean annual temperature is 3.5°C, with a May to September average of 12°C. Annual precipitation is up to 63 cm, a third of which is snow. Table 2 gives a June-September monthly temperature and precipitation summary for the duration of the trial.

Planting, Experimental Design and Assessment

Seedlings (1-0) of each species grown in the bullets and styroblocks were outplanted 1) in the bullets, 2) as bullet-plugs (Arnott 1971), and 3) as styroplugs. Cold-stored (2-0) and fresh-lifted (2-1) bare-root stock

Table 1. Morphological characteristics of container and bare-root stock at time of planting

Species and seedlot	Stock type	Shoot length (cm)	Root collar diam. (mm)	Dry weight (g) Shoot	Root	Total	Shoot:root ratio
Douglas-fir 590[a]	bullet	9.1	1.6	0.30	0.17	0.47	1.8
	styroplug	18.9	2.1	0.83	0.43	1.26	1.9
	bare-root	17.1	3.3	1.65	0.86	2.51	1.9
Lodgepole pine 55	bullet	8.4	1.8	0.62	0.27	0.89	2.6
	styroplug	11.6	2.3	1.02	0.53	1.55	2.0
	bare-root	14.7	4.3	3.80	1.02	3.82	3.8
White spruce 779	bullet	10.2	1.9	0.50	0.30	0.80	1.7
	styroplug	15.9	2.0	0.66	0.33	0.99	2.0
	bare-root	16.7	3.9	2.54	0.98	3.52	2.7

[a]B.C. Ministry of Forests registered seedlot numbers.

---

[2]Soils description taken from project record compiled by E. Van Eerden (unpublished data).

Table 2. Mean monthly temperature (°C) and precipitation (mm) for June, July, August and September at Prince George, B.C., for the period 1970-1980a

Year	June temp.	Precip.	July temp.	Precip.	August temp.	Precip.	September temp.	Precip.
1970	14.3	74.7	14.5	73.4	14.2	46.9	8.5	55.6
1971	12.7	73.9	14.7	84.1	16.0	32.8	8.2	61.2
1972	12.9	107.7	14.1	94.1	14.4	43.7	7.7	24.1
1973	11.7	90.2	14.5	50.0	12.5	48.7	9.0	63.2
1974	12.6	41.9	13.7	97.5	15.4	23.6	11.1	45.7
1975	12.1	88.1	17.1	43.4	12.6	86.4	10.4	22.7
1976	10.9	122.1	13.8	80.8	14.4	58.7	10.9	41.4
1977	13.0	54.3	14.1	109.5	15.6	52.2	8.6	65.8
1978	13.0	37.0	17.0	37.9	14.2	62.8	9.3	52.4
1979	12.5	72.6	16.0	24.6	16.1	31.7	11.9	50.2
1980	13.5	84.4	14.3	83.4	12.7	106.2	9.8	85.3
Average[b]	13.0	58.2	14.9	57.9	13.7	73.4	9.8	54.9

[a] Source: Monthly meteorological observations Canada, Department of the Environment, 1970-1980.

[b] Average monthly temperature and precipitation for the period 1970-1980.

of each species was planted as a control. Planting was carried out four times throughout the summer of 1970: on 23 and 24 June (container stock and 2-0 cold-stored bare-root stock), on 25 and 26 July, on 20 August and from 15 to 21 September (container stock and 2-1 fresh-lifted bare-root stock). Bullet plugs and styroplugs were extracted from their containers on site and were dibble planted. Bullet seedlings were planted with a "gun" (Walters 1969) and bare-root seedlings were mattock planted.

The trial was arranged in a randomized block design with a block consisting of three plantations, each of 16 rows. Each species was assigned to a plantation and each stock type was assigned four rows within a plantation. A row contained 35 trees for the bullet, styroplug and bare-root stock types, but only eight trees for the bullet-plug type. Styroplugs were planted in a single line by themselves at a 2 m spacing, whereas the bullet, bullet-plug and bare-root types were planted in cluster plots consisting of a central stake with a bullet seedling in front, a bare-root seedling to the right and a bullet-plug to the rear, all within a 0.5 m^2 area. Bullet-plugs were located at the first plot and at every fifth plot thereafter, including the last plot. There were three replications of the blocks, for a total of 4068 trees.

The trial was assessed for survival and height growth annually until 1975 and again in 1980. For brevity, only the first, third, fifth and tenth year assessments are reported here.

The data were subjected to analysis of variance and multiple range tests for determination of significant effects.

RESULTS AND DISCUSSION

Survival data by species and container types up to 10 years following outplanting are given in Table 3.

There were no statistically significant differences in survival among container types for white spruce or lodgepole pine over the duration of the trial.

Douglas-fir survival stabilized following the third growing season. Survival of styroplug and bare-root seedlings was significantly higher than that of bullet and

Table 3. Summary of survival of Douglas-fir, white spruce and lodgepole pine by stock type (%)

Species	Years from planting	Stock type			
		Styroplug	Bullet	Bullet-plug	Bare-root
Douglas-fir	1	89.5^{a}	77.3^{b}	82.3^{ab}	80.9^{ab}
	3	83.3^{a}	63.5^{c}	69.7^{bc}	75.7^{ab}
	5	80.2^{a}	59.7^{b}	64.5^{b}	74.0^{a}
	10	74.7^{a}	52.8^{b}	52.0^{b}	66.1^{a}
White spruce	1	96.9^{a}	91.1^{a}	95.8^{a}	93.3^{a}
	3	93.3^{a}	88.9^{a}	95.8^{a}	91.4^{a}
	5	91.4^{a}	87.7^{a}	94.7^{a}	90.3^{a}
	10	87.6^{a}	80.7^{a}	81.2^{a}	87.4^{a}
Lodgepole pine	1	96.6^{a}	86.9^{a}	89.5^{a}	87.6^{a}
	3	94.7^{a}	85.0^{a}	84.3^{a}	85.3^{a}
	5	94.0^{a}	84.7^{a}	84.3^{a}	84.4^{a}
	10	89.5^{a}	80.9^{a}	78.1^{a}	82.1^{a}

Note: Within each row, means followed by the same letters are not significantly different ($p \leqslant .05$).

bullet-plug seedlings. Climatic data in Table 2 indicate that the establishment year of planting (1970) was generally warmer and wetter than normal, except for a moisture deficit in August and a slight drop in temperature in September. It is probable that conditions for establishment of the seedlings were better than normal, and this may explain the relatively high survival rates encountered.

Styroplugs invariably produced the best survival rates by the tenth year, followed by bare-root seedlings and then by bullets and bullet-plugs (for Douglas-fir and lodgepole pine) or bullet-plugs and bullets (for white spruce). Data in Table 1 show that seedlings grown in bullets were physically smaller than bare-root or styroplug stock. This may have put them at a disadvantage when outplanted in terms of their ability to resist vegetative competition. Such competition was a common cause of mortality among all species in the first growing season.

Survival of Douglas-fir was considerably lower than that of lodgepole pine or white spruce, regardless of container type. It was noted by Van Eerden (1972) that this location approaches the northern limit of the range of Douglas-fir and consequently this species may have had difficulty in adapting to the site.

Table 4 summarizes height growth by species and container type. Bare-root seedlings generally had faster growth rates and were the tallest seedlings by the tenth year. There were two exceptions. Douglas-fir styroplug seedlings outgrew their bare-root counterparts by the first assessment. This result was likely due to the initial size difference between the stock types, as indicated in Table 1. Thereafter the bare-root seedlings assumed dominance over styroplugs in terms of height growth. Between the fifth and tenth years, lodgepole pine styroplugs grew faster than the bare-root seedlings, but by year 10 there was no significant difference in height between these stock types (Table 4). Bare-root seedlings maintained a consistently significant height advantage over bullets and bullet-plug seedlings except in the case of Douglas-fir, where the average height of bullet-plug seedlings by year 10 was not significantly different from that of bare-root seedlings.

Bullet-plugs invariably exhibited faster growth rates and produced taller seedlings than bullets, although differences were rarely significant. Styroplugs, initially larger than bullet grown stock, continually outgrew both bullet and bullet-plug seedlings of all species. However, lodgepole pine was the only species in which the average height of

Table 4. Summary of height growth (cm) of Douglas-fir, white spruce and lodgepole pine by stock type

Species	Years from planting	Stock type			
		Styroplug	Bullet	Bullet-plug	Bare-root
Douglas-fir	1	18.9^{a}	10.8^{b}	11.5^{b}	17.1^{a}
	3	25.5^{a}	14.8^{b}	16.3^{b}	28.9^{a}
	5	36.7^{ab}	21.7^{c}	26.0^{bc}	44.0^{a}
	10	103.6^{ab}	81.8^{b}	92.6^{ab}	130.9^{a}
White spruce	1	16.7^{b}	12.6^{c}	13.0^{c}	20.2^{a}
	3	27.1^{b}	19.2^{c}	23.6^{b}	36.6^{a}
	5	39.3^{b}	28.5^{b}	34.9^{b}	54.6^{a}
	10	113.6^{b}	88.1^{b}	99.2^{b}	150.0^{a}
Lodgepole pine	1	17.7^{a}	14.2^{b}	14.0^{b}	18.3^{a}
	3	41.3^{b}	30.3^{c}	32.6^{c}	52.0^{a}
	5	82.4^{b}	62.3^{d}	71.8^{c}	99.9^{a}
	10	297.1^{a}	248.2^{b}	265.7^{b}	302.0^{a}

Note: Within each row, means followed by the same letters are not significantly different ($p \leqslant .05$).

styroplugs was significantly higher by year 10 than that of bullet and bullet-plug seedlings.

Table 5 presents a summary of first-year survival of all species by container type and planting date. Planting date produced little significant variation in survival within species. Seedlings planted in June tended to have a somewhat higher mortality rate than seedlings planted later in the season. The author suggests that June-planted stock underwent the dual stress of having to establish root-soil contact at the same time that it was initiating shoot activity. Tinus (1974) states that it is preferable for shoots of seedlings to be dormant during the initial establishment phase because if shoots are actively flushing, food reserves within a seedling are generally utilized to support the flush, and root extension, critical to successful seedling establishment, is minimal. Stock planted Later in the season would not likely have flushed that year, thereby allowing for better root establishment prior to the next shoot extension period.

Arnott (1972) states that, for container-grown trees, the single most important factor affecting seedling mortality and early growth rate in similar trials under coastal conditions was the removal of the container at the time of planting. The results of this study tend to substantiate this, though perhaps not as definitively. Styroplug seedlings consistently, though not significantly, achieved the highest survival rates coupled with the second best growth rates, regardless of species. On the other hand, bullet seedlings exhibited the poorest growth rates together with either third best or lowest survival. The data also indicate that the styroblock container produced a better seedling for planting purposes than did the bullets. Simple removal of the container at planting, as was done to create bullet-plug seedlings, did not necessarily achieve greater performance. Survival of bullet plugs was never significantly greater than that of bullets, and for Douglas-fir and lodgepole pine it was lower than that of the bullets by year 10. Bullet-plugs maintained growth rates superior to those of bullet seedlings throughout the trial, but the differences were rarely significant and, by the tenth year, were not statistically significant for any species.

Reforestation systems such as the styroblock and bare-root systems were designed partly to produce seedlings with root systems which would quickly establish contact with,

Table 5. First-year survival of Douglas-fir, white spruce and lodgepole pine by planting date and stock type (%)

Species	Stock type	Time of planting			
		June	July	August	September
Douglas-fir	styroplug	85.7^{ab}	85.7^{ab}	91.4^{a}	95.2^{a}
	bullet	73.3^{ab}	82.8^{ab}	78.1^{ab}	75.3^{ab}
	bullet-plug	79.1^{ab}	79.1^{ab}	79.1^{ab}	91.7^{a}
	bare-root	64.3^{b}	93.1^{a}	76.2^{ab}	89.5^{a}
White spruce	styroplug	92.3^{a}	99.0^{a}	96.1^{a}	100.0^{a}
	bullet	75.8^{a}	97.1^{a}	93.3^{a}	98.1^{a}
	bullet-plug	91.7^{a}	91.7^{a}	100.0^{a}	100.0^{a}
	bare-root	82.8^{a}	94.3^{a}	96.1^{a}	100.0^{a}
Lodgepole pine	styroplug	93.3^{a}	98.0^{a}	97.1^{a}	98.1^{a}
	bullet	75.2^{a}	96.1^{a}	83.8^{a}	92.4^{a}
	bullet-plug	87.5^{a}	87.5^{a}	83.3^{a}	100.0^{a}
	bare-root	82.8^{a}	89.5^{a}	85.7^{a}	92.4^{a}

Note: Within each row, means followed by the same letters are not significantly different ($p \leqslant .05$).

and extend into, the soil. The generally slower growth rates and lower survival of bullet seedlings may be due, in part, to the fact that the roots of these plants are almost totally encapsulated by the container at planting and have little initial contact with the soil (Van Eerden 1978). Subsequent root egress into the soil may occur only from the side slits or drainage holes at the base of the container. Roots of container-free seedlings have immediate contact with the soil and experience less restriction of root extension into the surrounding soil.

Long (1978) and Arnott (1978) concluded that reforestation systems influence survival and growth for a relatively short time following planting. Data from this study indicate that the influence of containers on survival does not generally last beyond the first growing season, except for Douglas-fir, where final relationships between stock types were not determined until after the third growing season. It must be stressed, however, that survival of Douglas-fir in this study may have been influenced by other ecological factors resulting from the fact that the study area is close to the northern limit for this species.

Height relationships between container types (excluding bare-root stock) tended to stabilize after three growing seasons; however, early differences in height may be related as much to differences in initial size at planting as to container influence (Arnott 1978). Given this and the observation that stock type had no significant influence on survival of lodgepole pine and white spruce, it may be concluded that all reforestation systems employed in the study were successful in facilitating adaptation of the seedlings to the environment in which they were planted. In view of the fact that the bare-root seedlings used in the study were one or two years older than the containerized stock, and always larger, it may also be concluded that container-grown seedlings (especially the styroplugs) are capable of survival and height growth rates comparable with or superior to those of bare-root seedlings.

It should be noted that neither container type studied here is currently in use. The unribbed BC/CFS styroblock-2 has been replaced by the ribbed model 2A, and the 11 cm Walters bullet model used in the study has not been in general use for several years. This study is important as a contribution to the development of container systems and should be looked upon as an affirmation of the concept of containerization as a workable reforestation alternative, rather than as a statement of superiority of one system over another.

SUMMARY

1. Styroplug seedlings produced the highest survival rates of any of the stock types tested.
2. Bare-root stock produced the tallest seedlings of the study, but styroplug seedlings achieved comparable average heights despite the initial size advantage of the former.
3. Seedlings planted with container removed tended to achieve higher survival and faster growth rates than those planted

with the container still encasing the roots.

4. Container influence on survival and growth does not appear to last beyond the third growing season.

5. Planting container-grown seedlings and bare-root seedlings (using a mixture of cold-stored and fresh-lifted stock) throughout the growing season proved feasible for the Prince George region, provided that moisture conditions were near or above normal.

LITERATURE CITED

Arnott, J.T.
1971. Progress report on field performance of Douglas-fir and Western hemlock container seedlings on Vancouver Island, British Columbia. Dep. Environ., Can. For. Serv., Victoria, B.C. Inf. Rep. BC-X-63, 59 p.

Arnott, J.T.
1972. Influences affecting container seedling performance on Vancouver Island, British Columbia. p. 84-91 in Waldron, R.M., *Ed.* Proceedings of a Workshop on Container Planting in Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. DPC-X-2.

Arnott, J.T.
1978. Root development of container-grown and bare-root stock: Coastal British Columbia. p. 257-266 in Van Eerden, E. and Kinghorn, J.M., *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv., Joint Rep. No. 8.

Kinghorn, J.M.
1972. Container planting program at the Pacific Forest Research Centre. p. 7-14 in Waldron, R.M., *Ed.* Proceedings of a Workshop on Container Planting in Canada Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. DPC-X-2.

Long, J.M.
1978. Root system form and its relationship to growth in young planted conifers. p. 222-234 in Van Eerden, E., and Kinghorn, J.M., *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8.

Rowe, J.S.
1972. Forest regions of Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Publ. No. 1300. 172 p.

Sjoberg, N.E.
1974. The Styroblock container system. p.217-228 in R.W. Tinus, W.I. Stein, and W.E. Balmer *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Tinus, R.W.
1974. Characteristics of seedlings with high survival potential. p. 276-282 in R.W. Tinus, W.I. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Van Eerden, E.
1972. Influences affecting container seedling performance near Prince George, British Columbia. p. 92-100 in Waldron, R.M., *Ed.* Proceedings of a Workshop on Container Planting in Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. DPC-X-2.

Van Eerden, E.
1978. Roots of planted trees in central British Columbia. p. 201-208 in Van Eerden, E. and Kinghorn, J.M., *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8.

Walters, J.
1969. Container planting of Douglas-fir. For. Prod. J. 19(10):10-14.

SIZE OF CONTAINER-GROWN SEEDLINGS SHOULD BE MATCHED TO SITE CONDITIONS

R.G. McMinn'

Abstract.--Trials with container-grown white spruce *(Picea glauca* [Moench] Voss) under different site conditions in the Sub-Boreal Spruce Zone of British Columbia showed that stock size and site condition significantly affected survival and growth and that stock size can and should be matched to site conditions. Large stock without site treatment may be a feasible alternative to small stock plus site treatment. The use of a seedling size appropriate to the density of competing vegetation should result in cost savings. Container-grown stock must reach size and quality standards consistent with the size of container used if performance is to meet expectations.

Résumé.--À la suite d'essais faits avec des plants d'épinette blanche en mottes emballées *(Picea glauca* [Moench] Voss), dans le centre-nord de la Colombie-Britannique, on a constaté qu'il y avait un rapport entre la grosseur du matériel de reproduction et l'état de l'emplacement. Les petits plants se développaient mal sauf si l'emplacement avait été traité de façon à empêcher la végétation de leur faire concurrence. Les gros plants se développaient bien dans les emplacements qui n'avaient pas été traités. On a constaté expérimentalement qu'on pouvait faire correspondre la grosseur des plants à l'état de l'emplacement.

INTRODUCTION

Successful plantation establishment depends primarily on type and condition of planting stock, planting quality, condition of site and weather at time of, and shortly after, planting. This paper, which is based on results from trials with 1-0 styroplug white spruce *(Picea glauca* [Moench] Voss) in the Sub-Boreal Spruce Zone (Krajina 1965) of the north central interior of British Columbia, discusses interactions between stock size and site condition.

Trials were established east of Prince George between 1972 and 1979 in randomized blocks, with the same spruce seed lot being used in any one trial. Measurements made at intervals since planting were analyzed by the Newman-Student-Keuls multiple range test and have been presented in various preliminary reports (Dobbs 1976, McMinn and Homoky 1977, McMinn and Van Eerden 1977, McMinn 1978, 1980).

SURVIVAL AND GROWTH OF CONTAINER-GROWN STOCK

White spruce seedlings which have been grown in small containers (styroplug-2)[2] usually perform poorly following outplanting on untreated sites with high potential for dense competing vegetation. They are readily smothered when snow presses vegetation down at the end of the growing season and growth of surviving seedlings is usually slow. Survival and growth can be improved by bull-

---

[1] Forest Ecologist, Pacific Forest Research Centre, Canadian Forestry Service, Victoria, British Columbia.

[2] Styroplug-2, -4 and -8 containers have nominal volumes of 40, 80 and 125 ml (2, 4 and 8 in^3), respectively.

dozer-blade scarification (Table 1). Blade scarification controls competing vegetation (Fig. 1) by removing plant roots, together with surface organic matter and the uppermost mineral soil. Reduction of shading vegetation and exposure of mineral soil by removing surface organic matter enhance soil temperature (Fig. 2) within the range favorable for tree seedling growth (Fig. 3).

Table 1. Performance of styroplug-2 white spruce seedlings after 10 growing seasons in untreated and blade-scarified plots[a].

Treatment	Survival[b] (%)	Height (cm)	Stem volume[c] (ml)
Untreated	76	181	528
Scarified	87	199	653

[a] Values in each column differ significantly ($p = 0.05$).

[b] Values based on 120 seedlings planted.

[c] Height times one-third area of base.

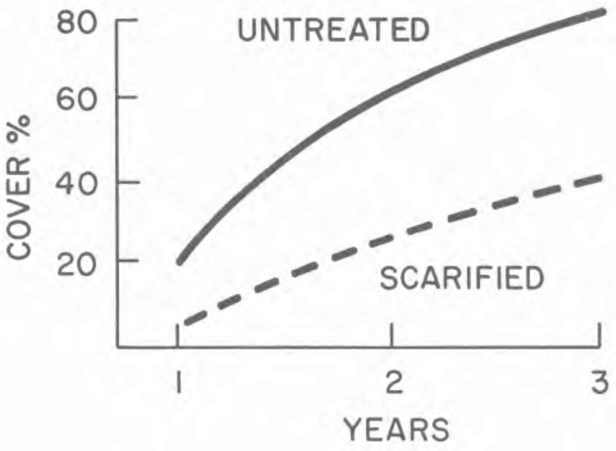


Figure 1. Change in density (% cover) of competing vegetation on untreated and bulldozer-blade scarified sites with time since clearcutting or treatment.

The type of site treatment can influence performance of container-grown stock, especially in fine-textured soils. Although blade scarification enhances soil temperature, surface organic matter is pushed aside so that its inherent fertility is beyond the immediate reach of planted seedlings. This fertility can be retained by mixing competing vegetation and surface organic matter with the underlying mineral soil to form a new organic-matter-enriched surface horizon. Styroplug-2 seedlings planted in sites prepared by such a mixing treatment grew better than seedlings planted in scalped sites left by blade scarification (Table 2). Roots of competing vegetation were sufficiently comminuted by the mixing treatment to control vegetation effectively.

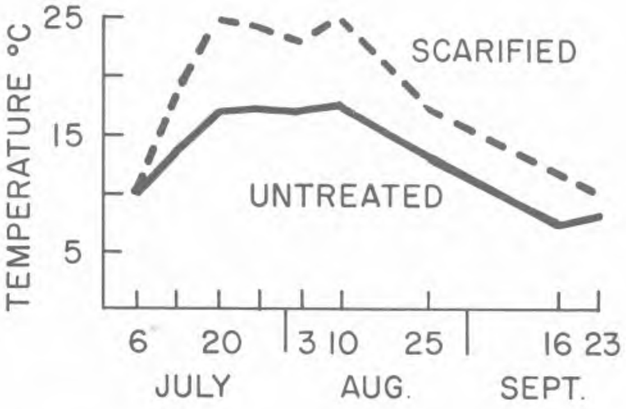


Figure 2. Seasonal change in afternoon (1500 to 1700 hr) soil temperature at 5 cm depth on untreated and bulldozer-blade scarified sites (Dobbs and McMinn 1973).

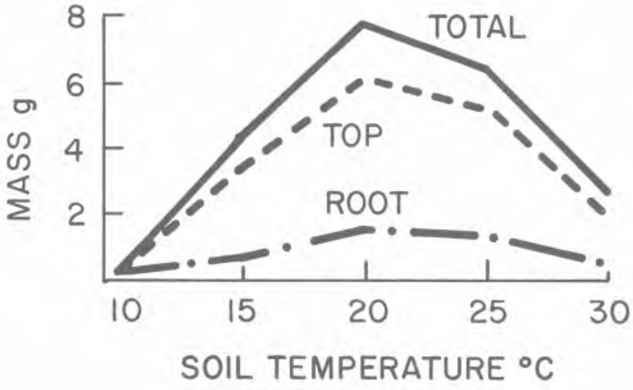


Figure 3. Dry mass of white spruce seedlings grown at various root temperatures for 17 weeks (Dobbs and McMinn 1977).

Trial results indicated that large stock can be an alternative to small stock plus site treatment (Table 3). Styroplug-8 white spruce seedlings grew better in untreated plots with heavy competition potential than did styroplug-2 stock in plots where vegetation was controlled by blade scarification. In this experiment, conducted in a fine-

Table 2. Performance of styroplug-2 white spruce seedlings after seven growing seasons in untreated, blade-scarified and mixing-treatment plots on a fine-textured soil[a].

Treatment	Survival[b] (%)	Height (cm)	Stem volume[c] (ml)
Untreated	93a	122a	152a
Scarified	97a	110a	113a
Mixing	99a	141b	208b

[a]Values in each column followed by same letter do not differ significantly (p = 0.05).
[b]Values based on 150 seedlings planted.
[c]Height times one-third area of base.

textured soil, blade scarification did not improve performance of the larger stock. Although styroplug-8 seedlings responded well to the mixing treatment, economic analysis based on long-term performance would be needed to show whether the extra cost of the larger stock plus mixing treatment would be justified. Large stock without site treatment or small stock with mixing treatment provided gains in total mass of 50 to 100% at the end of five growing seasons over small stock that had no treatment or blade scarification (Table 3).

Table 3. Oven-dry mass of styroplug-2 and -8 white spruce seedlings at planting and after five growing seasons in variously treated, fine-textured soils[a].

Stock Treatment	At planting[b] Root mass (g)	At planting[b] Total mass (g)	At 5 years[b] Root mass (g)	At 5 years[b] Total mass (g)
Styroplug-2				
Untreated	0.7a	1.6a	12.4a	98a
Scarified			16.6a	83a
Mixing			20.0b	146b
Styroplug-8				
Untreated	1.6b	3.2b	23.9bc	168c
Scarified			16.6a	104d
Mixing			29.3c	212e

[a]Values in each column followed by same letter do not differ significantly (p = 0.05).
[b]Values based on 30-seedling sample.

In comparison with stock planted immediately following clearcutting (Table 4: i. Recently cut site), each of the three sizes of container-grown stock tested exhibited reduced growth when planting was delayed for two years following clearcutting (Table 4: ii. Backlog site). The density of competing vegetation at time of planting on the backlog site was considerably greater than that on the recently cut site. The styroplug-4 stock performed about as well on the recently cut site as did the styroplug-8 stock on the backlog site. This performance comparison shows that planting untreated sites immediately after clearcutting could result in cost saving because styroplug-4 stock is cheaper to produce than styroplug-8 stock. The use of styroplug-4 stock on backlog sites which are already occupied by dense competing vegetation would seem economically questionable, however, because performance of styroplug-4 stock could well be poor. The low stem volume of the styroplug-2 stock on both sites (Table 4) suggests that planting styroplug-2 white spruce seedlings without site preparation on sites with potential for dense com-

Table 4. Parameters for styroplug-2, -4 and -8 white spruce seedlings at planting and after two growing seasons in untreated, recently cut and backlog (cut 2 years previously) sites[a].

Stock	At time of planting[b] Height (cm)	At time of planting[b] Root mass (g)	At time of planting[b] Total mass (g)
Styro-2	16a	0.2a	0.8a
Styro-4	20b	0.4b	1.5b
Styro-8	22c	0.6c	2.1c

	After two growing seasons[c] Survival (%)	After two growing seasons[c] Height (cm)	After two growing seasons[c] Stem volume[d] (ml)
i. Recently cut site			
Styro-2	91a	28a	1.6a
Styro-4	96a	35b	2.7b
Styro-8	99b	40c	4.7c
ii. Backlog site			
Styro-2	94a	25d	0.8d
Styro-4	92a	31e	1.7a
Styro-8	93a	37f	2.9b

[a]Values in each column followed by same letter do not differ significantly (p = 0.05)
[b]Values based on 50-seedling sample.
[c]Values based on 250 seedlings planted.
[d]Height times one-third area of base.

peting vegetation would be false economy even though styroplug-2 stock has the lowest production cost of any of the styroplug stocks tested.

Data appear to be lacking for the Sub-Boreal Spruce Zone to indicate whether large or small seedlings from the same styroblock might perform differently following outplanting. However, results from a trial with different sizes of 2-1 bare-root transplants lifted from the same nursery bed suggest that different performances can be expected (Table 5). Transplants from shipping boxes filled from the same nursery bed following routine culling procedures were regraded into small and large on the basis of mass. After three growing seasons, it was evident that small transplants had performed so poorly that they were of dubious value for reforestation. Performance differences between large and small transplants might have been predicted from differences in root growth capacity at time of planting. These results suggest that discrimination in culling standards to discard poor seedlings in styroblocks might be advisable. Differences in size among seedlings in the same styroblock may be at least partially under genetic control because growing conditions in any given size of styroblock are relatively uniform.

The use of large containers to obtain improved survival and growth presupposes that the seedlings will have reached size standards which justify the cost of using such containers. White spruce seedlings which had not fully utilized styroplug-4 containers performed no better than styroplug-2 stock in either untreated or mixing-treatment planting spots (Table 6). Stock of both sizes performed better in mixing-treatment planting spots than in untreated plots. Relative performance of substandard-sized[3] styroplug-2 stock with respect to 2-1 "reclaims"[4] did, however, differ according to site treatment. The larger initial mass of the 2-1 reclaims

Table 5. Parameters for 2-1 bare-root white spruce transplants regraded into large and small at planting and after three growing seasons in untreated, recently cut and backlog sites[a].

	At time of planting[b]			
Stock	Height (cm)	Root mass (g)	Total mass (g)	R.G.C. Class[c]
Small	20	3.8	9.8	1.75
Large	33	6.5	22.3	3.18

	After three growing seasons[d]		
	Survival (%)	Height (cm)	Stem volume[e] (ml)
i. Recently cut site			
Small	65	37	7.6
Large	86	57	21.7
ii. Backlog site			
Small	30	33	3.6
Large	60	52	13.2

[a] All values in each column significantly different (p = 0.05).
[b] Values based on 50-seedling sample.
[c] Root growth capacity class (Burdett 1979).
[d] Values based on 250 seedlings planted.
[e] Height times one-third area of base.

Table 6. Parameters for "substandard" styroplug and "reclaim" bare-root white spruce stock, at planting, and after five growing seasons in mixing treatment and untreated, backlog sites[a].

	At planting[b]		At 5 years[c]		
Stock	Height (cm)	Mass (g)	Survival (%)	Height (cm)	Stem volume (ml)
i. Untreated site					
Styro-2	7a	1.09a	67a	35a	4.6a
Styro-4	9b	1.34a	70a	35a	4.8a
Bare-root	13c	3.37b	64a	40b	6.6b
ii. Mixing treatment site					
Styro-2	7a	1.09a	97b	55c	20.4c
Styro-4	9a	1.34a	96b	55c	18.2cd
Bare-root	13c	3.37b	92b	50d	15.7d

[a] Values in each column followed by same letter do not differ significantly (p = 0.05).
[b] Values based on 50-seedling sample.
[c] Values based on 190 seedlings planted.
[d] Height times one-third area of base.

---

[3] Smaller than expected for the container size used.

[4] Reclaims are transplants which are too small for outplanting at the 2-0 stage so are transplanted in the expectation that they will be large enough for outplanting a year later.

seems to have been advantageous under the competitive conditions of the untreated site, but not in the mixing treatment site where even substandard-sized styroplugs performed better than 2-1 bare-root reclaims. These results suggest that the practice of reclaiming small 2-0 stock at the end of the growing season might be viewed critically lest a significant amount of genetically inferior stock be introduced into planting sites.

Table 7 compares the performance of various sizes of styroplug white spruce seedlings with 2-0 and 2-1 (not reclaims) bare-root stock on an untreated, recently cut site with heavy competition potential. The height of styroplug-2 and -4 stock after two growing seasons was comparable with that of 2-0 and 2-1 bare-root stock, respectively. The stem volume of styroplug-4 seedlings was comparable with that of the 2-0 bare-root seedlings, which is impressive because the bare-root seedlings had twice the mass of the styroplug-4 seedlings at the time of planting. Although stem volume of the styroplug-8 seedlings after two growing seasons was less than that of the 2-1 transplants (which had much greater mass at time of planting), height was greater. These data suggest that styroplug-8 seedlings, which take only one year to grow, may be interchangeable with 2-1 transplants where larger stock is required.

Table 7. Parameters for styroplug and bare-root white spruce stock, at planting, and after two growing seasons, in an untreated, recently cut site[a].

	At planting[b]		After 2 years[c]		
Stock	Height (cm)	Mass (g)	Survival (%)	Height (cm)	Stem volume[d] (ml)
Styro-2	16a	0.76a	91a	28a	1.6a
Styro-4	20b	1.46b	96a	35b	2.7b
Styro-8	22c	2.11c	99b	40c	4.7c
2-0	20b	3.07d	88a	29a	2.7b
2-1	21c	10.60e	90a	33b	5.8d

[a] Values in each column followed by same letter do not differ significantly ($p = 0.05$).

[b] Values based on 50-seedling sample.

[c] Values based on 250 seedlings planted.

[d] Height times one-third basal area.

CONCLUSIONS

Results from trials with container-grown white spruce seedlings in the Sub-Boreal Spruce Zone of British Columbia showed that survival and growth are affected by both size of stock and condition of site. The following points were demonstrated.

1. Seedlings raised in small containers may perform poorly following outplanting on sites with potential for dense competing vegetation unless such vegetation is controlled by site treatment.
2. Performance of container-grown seedlings in fine-textured soils prepared by biologically favorable site treatments which retain the fertility inherent in surface organic matter available to seedlings can be superior to that of seedlings in soils prepared by scalping site treatments.
3. Container-grown seedlings raised in large containers may be substituted for site treatment where or when site treatment is not feasible.
4. Container-grown seedlings raised in large containers may be an alternative to 2-1 bare-root transplants where large stock is needed.
5. Performance of container-grown seedlings will be poorer than expected if seedling size is substandard for the size of container used or if seedling quality (e.g., root growth capacity) is poor.
6. Cost savings may be possible by the use of seedlings grown in containers of a size commensurate with that needed to perform satisfactorily at the density of competing vegetation to be expected on a given site.
7. If planting is delayed following clearcutting, larger container-grown stock is needed because the density of competing vegetation increases with increasing time since clearcutting.
8. Since growing conditions in styroblocks are relatively uniform, size differences among container-grown seedlings raised in a given size of styroblock may be at least partially under genetic control; the small-sized seedlings in a styroblock consequently may be unsuitable for outplanting.

The relationships found show that size of container-grown stock can and should be matched to site conditions.

LITERATURE CITED

Burdett, A.N.
1979. New methods for measuring root growth capacity: their value in assessing lodgepole pine stock quality. Can. J. For. Res. 9:63-67.

Dobbs, R.C.
1976. Effect of initial mass of white spruce and lodgepole pine planting stock on field performance in the British Columbia interior. Dep. Environ., Can. For. Serv., Victoria, B.C. Inf. Rep. BCX-149. 14 p.

Dobbs, R.C., and McMinn, R.G.
1973. The effects of site preparation on summer soil temperature in spruce-fir cutovers in the British Columbia Interior. Dep. Environ., Can. For. Serv., Ottawa, Ont. Bi-mon. Res. Notes 29:6-7.

Dobbs, R.C. and McMinn, R.G.
1977. Effects of scalping on soil temperature and growth of white spruce seedlings. p. 66-73 in T.A. Black et al., Ed. Energy, Water and the Physical Environment. 6th Soil Sci. Workshop Rep., B.C. Min. Agric., Victoria, B.C.

Krajina, V.J.
1965. Bioclimatic zones and classificaton of British Columbia. p. 1-34 in V.J. Krajina, *Ed.* Ecology of western North America. Univ. B.C., Bot. Dep., Vancouver, B.C.

McMinn, R.G.
1978. Root development of white spruce and lodgepole pine seedlings following outplanting. p. 186-190 in E. Van Eerden and J.M. Kinghorn, *Ed.* Proc. Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv., Jt. Rep. No. 8, Victoria, B.C.

McMinn, R.G.
1980. Root growth capacity and field performance of various types and sizes of white spruce stock following outplanting in the central interior of British Columbia. p. 37-41 in H. Schmidt-Vogt, *Ed.* Characterization of Plant Material. Proc. IUFRO Meeting Working Group S1.05-04. Freiburg, West Germany.

McMinn, R.G. and Homoky, S.G.
1977. Biological effectiveness of equipment tested in silvicultural-mechanical site preparation trials. Dep. Environ., Can. For. Serv., Victoria, B.C., File Rep., Study PC-21-111. 18 p.

McMinn, R.G. and Van Eerden, E.
1977. Response of white spruce and lodgepole pine seedlings to various site treatment options. Dep. Environ., Can. For. Serv., Victoria, B.C., File Rep., Study PC-21-111. 9 p.

PRODUCTION, USE, AND FIELD PERFORMANCE OF CONTAINER SEEDLINGS IN THE PRAIRIE PROVINCES

W.J. Ball and L.G. Bracel

Abstract.--Data on the production, use, and field performance of container seedlings in the prairie provinces are presented. About 10% of the area harvested is planted to container stock, 70% of which is white spruce *(Picea glauca* [Moench] Voss). Refinements in container use await application of effective operational performance assessment procedures.

Résumé.--Un exposé est présenté sur la production, l'utilisation et le comportement sur le terrain de semis en récipients dans les provinces des Prairies. La superficie cultivée comporte environ 10% de semis en récipients, dont 70% sont des semis d'épinette blanche *(Picea glauca* [Moench] Voss). On attend l'application de méthodes efficaces d'évaluation des opérations avant de raffiner l'utilisation des récipients.

INTRODUCTION

The ultimate test of any regeneration method or material lies in the field performance of the new forest crop. In the case of container stock in the prairie provinces (Alberta, Saskatchewan and Manitoba), there are few available operational results from which to draw performance conclusions. However, there are some research results that can be interpreted and applied to illustrate container performance potential.

This report presents a region-wide view of the production, use, and field performance of container stock in terms of the three primary commercial tree species: white spruce *(Picea glauca* [Moench] Voss), lodgepole pine *(Pinus contorta* Dougl.), and jack pine *(Pinus banksiana Lamb.).*

OVERVIEW OF REGIONAL REFORESTATION

From 1975 to 1979 the estimated total area harvested in the three prairie provinces was 281,000 ha (Table 1), of which 7% were seeded, 9% were planted to containers, 11% were planted to conventional stock, 32% were scarified for natural regeneration, and 41% were untreated.[2]

CONTAINER PRODUCTION AND USE 1975-1979

The container stock sizes that are produced vary according to species, container size, and greenhouse rearing times (Table 2). Seedling production doubled from 12.3 million in 1975 to 23.6 million in 1979. On the average, 46.4% of the stock produced during this period was grown in containers. In 1980, total planting stock production was 36.5 million seedlings, or three times 1975

---

[1] Forestry Officer and Research Scientist, respectively, Northern Forest Research Centre, Canadian Forestry Service, Edmonton, Alberta.

[2] Data aggregated from provincial estimates.

Table 1. Reforestation activities in the prairie provinces 1975-1979a.

Year	Total seedling production (000,000)	Area planted[b]	Area seeded	Area scarified for natural regeneration	Area harvested[c]
		(000 ha)			
1975	12.3	8.2	1.9	20.4	55.5
1976	15.2	10.1	3.1	13.7	48.4
1977	14.7	9.8	5.0	13.6	54.2
1978	17.8	11.9	4.8	17.3	60.1
1979	23.6	15.8	5.5	23.9	63.2
Totals	83.6	55.8	20.3	88.9	281.4

[a] Data aggregated from provincial estimates.

[b] Based on 1500 stems·ha^{-1}. An average of 72% of the planted area in the period 1975-1979 was given some kind of site preparation.

[c] Total for areas planted, seeded, naturally regenerated, and left untreated does not add up to total harvest area. For example, area planted included both burn and backlog areas.

Table 2. Types of container stock commonly used in the prairie provinces.

Species	Container[a] type	Container[a] cross-sectional area (cm^2)	Container[a] volume (cm^3)	Greenhouse rearing time[a] (wk)
White spruce Lodgepole pine	Spencer-Lemaire (Ferdinand)	3.6	40	4 - 15
White spruce Jack pine	Paperpot (FH 308)	5.6	44	12 - 15
White spruce Jack pine	Paperpot (FH 315)	5.6	88	12 - 15
White spruce Jack pine	Paperpot (FH 408)	9.8	70	12 - 15

[a] Larger sizes and longer greenhouse rearing would increase establishment costs but should also improve growth performance in the field.

production. Container production for 1980 consisted of 62% white spruce, 25% lodgepole pine, 12% jack pine and 1% black spruce, and in 1981 comprised just over 50% of the total seedling production.

Trends in regional container use during the period 1975-1979 can be inferred from production data shown in Figure 1. In general, the proportion of container stock produced was stable at 42-44% of total seedling production from 1976 to 1979; actual amounts began to increase considerably after 1977.

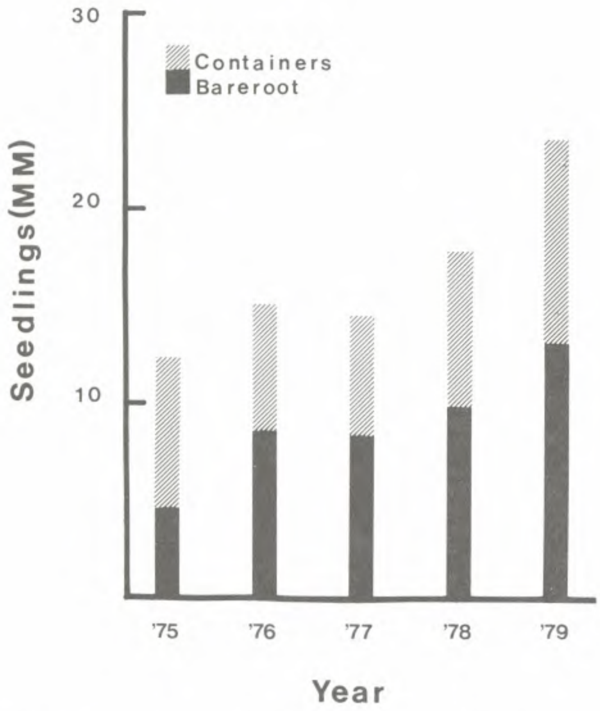


Figure 1. Trends in regional container use.

There appears to be a trend toward decreased container use for the pines and increased use for white spruce. The primary reasons for the relative decrease for pines are the suitability of lodgepole and jack pine for natural regeneration, usually following scarification, and the susceptibility of container-grown pine to root deformity and to winter storage damage in prairie nurseries and industrial storage sites.

On the other hand, the demand for container-grown spruce is likely to increase as forest management intensifies, and as refinements are made in silvicultural prescriptions to match stock size to site.

At present, container production tends to be limited to relatively small stock sizes (less than 1 g dry weight) with planting usually confined to sites with little vegetative competition; bare-root stock is usually preferred for more severe conditions of competition.

OPERATIONAL ADVANTAGES AND DISADVANTAGES OF CONTAINER STOCK

The characteristics and related advantages and disadvantages of container stock are summarized in Table 3. The information is based on the experience of the authors and comments from provincial and industrial foresters in the region.

Among the primary advantages of the use of container stock are flexibility in planning stock requirements and production timing. For example, container use eliminates the 2- to 3-year lead time for stock requirements and circumvents problems of lifting bare-root stock in the spring when ground may be frozen in bed centres and stock on bed edges begins to flush. Containers also provide good root protection in all phases of production, transportation, and planting. Greater planting productivity, improved planting quality, suitability for mechanization, and extended planting seasons are other reasons for container use.

Major disadvantages include conditioning and overwintering problems (especially with pine), root and top crowding if planting is delayed, extra space requirements for storage and shipping, and added distribution problems at the planting site. Problems with permanent root deformity and subsequent toppling with pines are minimized by planting grooved root plugs without the container and coordinating cavity size with rearing time to avoid severe root-bound situations. The high cost of producing large stock has led to a limited range of site choices because of the small seedling size currently being produced. The latter situation may change in the future if production costs for larger container stock can be justified in terms of other advantages gained in reforesting specific sites. For example, on sites where competition is too severe for slow-growing, small container stock, and where planting must be delayed until early summer because of site-related access problems, large container stock with its faster growth and good root protection may well be the key to success. Such refinements await development of regeneration prescriptions under more intensive management.

Table 3. Operational advantages and disadvantages of container stock for forest regeneration.

Stock characteristic	Advantage	Disadvantage
Produced in greenhouse environment on short production cycle	Short lead time. Flexibility in timing of production and in selection of stock and lot sizes. Minimal risk of crop loss during production.	Potential conditioning problems when removing crops from greenhouse in spring and fall. Survival and stock damage problems can develop during outside overwintering, especially for pine.
Bulky container units with upright orientation	Reduced risk of mold. Easy checking for major problems during storage and transit. Upright orientation and separation facilitates plant selection during planting.	Large storage and transportation space requirements. Increased distribution problems at planting sites. Some extra work is involved in pick-up and return of containers.
Seedlings rooted and retained in growing medium as individuals	Permits efficient use of valuable or genetically improved seed. Provides root protection in all phases of production through planting; this should result in improved survival and growth. No limitations on spring shipping time as no spring lifting is required.	Individual seedlings require intensive care. If planting is attempted too early, insufficient root development results in a weak plug that falls apart, while prolonged delays between production and planting can lead to top and root cavity crowding and reduced planting quality.
Uniform shape of container seedling root plug and small size grown under current production practices	Permits dibble planting, thereby improving planting productivity. Spacing and microsite selection are improved. Uniform, compact root mass is well suited to mechanization of planting.	Relatively low dry weight of seedlings from most current production practices limits the range of sites that can be planted. Incidence of permanent root deformity and subsequent toppling with pines.

PERFORMANCE ASSESSMENT

Operational assessment of container stock field performance in this region is in its infancy and a region-wide report is not possible. Assessments, where done, are confined mainly to survival.

Ball (1980) recommended a performance index, aimed at operational application, which combines plantation establishment costs with subsequent survival and height at 5 years.

Some regional performance results from research plantings are presented in the following section in terms of both survival and growth of container stock.

Survival

Five-year field results from research trials in Alberta show that plug-type container seedlings have better survival rates than conventional bare-root stock, particularly when planted during July and August (Walker and Johnson 1980).

If we disregard the snowshoe hare *(Lepus americanus)*, fires, severe flooding, and other disasters that can destroy all types of stock impartially, 5-year survival rates for all plug-type seedlings are high on prepared sites in Alberta and Saskatchewan. Survival data for all three species collected by the Canadian Forestry Service from several research plantations established between 1971 and 1974 based on 29,403 seedlings averaged 87% (range 75-97%) (Walker and Ball 1981).

Planting on poorly prepared or unprepared sites has been a major cause of low survival of past operational plantations in Alberta and Saskatchewan (Froning 1972). From 1975 to 1979, 40,300 ha or 72% of the area planted in this region (Table 1) was site prepared. No control of vegetative competition following planting is carried out in the region, primarily because of the lack of licensed herbicides for forestry use.

Growth

The ability of a seedling to grow cannot be inferred from its ability to survive (Zaerr and Lavender 1976). Site preparation on many sites improves growth of stock. Using a 5-year performance index, Ball (1980) calculated an average value of $1.16/m for white spruce styroblock-2 plugs on mixedwood sites in Saskatchewan in the mid-1970s. Performance was improved considerably by planting on prepared sites and by maximizing planting density to optimum levels for the species, site, and wood products concerned.

In the most comprehensive study of container seedling field performance in Alberta (and the region) Walker and Johnson (1980) found seedling size at outplanting to be the most important factor in subsequent seedling growth; larger white spruce seedlings with larger shoot:root ratios (up to 7.40) had significantly greater dry weight increases than smaller seedlings with smaller shoot: root ratios (ca. 2.00) (Fig. 2). Lodgepole pine and jack pine container seedlings showed a similar relationship.

It is not possible to aggregate growth data on container seedlings when outplanting weights vary. Data from Walker and Johnson (1980) show that relatively small additional increases in dry weights at outplanting are amplified considerably with time: mean outplanting dry weights of lodgepole pine seedlings grown in 40 cm^3 styroblock and RCA sausage containers were 0.632 and 0.417 g, respectively. (The size differences were attributed mainly to difficulty in watering the RCA sausages.) After 3 years in the field, styroblock seedlings averaged 17.2 g while sausages averaged 11.0 g. After 5 years, these weights were 110.8 and 60.3 g, respectively.

Walker and Ball (1981) showed that lodgepole pine and white spruce seedlings reared in 164-cm^3 containers for 14 weeks in the greenhouse were 106 and 84% taller, respectively, 5 years after outplanting, than seedlings reared for 4-12 weeks in 40 cm^3 containers (Fig. 3).

In a current study of lodgepole pine and white spruce reared "operationally" in 40- and 55-cm^3 Spencer-Lemaire "Rootrainers", both spruce and pine in the larger containers attained dry weights of 1000 mg--25% larger than the same species reared for the same period in smaller containers (Fig. 4). This indicates the potential for heavier stock production in the larger container when greenhouse rearing periods exceed 13 weeks. Spruce also showed generally increased height growth in the large container.

SUMMARY AND CONCLUSIONS

The main tree species produced in containers for the purpose of forest regeneration in the prairie provinces are white spruce, lodgepole pine, and jack pine. Over the period 1975 to 1979 about 20% of the regional cutovers were planted, 9% with container stock.

Operational container performance assessments are not well established in the prairie provinces; however, operational advantages and disadvantages of container stock over bare-root stock can be summarized from regional experience (Table 3).

Regional research on container seedling survival in Alberta indicates that plug-type container stock has better survival rates than bare-root stock, especially during July and August (Walker and Johnson 1980). Five-year survival figures for a total of over 29,000 container seedlings studied on a variety of sites in Alberta and Saskatchewan between 1971 and 1974 averaged 87% (Walker and Ball 1981). Inadequate site preparation and lack of competition control after planting are two major factors reducing container survival.

Research on container growth has shown that seedling growth is directly related to degree of site preparation and seedling weight at time of planting. There is a tendency for relatively small dry weight advantages at the time of outplanting to be amplified over time in terms of superior growth.

In the future, refined prescriptions that match stock type and size to site may help to justify higher production costs of larger container stock, especially when their other advantages for particular sites and operating conditions are taken into consideration.

Container use is well established in the prairie provinces but is still not refined to the point at which type and size of container are being most effectively matched to

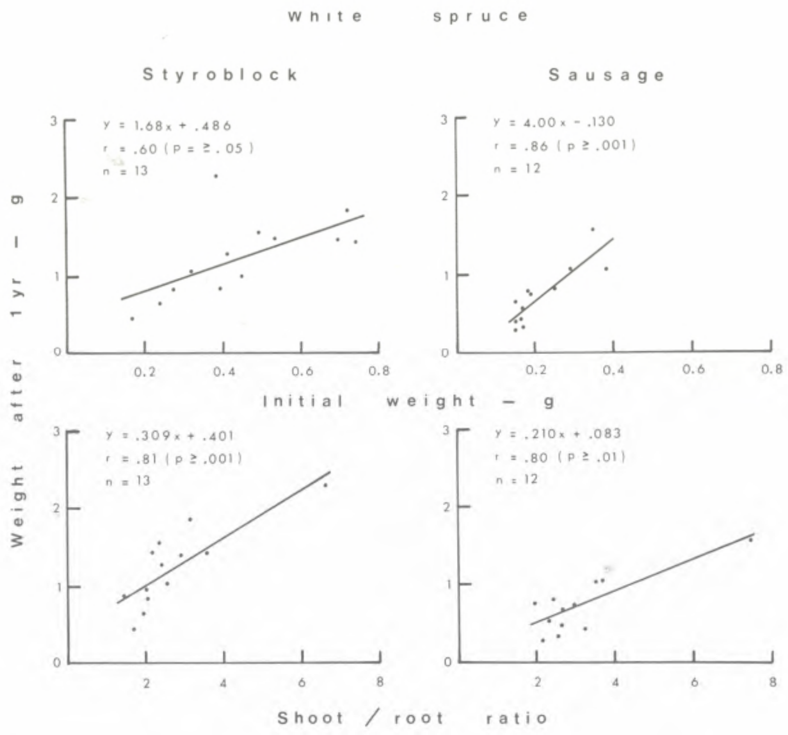


Figure 2. Relationships between seedling weight after 1 year and initial weight or shoot:root ratio (from Walker and Johnson 1980).

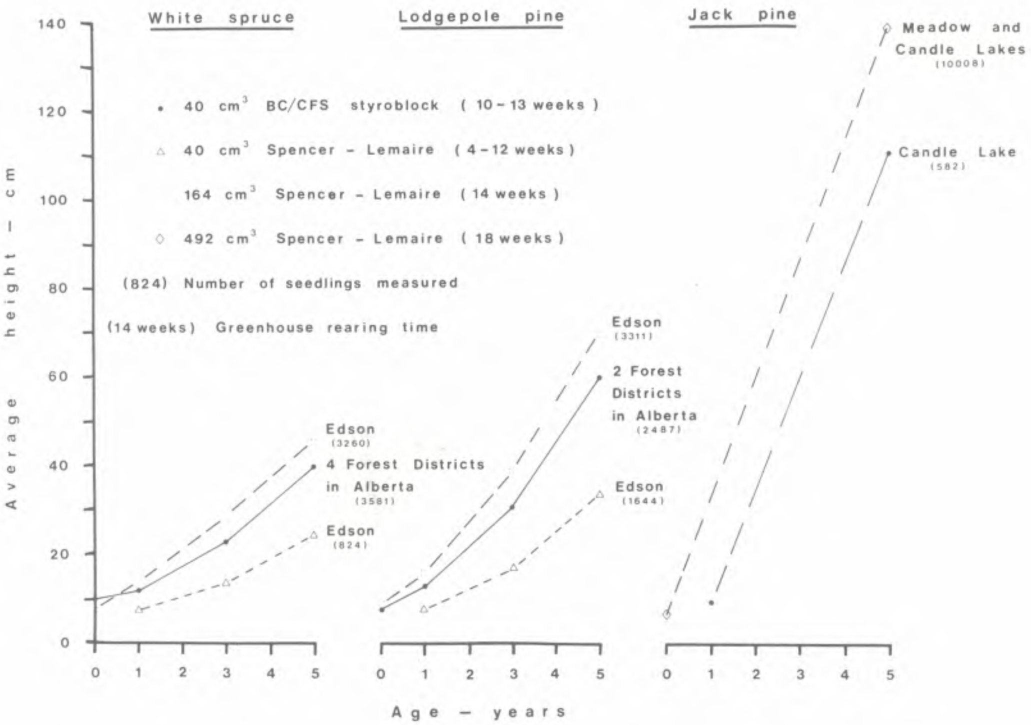


Figure 3. The effects of container size and rearing time on seedling height 1-5 years after planting (from Walker and Ball 1981).

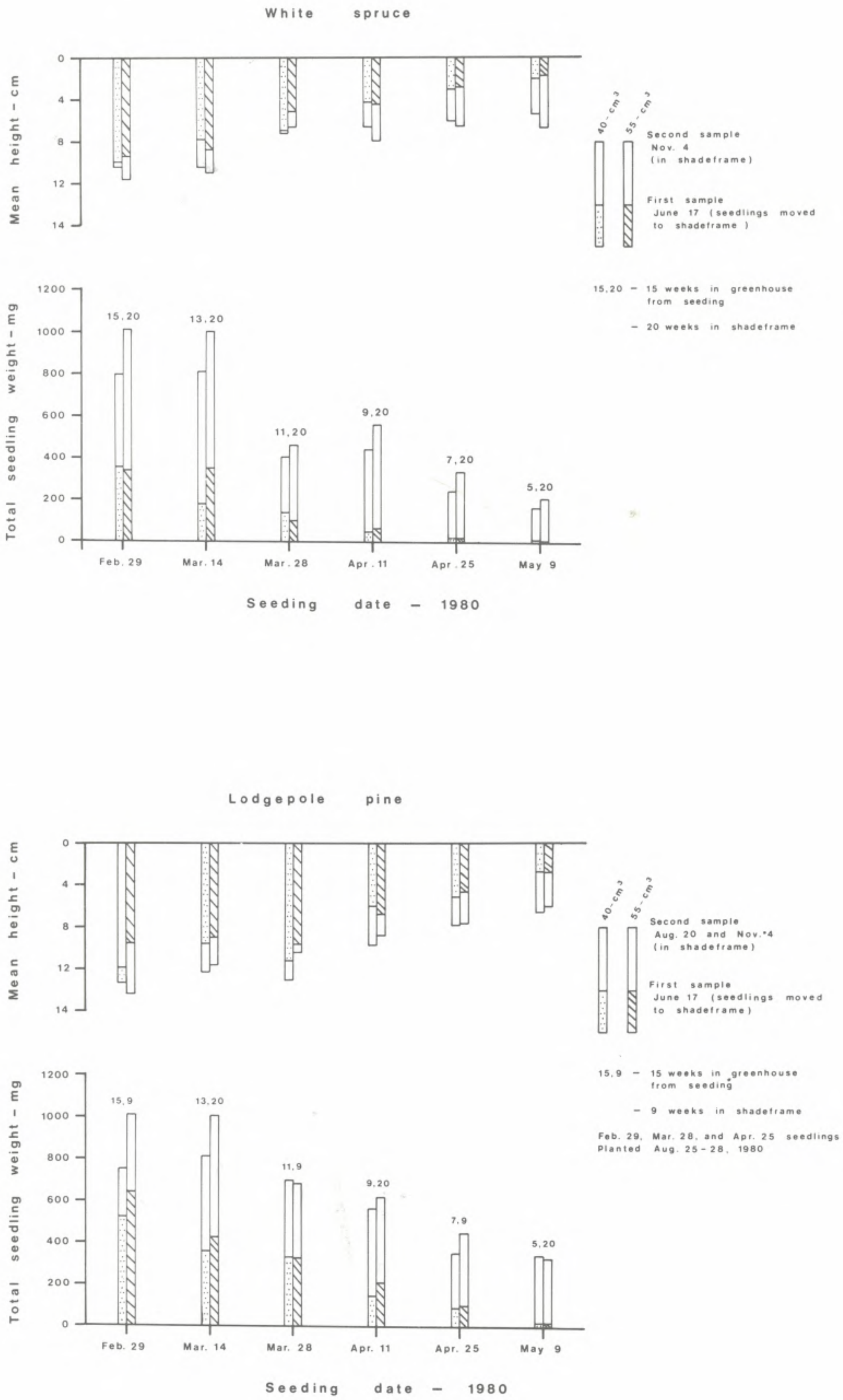


Figure 4. The effect of greenhouse rearing time on total weight and mean height for two sizes of white spruce (top) and lodgepole pine (bottom) container seedlings.

site. There is a need for operational field performance assessment to provide feedback necessary for refining the operational application of various container types.

LITERATURE CITED

Ball, W.J.
1980. Plantation performance in perspective. Dep. Environ., Can. For. Serv., Edmonton, Alta., For. Manage. Note 4.

Froning, K.
1972. An appraisal of recent plantations in forests of the prairie provinces. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-31.

Walker, N.R. and Johnson, H.J.
1980. Containerized conifer seedling field performance in Alberta and the Northwest Territories. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-218.

Walker, N.R. and Ball, W.J.
1981. Larger cavity size and longer rearing time improve container seedling field performance. Dep. Environ., Can. For. Serv., Edmonton, Alta., For. Manage. Note 6.

Zaerr, J.B. and Lavender, D.P.
1976. Size and survival of 2-0 Douglas-fir seedlings. Oregon State Univ., Corvallis. Res. Pap. 32.

COMPARATIVE FIELD PERFORMANCE OF PAPERPOT AND BARE-ROOT PLANTING STOCK IN NORTHEASTERN ONTARIO

C.R. Mattice, R.P.F.[1]

Abstract.--Between 1974 and 1980 numerous experimental plantings were established in northeastern Ontario to compare the biological performance of black spruce *(Picea mariana* [Mill.] B.S.P.), white spruce *(Picea glauca* [Moench] Voss), and jack pine *(Pinus banksiana* Lamb.) paperpot and bare-root planting stock. Morphological specifications of the various stock types at planting, and seedling survival and height growth after one to five growing seasons, are presented and compared.

Résumé.--Entre 1974 et 1980, on a établi un grand nombre de plantations expérimentales dans le nord-est de l'Ontario afin de comparer les caractéristiques biologiques de plants d'épinette noire *(Picea mariana* [Mill.] B.S.P.), d'épinette blanche *(Picea glauca* [Moench] Voss) et de pin gris *(Pinus banksiana* Lamb.) en pots de carton et à racines nues. On présente et on compare les caractéristiques morphologiques des divers matériels au moment de leur plantation ainsi que le taux de survie et la croissance en hauteur des jeunes pousses après une à cinq saisons de croissance.

INTRODUCTION

Ever since 1966 when Ontario initiated an operational containerized tree planting program, which featured the use of small temporary greenhouses and styrene tubelings, there has been debate over the role of containerized trees in the provincial planting program. Resolution of this debate requires reliable information on the comparative biological performance of containerized and bare-root planting stock. Relevant studies were initiated in 1973, and this report summarizes the results obtained to date.

OBJECTIVES

The objective of the series of experiments reported here was to compare the biological performance of containerized and bare-root trees on a variety of important site types in northeastern Ontario.

Containerized trees were reared in Japanese paperpots, because it was believed that deterioration of the paperpots would enable tree roots to penetrate the container wall, minimizing distortions in root form and facilitating root egress into the soil. The fact that the paperpot remained around the root mass and its growing medium during shipping and outplanting was also regarded as a significant advantage. A third major reason for the selection of the paperpot was the existence of commercial equipment to assemble, load, and sow the paperpots.

Initially, only black spruce *(Picea mariana* [Mill.] B.S.P.) and white spruce *(Picea glauca* [Moench] Voss) were included in the study, but by 1976 interest in the performance of jack pine *(Pinus banksiana* Lamb.) led to the inclusion of this species also. While only medium grade bare-root

---

[1] Consultant, Matcam Forestry Consultants Inc., Sault Ste. Marie, Ontario.

stock was compared with containerized stock in the early experiments, the provincial trend toward increased use of heavy grade bare-root stock led to the incorporation of this additional stock grade into the study from 1978 onwards.

METHODS

Experimental Design and Layout

Changes in emphasis of the overall study and the desire to include variations in site type and condition necessitated some changes in experimental design over the period reported. However, all experiments involved a factorial design with species, stock type and grade, and planting date as the factors. The number of levels of each factor varied (species 1 to 3, stock type and grade 2 to 4, and planting date 1 to 2) from site to site.

Variation in site type, even within small sample areas (e.g., 0.25 ha), led to a number of modifications in design to minimize potential site bias. On the largest scale, variations in site were accommodated by establishing separate experimental plots. On a smaller scale site variation was accommodated by establishing partially randomized blocks of treatments. At the smallest scale, plots were stratified by replicate to distribute treatments within the sample area. Sampling intensity also varied between experiments (e.g., number of trees per replicate and number of replicates per treatment).

All plots were established by first locating a baseline along a slope within the prospective sample area. Treatment rows, at 2 m spacing, were oriented at right angles to this baseline. Use of a baseline consisting of a series of straight-line segments allowed an experiment to be fitted into an irregularly shaped site. The location of each tree in a treatment row was marked with a looped wire pin to which flagging tape was attached. Every fifth seedling was numbered with a metal tag.

Data Collection

For each sample tree, survival, morphological condition and form were observed, and total height and current height increment were measured. Only survival and total height data are reported here. Trees were classified as alive so long as the slightest evidence of life was detected. Total height was the above-ground length of the main stem extending to the base of the terminal bud.

To characterize the planting stock used in each experiment, samples of 25 or 50 sorted seedlings were taken at the end of planting for each species, stock type and grade, planting date, and planting location. Each sample was measured for shoot height, root-collar diameter, total dry weight, shoot:root ratio and root area index. Sorting was undertaken to remove any diseased, badly deformed or damaged seedlings. Samples taken during the 1978-1980 period, when both medium and heavy grade seedlings were included in experiments, are summarized in Tables 1-3.

Data Analysis

Since the intention of this report is to provide a general summary of results obtained to date, it combines experiments varying in both design and sampling intensity; consequently, no statistical analysis of results is presented. The data in this report summarize the treatment means only for all the experiments undertaken during the period 1974 to 1980.

The size of the data base varies because the number of assessments received by an experiment varies, depending on its date of planting, and because in 1976 only spring planting was undertaken, so that the data available on summer planting were reduced. The standard error of means quoted in the tables provides a measure of variation in results between experiments at a particular assessment date.

RESULTS

Planting Stock Characteristics

Tables 1 to 3 summarize planting stock characteristics for black spruce, white spruce, and jack pine, respectively.

In black spruce, heavy grade bare-root trees (1-2) were consistently shorter with a lower shoot:root ratio and a larger root area index than their medium grade (3-0) counterparts. Bare-root trees for spring and summer planting, though nominally of equivalent grade, differed substantially in dry weight, root collar diameter and root area. Paperpot seedlings differed substantially in all parameters from the two grades of bare-root trees, the differences being more pronounced for the spring plant.

Table 1. Black spruce planting stock characteristics (1978-1980).

		Spring planting (5 May - 15 June)			Summer planting (15 June - 30 July)		
		Paperpot[a]	Bare-root[b]		Paperpot	Bare-root[c]	
		Medium	Medium (3-0)	Heavy (1-2)	Medium	Medium (3-0)	Heavy (1-2)
Dry weight (g)	Mean	0.84	4.72	6.84	0.60	2.48	3.54
	SEM[d]	0.15	0.58	1.32	0.07	0.09	1.28
Shoot:root ratio	Mean	2.2	6.1	3.0	4.4	5.1	4.3
	SEM	0.2	2.5	0.6	1.5	0.7	1.1
Root area index (cm^2)	Mean	8.0	25.7	59.0	7.0	9.0	20.7
	SEM	1.0	5.5	12.4	2.1	--	5.2
Shoot length (cm)	Mean	9.7	30.0	25.2	14.7	28.8	25.5
	SEM	0.5	2.1	3.4	1.0	4.7	4.5
Root-collar diameter (mm)	Mean	1.8	4.1	4.8	1.5	3.2	3.5
	SEM	0.1	0.2	0.2	0.2	0.3	0.4

[a] Containerized stock reared in both the FH 308 and FH 408 paperpots is combined.

[b] Spring planted bare-root trees are primarily spring-lifted with a short period of cool storage.

[c] Summer planted bare-root trees are primarily "rising" stock planted directly after lifting.

[d] Standard error of mean.

Table 2. White spruce planting stock characteristics (1978-1980).

		Spring planting (5 May - 15 June)				Summer planting (15 June - 30 July)			
		Paperpot[a]	Bare-root[b]			Paperpot	Bare-root[c]		
		Medium	Light (3-0)	Medium (2-1)	Heavy (2-2)	Medium	Light (3-0)	Medium (2-1)	Heavy (2-2)
Dry weight (g)	Mean	0.65	6.08	7.93	10.72	0.54	1.98	2.08	4.61
	SEM[d]	0.09	0.16	0.56	0.50	0.06	0.03	0.29	0.08
Shoot:root ratio	Mean	2.5	4.6	3.2	3.0	2.3	5.8	4.8	4.7
	SEM	0.2	0.1	0.4	0.2	0.5	0.1	0.7	0.2
Root area index (cm^2)	Mean	5.0	23.5	47.3	57.0	4.3	10.5	19.0	25.5
	SEM	1.5	4.3	1.8	2.9	1.2	0.3	3.5	1.4
Shoot length (cm)	Mean	6.8	34.0	25.8	29.3	9.2	21.7	20.3	24.7
	SEM	1.2	4.8	1.0	0.8	1.2	0.2	1.1	0.3
Root-collar diameter (mm)	Mean	1.4	4.4	5.2	6.1	1.5	3.2	3.6	4.3
	SEM	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1

[a] Containerized stock reared in both the FH 308 and FH 408 paperpots is combined.

[b] Spring planted bare-root trees are primarily spring-lifted with a short period of cool storage.

[c] Summer planted bare-root trees are primarily "rising" stock planted directly after lifting.

[d] Standard error of mean.

Table 3. Jack pine planting stock characteristics (1978-1980).

		Spring planting (5 May - 15 June)		Summer planting (15 June - 30 July)	
		Paperpot[a] Medium	Bare-root[b] Heavy (2-0)	Paperpot Medium	Bare-root[c] Heavy (2-0)
Dry weight (g)	Mean	1.06	4.14	0.96	1.74
	SEM[d]	0.08	0.09	0.33	0.29
Shoot:root ratio	Mean	2.4	4.8	2.6	3.8
	SEM	1.0	0.8	0.4	1.5
Root area index (cm^2)	Mean	13.0	32.3	10.3	15.9
	SEM	1.5	2.3	3.3	2.1
Shoot length (cm)	Mean	1.6	2.0	1.5	2.1
	SEM	0.4	0.2	0.3	0.1
Root-collar diameter (mm)	Mean	2.1	4.7	2.0	2.9
	SEM	0.2	0.1	0.4	0.2

[a] Containerized stock reared in FH 408 paperpots only.
[b] Spring planted bare-root trees are primarily spring-lifted with a short period of cool storage.
[c] Summer planted bare-root trees are primarily "rising" stock planted directly after lifting.
[d] Standard error of mean.

Similar differences between stock types existed with white spruce. An exception was the heavy grade (2-2) bare-root stock, which was taller than either of the two lighter grades (3-0 and 2-1) while maintaining its lower shoot:root ratio and larger root area index. There was also a much larger differential in dry weight between the paperpot and bare-root trees in white spruce.

Smaller differences existed between jack pine paperpot and bare-root stock than in either of the spruces. The paperpot seedlings were much better balanced than the bare-root trees in terms of shoot:root ratio.

Planting Stock Performance

Tables 4 to 9 present an overview of planting stock performance to date. Data are drawn from samples established in every year except 1977, when poor quality planting stock yielded anomalous results.

Note that the "n" value given in the tables indicates the number of experiments which were of sufficient age to be included in a particular assessment. By multiplying this "n" value by 150 (the number of trees per treatment in each experiment), it is possible to determine the approximate number of trees on which the figures for a particular row in the tables are based. For a given time of planting (e.g., spring) and assessment (e.g., first), all the stock comparisons are drawn from the same experiments. The same number of trees were assessed.

With spring planting, black spruce paperpot stock attained higher survival rates than medium grade (3-0) bare-root, but lower survival rates than heavy grade (1-2) bare-root stock (Table 4). The difference is considerably greater in the former instance. However, with summer planting, black spruce paperpot seedlings attained lower survival rates than the medium grade bare-root but higher rates than the heavy grade stock type. This incongruity will be discussed later.

Only in one experiment involving summer-planted paperpot seedlings and heavy grade (1-2) bare-root trees has black spruce paperpot stock attained a greater total height by the time of the third assessment (Table 5). The difference in total height between stock types decreased generally for the first three years but subsequently increased.

With spring planted white spruce, all three grades of bare-root trees had a survival rate superior to that of the paperpot stock (Table 6). However, the difference was generally less than 5% in the test plantings conducted to date. With summer planting, the light (3-0) and heavy grades (2-2) of bare-root trees attained higher survival rates than paperpot seedlings, whereas the opposite was true for comparisons involving medium

Table 4. Percent survival of black spruce stock types (1974-1980).

			Spring planting (10 May - 15 June)			Summer planting (15 June - 30 July)	
Year assessed	n[a]		Paperpot Medium	Bare-root Medium (3-0)	n	Paperpot Medium	Bare-root Medium (3-0)
First	6	Mean	85.4	75.9	6	78.7	82.7
		SEM[b]	4.3	5.0		7.2	5.0
Second	6	Mean	71.5	65.0	6	71.1	72.2
		SEM	5.5	5.5		8.8	4.4
Third	5	Mean	78.0	63.4	5	65.4	69.6
		SEM	4.8	6.4		8.9	4.7
Final[c]	4	Mean	68.0	57.5	4	48.2	62.3
		SEM	5.1	6.4		4.6	2.6
	n		Paperpot Medium	Bare-root Heavy (1-2)	n	Paperpot Medium	Bare-root Heavy (1-2)
First	12	Mean	87.9	93.4	4	99.2	88.4
		SEM	2.1	1.5		0.4	4.9
Second	9	Mean	83.6	88.8	3	97.1	83.5
		SEM	2.8	2.8		0.7	6.5
Third	7	Mean	80.2	88.0	1	98.5	69.5
		SEM	2.7	2.8		-	-
Final	6	Mean	77.5	84.6			
		SEM	2.8	2.5			

[a] Number of experiments

[b] Standard error of mean

[c] Final assessment was normally made at the end of the fifth year after outplanting.

grade (2-1) bare-root stock. Only in comparisons involving paperpots and light grade bare-root stock was the disparity large enough to be important: it ranged from 11 to 16% in the different years of assessment.

In no instance had any of the white spruce paperpot plantings outgrown, in height, any of the bare-root grades by the final assessment (Table 7). Although the height difference between paperpot and bare-root stock did diminish during the first three years after planting, for both spring and summer plantings, the gap remained wider than in black spruce, and actually increased by the final assessment (as in black spruce).

Jack pine has been planted over a much shorter period (1976-1980) than the spruces. The most dramatic result for jack pine was the dismal performance of summer-planted bare-root stock. The survival rate at the end of the first growing season, only 3 months after outplanting, was only 24.8% (Table 8). This contrasts with the very acceptable survival rates attained by summer-planted paperpot seedlings, which exceeded 97% after three growing seasons. Spring-planted paperpot seedlings attained a survival rate only slightly higher than that attained by bare-root trees.

Height growth of jack pine differed in two respects from that of white spruce and black spruce. With spring plantings, the larger bare-root trees increased their height advantage continuously from time of planting (Table 9). With summer plantings the paperpot trees, which exhibited a dramatically higher survival, also outgrew the rising 2-0 bare-root trees by a wide margin. Jack pine did not exhibit the same trends of decreasing height differential between stock grades, followed by an increase, that were found in the spruces.

Table 5. Total height of black spruce stock types (1974-1980).

Year assessed	n[a]		Spring planting (10 May - 15 June)		n	Summer planting (15 June - 30 July)	
			Paperpot Medium (cm)	Bare-root Medium (3-0) (cm)		Paperpot Medium (cm)	Bare-root Medium (3-0) (cm)
First	6	Mean	11.9	26.7	6	11.1	20.8
		SEM[b]	1.1	0.9		1.5	1.9
Second	6	Mean	21.4	32.3	6	20.6	24.0
		SEM	1.3	2.0		1.8	1.7
Third	5	Mean	31.6	41.1	5	29.3	31.2
		SEM	2.1	4.3		2.8	2.4
Final	4	Mean	70.1	86.4	4	56.9	71.7
		SEM	7.5	17.9		7.0	1.2
	n		Paperpot Medium (cm)	Bare-root Heavy (1-2) (cm)	n	Paperpot Medium (cm)	Bare-root Heavy (1-2) (cm)
First	12	Mean	9.0	26.9	4	12.8	21.9
		SEM	0.4	1.2		1.4	3.6
Second	9	Mean	20.0	36.7	3	20.2	21.9
		SEM	1.2	2.2		3.4	1.0
Third	7	Mean	32.2	51.4	1	34.1	32.1
		SEM	1.8	1.3		-	-
Final	6	Mean	54.4	82.8	-		
		SEM	4.7	3.7			

[a] Number of experiments

[b] Standard error of mean

DISCUSSION

In Ontario containerized regeneration is viewed primarily as a supplement to bare-root planting. The hope was that containerization would enable the planting season to be extended into the summer months, thereby permitting an increase in the provincial planting program without necessitating an increase in spring planting.

By examining the comparative performance of spring and early summer plantings, it is possible to speculate whether bare-root or containerized planting stock are viable alternatives for either season. However, difficulties arise when two such inherently different regeneration systems are compared, particularly with regard to differences in rearing techniques, age and size of tree, and storage practices.

In this study, the paperpot seedlings used for spring planting were held through the winter under a natural snow cover. Summer-planted containers were not overwintered, and were outplanted directly after removal from the greenhouse, with a short period of conditioning in a shadehouse. Most spring-planted bare-root stock was fresh-lifted, with cool storage employed only where this was necessary to accommodate work schedules. Summer-planted bare-root trees were planted directly after lifting from the nursery as "rising" stock.

Differences in tree age also pose a problem when one is comparing performance. Is it more appropriate to compare performance in relation to tree age or to time since planting? By the former method containerized trees would need to grow for 1 to 3 years (depending on age of the bare-root trees) under forest conditions before they are comparable with bare-root trees at time of

Table 6. Percent survival of white spruce stock types (1974-1980).

Year assessed		n[a]	Spring planting (10 May - 15 June) Paperpot Medium	Spring planting (10 May - 15 June) Bare-root Medium (3-0)	n	Summer planting (15 June - 30 July) Paperpot Medium	Summer planting (15 June - 30 July) Bare-root Medium (3-0)
First	Mean	9	80.0	84.0	5	74.9	91.4
	SEM[b]		4.6	2.5		10.6	3.2
Second	Mean	9	73.5	74.3	5	64.8	76.2
	SEM		5.1	3.5		11.9	4.6
Third	Mean	8	69.0	73.5	4	54.6	77.2
	SEM		4.8	3.7		11.7	3.6
Final	Mean	8	64.7	69.6	4	45.1	69.0
	SEM		4.3	4.0		6.7	4.4
		n	Paperpot Medium	Bare-root Medium (2-1)	n	Paperpot Medium	Bare-root Medium (2-1)
First	Mean	5	94.9	98.7	3	98.8	96.9
	SEM		1.5	0.7		0.4	1.3
Second	Mean	2	89.7	92.4	2	96.2	91.3
	SEM		0.4	5.6		1.8	2.0
		n	Paperpot Medium	Bare-root Heavy (2-2)	n	Paperpot Medium	Bare-root Heavy (2-2)
First	Mean	1	96.0	96.7	1	98.0	99.0
	SEM	-	-	-		-	-
Second	Mean	1	89.3	93.3	1	94.5	96.0
	SEM	-	-	4.0		-	-

[a] Number of experiments
[b] Standard error of mean

planting. Such a basis for comparison would be to the advantage of containerized trees in terms of height but to their disadvantage in terms of survival. In this series of experiments it was decided that early height performance in relation to height of competing vegetation was most crucial and that comparability ought to be sought in terms of total height by the end of a regeneration period of 5 years.

Large differences in initial tree size create another problem. In such a situation which is the better measure of performance: height increment in relation to initial height or absolute height increment? In fact, it is necessary to know both absolute height and rate of height increment in order to compare growth.

Scheduling of the summer plant created different problems for each stock type. The need to avoid or minimize any time gap between the spring and summer plantings, which, in operational practice, involves laying off and trying to rehire large planting crews after the work interruption, demanded that the later planting be initiated as soon as possible after the traditional spring plant was finished. For paperpot trees this reduced the time available for conditioning in the shadehouse and increased the vulnerability of succulent trees to harsh summer conditions. For bare—root trees, especially transplants, the greater concern was that root development would not have progressed sufficiently and that actively growing, top—heavy trees would have difficulty coping with more severe summer conditions.

Perhaps the most important result obtained to date is the generally satisfactory performance of summer planting regardless of stock type. Prior to these plantings, conventional wisdom asserted that failures would occur during most years and that only cool, wet summers would produce success. Except for summer planting of jack pine bare—root

Table 7. Total height of white spruce stock types (1974-1980).

			Spring planting (10 May - 15 June)			Summer planting (15 June - 30 July)	
Year assessed		n[a]	Paperpot Medium (cm)	Bare-root Light (3-0) (cm)	n	Paperpot Medium (cm)	Bare-root Light (3-0) (cm)
First	Mean	9	6.8	24.6	5	5.3	17.6
	SEM[b]		0.5	0.8		0.7	0.8
Second	Mean	9	13.2	29.7	5	11.4	20.3
	SEM		0.5	1.0		1.4	0.6
Third	Mean	8	20.2	34.9	4	18.6	26.8
	SEM		1.0	1.2		2.4	0.9
Final	Mean	8	33.7	49.5	4	34.9	47.2
	SEM		3.4	4.1		3.0	3.9
		n	Paperpot Medium	Bare-root Medium (2-1)	n	Paperpot Medium	Bare-root Medium (2-1)
First	Mean	5	5.8	26.9	3	6.8	14.2
	SEM		0.5	0.8		0.5	0.5
Second	Mean	2	8.7	27.5	2	9.4	16.3
	SEM		1.7	2.0		0.4	0.5
		n	Paperpot Medium	Bare-root Heavy (2-2)	n	Paperpot Medium	Bare-root Heavy (2-2)
First	Mean	1	7.0	31.8	1	6.2	21.9
	SEM		-	-		-	-
Second	Mean	1	10.4	32.8	1	9.8	23.5
	SEM		-	-		-	-

[a] Number of experiments

[b] Standard error of mean

stock, this does not appear to have been the case. The somewhat poorer performance with summer planted than with spring planted stock can be partially explained by the use of smaller grade seedlings and the short growth period following planting.

Tables 4, 6 and 8 reveal the relentless progression of mortality over the regeneration period regardless of stock type, with most mortality occurring during the first three years. The data also suggest that poor survival (<90%) at the end of the first season may provide a reliable indication of eventual plantation failure, given the present level of plantation tending.

The results in Tables 5, 7 and 9 indicate that, in nearly all cases, total tree height at the end of the first growing season is less than initial height as reflected by shoot lengths in Tables 1 to 3. Although differences are partially due to sample variability, the primary cause is probably deep planting. This tendency is more pronounced with bare-root trees since piece-rate planters, penalized for loose planting, tend to plant bare-root trees deeply to increase firmness.

These same tables reveal some interesting comparisons between the various species and stock types in terms of relative and absolute height growth. In all cases, relative height growth peaks during the assessment period, generally between the second and third growing seasons. Paperpot trees peak at a higher level than bare-root trees and maintain that superiority to the end of the assessment period. If the smaller paperpot trees are to overtake their bare-root counterparts they must do it during this period of peak relative height growth. Such is the case where paperpot trees have

Table 8. Percent survival of jack pine stock types (1976-1980).

Year assessed		n[a]	Spring planting (10 May - 15 June)		n	Summer planting (15 June - 30 July)	
			Paperpot Medium	Bare-root Heavy (2-0)		Paperpot Medium	Bare-root Heavy (2-0)
First	Mean	8	95.8	94.1	2	98.0	24.8
	SEM[b]		1.8	2.5		1.2	11.0
Second	Mean	6	91.5	89.6	2	96.5	20.3
	SEM		2.8	3.2		0.5	10.5
Third	Mean	5	91.4	89.3	1	97.8	10.8
	SEM		3.0	3.0		-	-
Final	Mean	4	88.4	86.0			
	SEM		3.2	3.0			

[a] No. of experiments
[b] Standard error of mean

Table 9. Total height of jack pine stock types (1976-1980).

Year assessed		n[a]	Spring planting (10 May - 15 June)		n	Summer planting (15 June - 30 July)	
			Paperpot Medium (cm)	Bare-root Heavy (2-0) (cm)		Paperpot Medium (cm)	Bare-root Heavy (2-0) (cm)
First	Mean	8	13.3	25.2	2	14.8	11.1
	SEM[b]		1.0	0.8		2.6	0.1
Second	Mean	6	31.8	52.8	2	29.2	18.4
	SEM		2.1	2.2		1.2	4.4
Third	Mean	5	54.9	83.7	1	50.3	23.8
	SEM		3.7	4.8		-	-
Final	Mean	4	123.4	164.5			
	SEM		6.2	10.4			

[a] Number of experiments
[b] Standard error of mean

achieved superiority in comparisons involving heavy-grade (1-2), summer-planted black spruce (Table 5) and summer-planted jack pine (Table 9). In jack pine, which is not as strongly affected by planting stress as the spruces, smaller paperpot trees should overtake bare-root stock within the first year if they are to gain superiority. After the peak in relative height growth is passed, the larger trees are able to take advantage of their superior size and, regardless of stock type, increase their height advantage.

CONCLUSIONS

A number of tentative conclusions may be drawn from the comparative plantings undertaken to date. If we recollect that in the early 1970s containerized regeneration was not generally considered suitable for northern Ontario, the most noteworthy conclusion must be that containerized seedlings can yield acceptable results for both spring and summer planting of the three most important boreal conifer species.

GROWTH, NUTRITION AND ROOT DEVELOPMENT OF ONTARIO TUBELINGS, PLUGS AND 3+0 BARE-ROOT BLACK SPRUCE

Keith M. McClain[1]

Abstract.--Young stands established with Ontario tubelings, plugs and 3+0 bare root black spruce *(Picea mariana* [Mill.] B.S.P.) were examined and their growth, nutrition, and root development were compared. Mean height and current annual height increments of bare-root stock significantly exceeded those of tubelings and plugs. Although all stand types were moderately deficient in nitrogen and phosphorus, growth differences were associated with original tree size, root development and overhead competition.

Résumé.--On a examiné des peuplements juvéniles d'épinette noire *(Picea mariana* [Mill.] B.S.P.) établis au moyen de semis en tubes Ontario, en cartouches et 3+0 à racines nues et on a comparé leur croissance, leur nutrition et le développement de leurs racines. La hauteur moyenne et la vitesse de croissance en hauteur annuelle des semis à racines nues étaient considérablement supérieures à celles des semis en tubes ou en cartouches. Même s'il y avait une carence modérée d'azote et de phosphore dans tous les trois types de peuplement, les différences de croissance étaient liées à la taille originale de chaque arbre, au développement de ses racines et à la concurrence du couvert.

INTRODUCTION

From its inception in 1957 and through various developmental phases in the 1960s, the Ontario tubeling program flourished, but has since waned. From the outset (McLean 1959) the small split cylindrical polystrene tube was regarded as a means of supplementing the province's bare-root production program, as well as supplying stock on short notice, for example, for planting areas destroyed by fire. Besides the biological advantages of minimal root disturbance at planting and extension of the planting season, considerable opportunity for mechanization was envisaged. The prospects of these advantages gave such impetus to the tubeling program that research into the biological implications of the system lagged behind.

The problems associated with the performance of tubed seedlings are now known to most of us and have been reviewed by Scarratt (1974). Most notable among the problems are frost heaving, low survival and slow subsequent growth of surviving trees.

In northern Ontario, fifth year survival of black spruce *(Picea mariana* [Mill.] B.S.P.) tubeling plantations established between 1966 and 1968 ranged from approximately 30% to 37% with an average height of 25 cm (MacKinnon 1974). In sharp contrast, mean survival and height of black spruce bare-root stock for the same period were 61% and 69 cm, respectively. These inconsistencies are as yet unexplained, but it is abundantly clear that if container stock is to assume a prominent role in light of its intended purpose, it must compare favorably with established regeneration techniques (i.e., in Ontario, bare-root planting) (Reese 1974).

In this study, growth performance of Ontario black spruce tubelings, plug and

---

[1] Research Scientist, Northern Forest Research Unit of the Ontario Tree Improvement and Forest Biomass Institute, Ontario Ministry of Natural Resources, Thunder Bay, Ontario.

bare-root stock was examined with reference to root development, nutrition, and competition. It must be emphasized, however, that these results and the performance of current containerized conifer and bare-root stock may not be directly comparable. Nevertheless, the results do provide a measure of growth differences between stock types that are presumably due to differences in stock size at the time of planting.

STUDY DESCRIPTION

Study Location and Stand History

The plantation area is located north of Reivonen Lake approximately 150 km northwest of Thunder Bay, Ontario in the Dog River working circle of the Great Lakes Forest Products Co. Ltd. In 1968, harvesting operations removed high cordage of black spruce, white spruce *(Picea glauca* [Moench] Voss), balsam fir *(Abies balsamea* [L.] Mill.) and jack pine *(Pinus banksiana* Lamb.), leaving a considerable poplar *(Populus* spp.) overstory.

The area was subsequently scarified with shark-finned barrels and chains, and in May, 1970 bare-root spring-lifted 3W 3+0 black spruce stock was planted in the northern portions of the cutover. The bare-root stock arrived at the planting site packed in sphagnum moss in veneer crates. Trees were graded stock with an average height of 25 cm. The remaining area was planted in 1971 with black spruce seedlings raised in Ontario tubes. At the time of planting, these tubelings were overwintered, 15-month-old seedlings approximately 6–8 cm high. Approximately half of the tubelings were planted as plugs, i.e., without the tube. In total, 130,000 bare-root seedlings and 113,000 plugs and tubelings were planted at approximate densities of 2,710 and 4,500 trees per ha, respectively.

Field Methods

Within each of the tubeling and plug plantations two plots were located so as to provide two levels of overstory competition. For comparative purposes, a single plot was located within the 3+0 bare-root plantation immediately adjacent to areas planted to tubelings and plugs. The plantation could have been classified as "free to grow", but it had an average height for which only mature residual poplar offered a moderate form of overhead competition. The bare-root plantation was 11 years old and the tubeling and plug plantations were 10 years old when assessed. Although this disparity does not permit direct growth comparisons on the basis of age, unformity of site and treatment is an overriding advantage in this study.

All assessment plots were circular and varied in size to permit an adequate number of sample trees for reliable estimates of plantation growth parameters. Sample plot statistics are presented in Table 1. Within each plot, all trees were tagged, numbered and measured for total height, diameter at breast height, length of live crown, and crown width. Once tallied, all bare-root and plug trees were harvested and transported to the laboratory for aging to ensure that the sample trees did not include natural trees. The root systems of two trees per plot were excavated and described according to their configuration and extent.

Ten trees from each sample plot were randomly selected across the range of heights and further measured for annual height increments from 1974 to 1980. The 1980 foliage of these same trees was sampled from the upper third of the crown and subsequently dried, ground, and analyzed for concentrations of N, P, K, Ca and Mg using standard laboratory procedures.

Site Conditions of Study Plots

All sample plots were located in close proximity to one another. Examination of the soil in each plot indicated little variation in profile development, texture, and soil moisture conditions. Common to each profile was evidence of past disturbance by logging and scarification. The LFH layers varied in thickness from 5 to 8 cm and were underlain by an intermittent and faint A_e horizon. The Bf1 and Bf2 horizons were easily observed as well as pockets or strata of charcoal which were possibly inverted on the profile during the scarification process. The presence of charcoal suggests the likelihood that the original stand originated after fire.

Textural analysis of each profile indicated that the soil is predominantly silt loam with pH ranging from 4.7 to 5.6. The C horizon was composed of unsorted, sandy gravels. The profile showed no mottling, and this suggests that the site is well drained. The site is moderately fresh and the size of stumps from the previous stand indicated that the site had a moderately high timber production potential.

The most commonly occurring species in the ground vegetation were blueberry *(Vaccinium angustifolium* Ait.), honeysuckle *(Diervilla lonicera* L.), prickly rose *(Rosa acicu-*

Table 1. Stand description of sample plots. Numbers within parentheses refer to the number of stems recorded in each sample plot.

			Density (stems/ha)			
Stand type	Competition level	Plot area (ha)	Planted black spruce	Poplar	Other conifer	Total
Tubeling	light	0.045	2,000 (90)	867 (39)	489 (22)	3,356
Tubeling	heavy	0.023	1,870 (67)	9,130 (210)	956 (22)	11,956
Plug	light	0.040	1,925 (77)	100 (4)	75 (3)	2,100
Plug	heavy	0.038	2,667 (100)	6,373 (239)	187 (7)	9,227
3+0 Bare-root	moderate	0.035	2,429 (85)	1,629 (57)	571 (20)	4,629

laris Lindl.), mountain maple *(Ater spicatum* Lam.), feather moss *(Pleurozium schreberi* BSG. Mitt.), Labrador tea *(Ledum groenlandicum* (Oeder), and other lower vegetation commonly found in a mixedwood forest association.

RESULTS

Height Growth

In this comparative study and in others like it, height growth is commonly utilized to assess the relative performance of various forms of planting stock. Each mention of statistical significance relates to the 5% level of probability.

In Figure 1, the progression of mean height of the five stand types is presented from 1973 through to 1980. Clearly, the difference between the 3+0 bare-root plantation and the tubeling and plug plantations remains significant regardless of the competition level. The removal of the tube at the time of planting had little early effect on height growth of plug stock in relation to tubeling stock. It was only by 1975 that a pattern of superiority emerged as plug stock under light competition achieved greater height than the other plug and tubeling sample plots. This growth advantage was consistent up to 1980, at which time plug trees under light competition attained the performance standard suggested by Mullin (1978). Over all, tubelings and plugs growing under light competition achieved 5% and 33% greater height, respectively, than when under heavy competition.

Although tubeling and plug stock achieved Mullin's growth standard 10 years after planting, this does not compare favorably with the performance of 3+0 bare-root stock, which achieved the growth standard (extrapolated back in time) five years after planting. This early achievement by 1974 and 50% over-achievement in 1980 substantiates the competitive growth advantage of 3+0 bare-root stock over Ontario black spruce tubelings and plugs. Tubelings grown under light and heavy competition and plug stock under heavy competition attained similar heights by 1980, but this was nearly 30% below the minimum acceptable performance standard for 3+0 bare-root black spruce stock. In 1980, mean height of 3+0 bare-root stock significantly exceeded the mean height of tubelings and plugs (competition levels combined) by 104% and 69%, respectively.

Current Annual Height Increment

Current annual height growth from 1974 through to 1980 for tubeling, plug and bare-root stock is presented in Figure 2. Several trends are readily apparent. First, mean annual height growth of the bare-root stock was greater than that of the tubeling or plug plantations, regardless of competition level. This difference is significant from 1974 to 1976, after which the height growth difference between the bare-root and the plug plantations under light competition was not significant. Specifically, the mean height increment of the bare-root plantation exceeded that of tubelings and plugs (competition levels combined) by 85.4% and 40.0%, respectively.

Second, the effect of competition on current annual increment of tubelings was not significant although height growth was

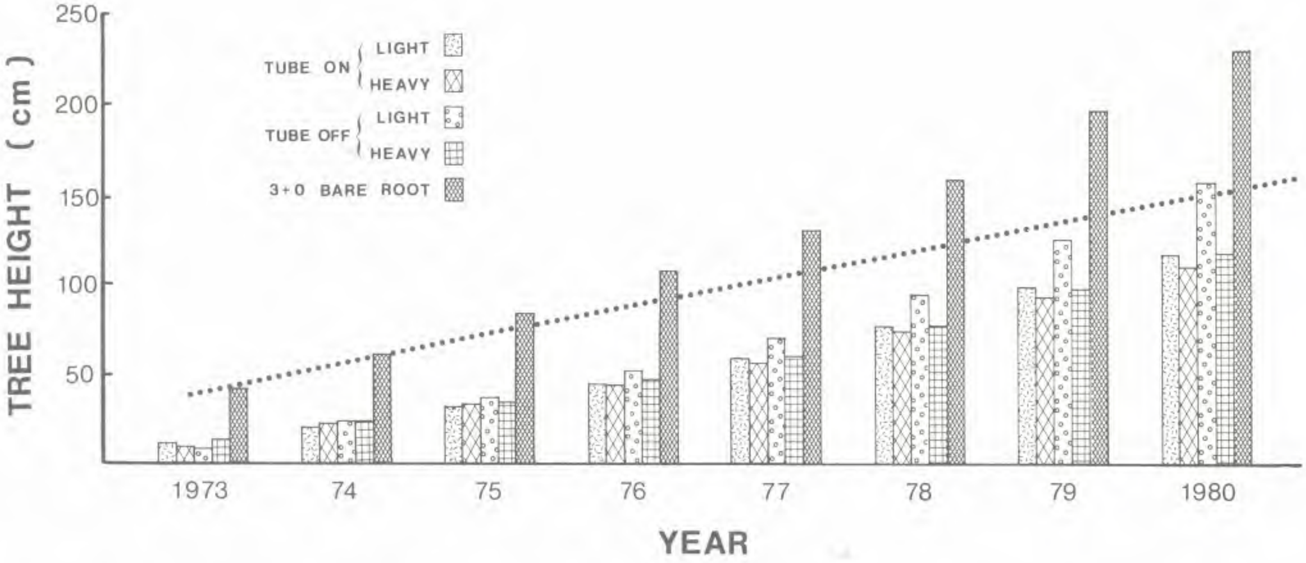


Figure 1. Average tree heights (1974-1980) for black spruce tubeling and plug stock under light and heavy competition, and 3+0 bare-root stock. Dotted line represents "minimum performance standard" (Mullin 1978) for 3+0 bare-root black spruce.

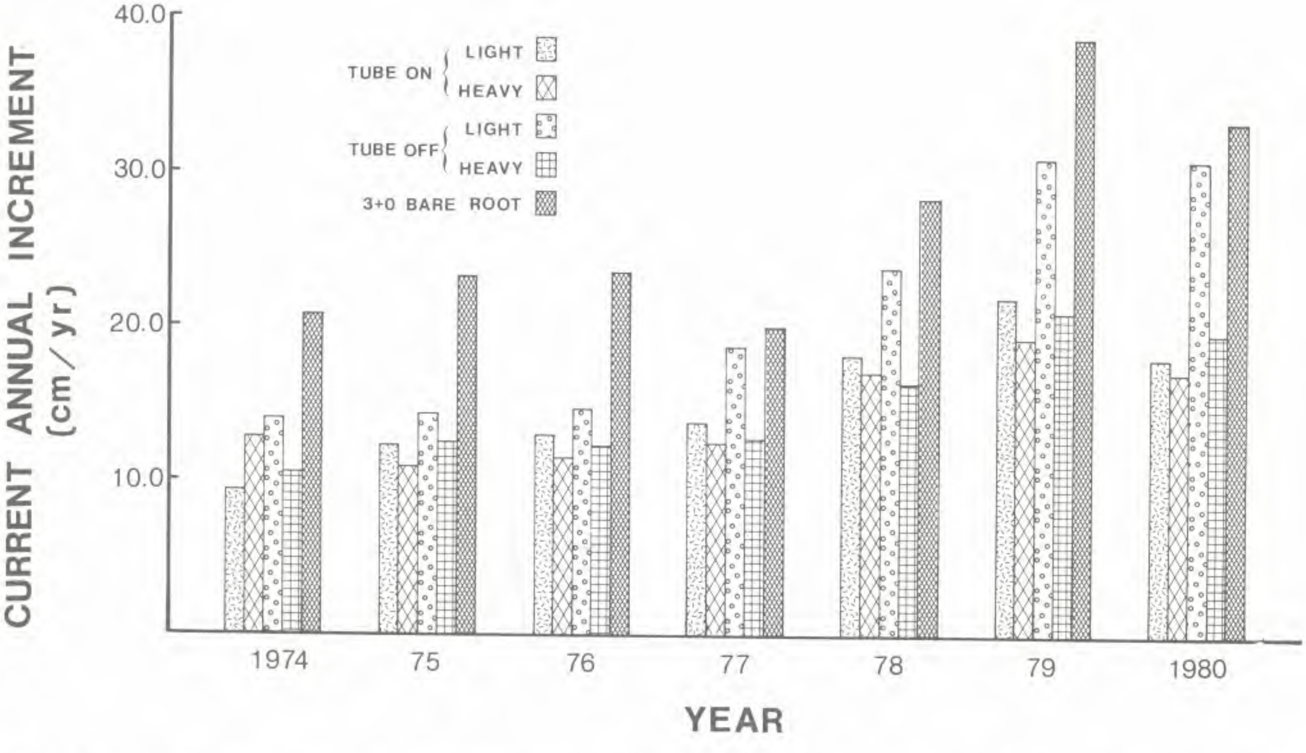


Figure 2. Current annual height increments (1974-1980) of black spruce tubeling and plug stock under light and heavy competition, and 3+0 bare-root stock.

Table 2. Stem diameters and crown dimensions of trees from sample plots of tubelings, plugs, and 3+0 bare-root black spruce.

Stand type	Competition level	DBH (cm)	Proportion of sample trees achieving DBH (%)	Crown dimensions		
				Length (cm)	Crown length / Total height (%)	Width (cm)
Tubeling	light	0.71	52	93	80	59
Tubeling	heavy	0.62	19	88	80	70
Plug	light	0.66	36	92	59	65
Plug	heavy	0.52	21	110	94	70
3+0 Bare-root	moderate	1.62	90	192	83	107

marginally better (9.3%) under light competition than under heavy competition. The difference in mean annual height increment between plugs under light and heavy competition was 39%. The difference in rate of growth increased from 1977 until 1980, at which time plug trees growing under light competition achieved 57% greater height growth than plug trees under heavy competition.

Stem Diameter and Crown Dimensions

Differences in performance of the five stand types are further evidenced by diameters at breast height (Table 2). DBH was greatest for bare-root stock, followed by plugs and tubelings under light competition, and finally by tubelings and plugs under heavy competition.

Crown dimensions are also presented in Table 2. For plug seedlings grown under light competition, crown lengths averaged approximately 59% of their total height whereas the crowns of trees of the other stand types represented a greater percentage of their respective mean heights. When crown widths were considered in relation to crown length, the crowns of bare-root trees and of tubelings and plugs under light competition were cylindrical, and were shorter and stockier for tubelings and plugs under heavy competition.

Root Development

Poor root form of planted trees has been of major interest for many years and is often considered a limiting factor in the potential development of plantations (Van Eerden and Kinghorn 1978). Root deformities caused by planting were expected to lessen with the advent of containerization but planting failures have, nevertheless, continued to occur. For black spruce tubeling plantations, slow growth is often associated with, among other deficiencies, poor root development. Frost heaving is a principal factor leading to deformities of root systems particularly in Ontario tubelings (Fraser and Wahl 1969, Anon. 1971). The obvious implication of severe root deformity is that the tree may not recover to reach maturity, let alone grow as well as bare-root trees. Figures 3 and 4 portray an extreme example of abnormal root system development. Root systems excavated in the present study came from trees which were fully established and had presumably achieved an adequate root system. Prior to excavation, there was no visible evidence of root deformation and trees exhibited reasonably good growth; hence it was expected that the root systems of these trees would be well developed.

Such was the case for the tubeling trees excavated. Figures 5 and 6 clearly portray the radiating development of the root system. The trees were well anchored and possessed omni-directional stability. It is notable that root egress from the bottom of the tube was virtually nil and that circumstances causing the tilt in the tube possibly led to the creation of conditions suitable for adventitious root development from the stem.

A somewhat similar, but less extensive, radiating root configuration was typical of plug seedlings (Fig. 7 and 8). In this example, two tiers of roots are obvious; the upper or major tier was adventitious in origin and the lower or minor tier of roots

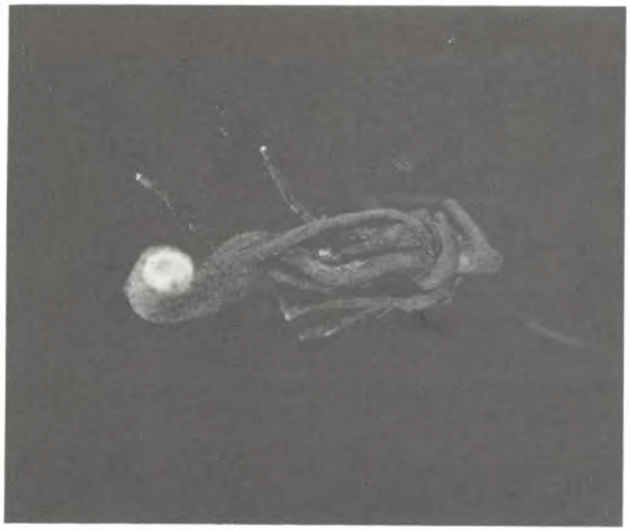


Figure 3. Top view of root deformation caused by frost heaving in a black spruce tubeling as it appeared 10 years after planting.

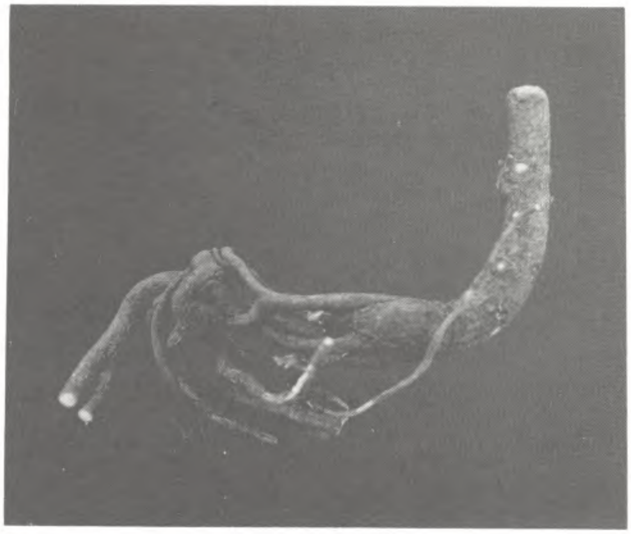


Figure 4. Side view of same root system as in Figure 3 showing extent of deformation.

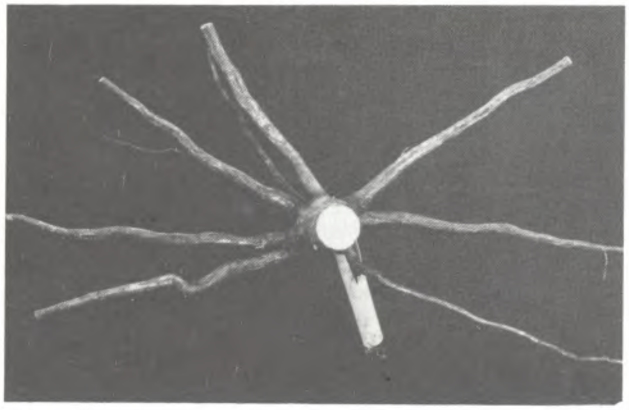


Figure 5. Top view of the root development of a black spruce tubeling 10 years after planting.

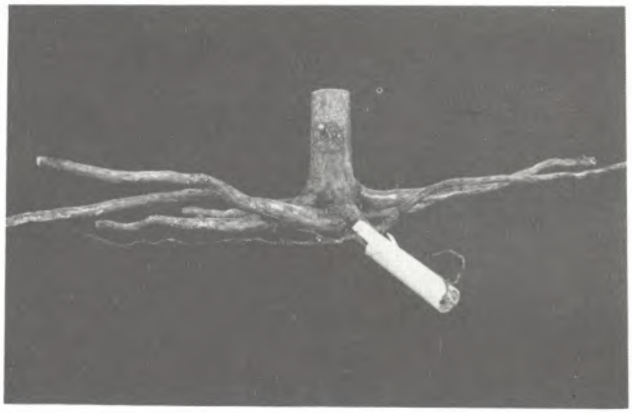


Figure 6. Side view of same root system as in Figure 5 exhibiting plate-like root form typical of black spruce. All roots emanating from above tube are adventitious roots.

was the original compact root system that had developed in the tube. Although the removal of the tube prior to planting allowed freedom of growth for the original root system, the new system was comprised entirely of adventitious roots.

The root system of a 3+0 bare-root tree, though larger, exhibits some similarities to the root system of a tubeling or plug tree (Fig. 9 and 10). The seedling root system developed a radiating root pattern, as well as a major tier of adventitious roots above an original root mass which was of low vitality.

A quantitative assessment of the excavated root systems revealed that plug trees, on the average, possessed nearly twice as many major lateral roots as tubelings, i.e., 8.5 vs 4.3, and that the number of major lateral roots for plug trees and bare-root

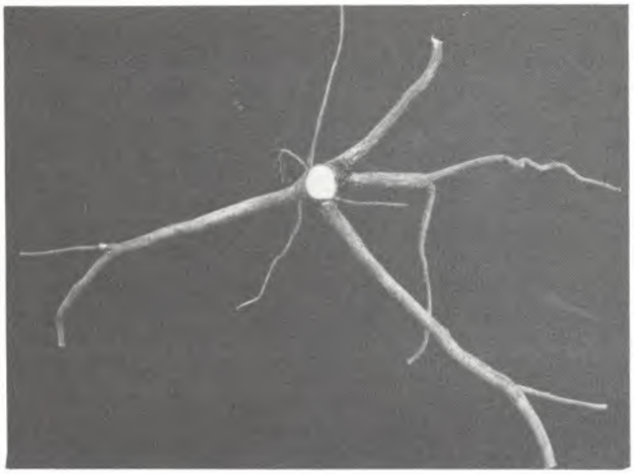


Figure 7. Top view of the root system of a black spruce plug 10 years after planting.

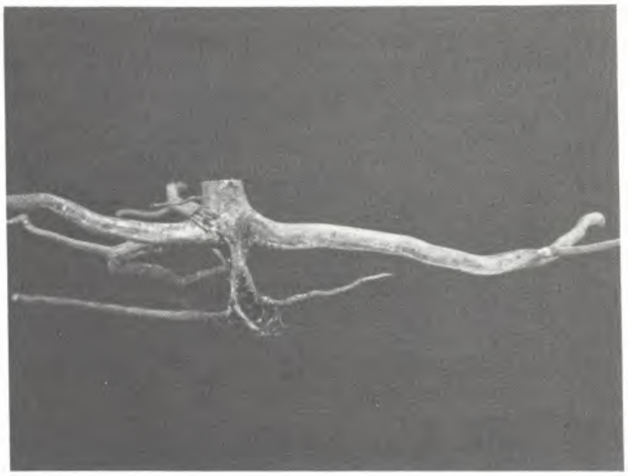


Figure 8. Side view of same root system as in Figure 7 exhibiting a major tier of adventitious roots and a lower tier of original roots.

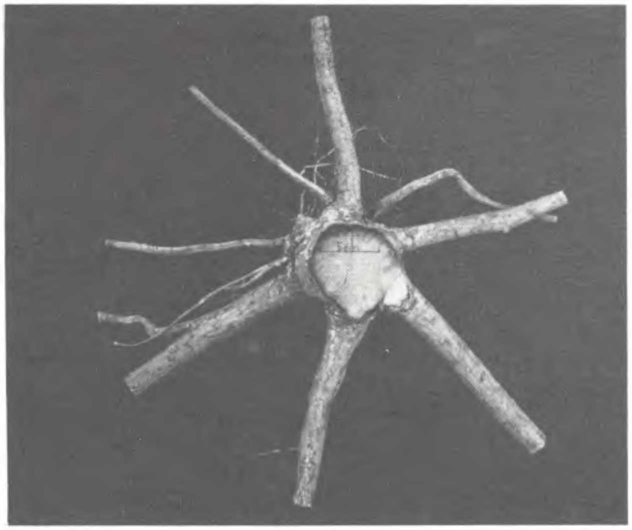


Figure 9. Top view of the root system of a 3+0 bare-root black spruce 11 years after planting.

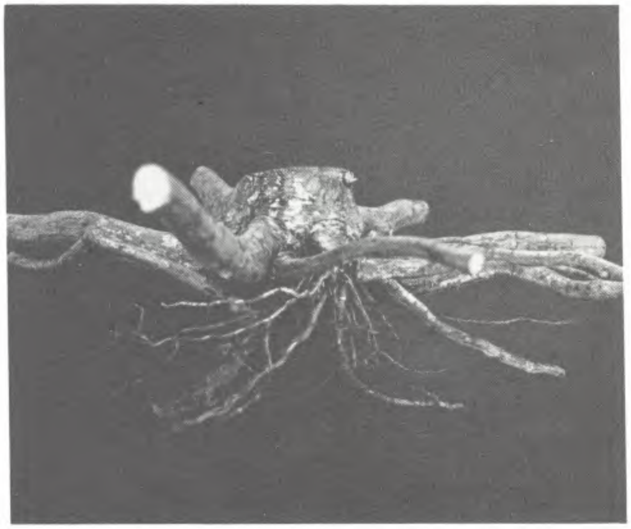


Figure 10. Side view of same root system as in Figure 9, exhibiting plate-like form. All roots are adventitious except for the remnant of the original root system.

trees was comparable. Root lengths varied considerably, but it was noteworthy that the average tubeling root was 1.35 m long, whereas the roots of plug trees average 1.24 m. The average root length of bare-root trees was 1.85 m and occasionally roots up to 3 m long were measured.

It would appear that, regardless of stock type, it is characteristic of black spruce to develop an entirely new root system. Apart from the original root system the ages of adventitious roots were less than the age of the tree from seed. Root ages for tubelings, plugs, and bare-root stock ranged from 3 to 8 years, 3 to 7 years, and 5 to 9 years, respectively.

Tree Nutrition

Nutrient maxima in tree foliage generally occur during the period from late summer

Table 3. Early spring nutrient concentrations of foliage from upper crowns of three sizes of black spruce tubelings, plugs, bare-root and natural trees.

Stand Type	Competition	Tree size	Height range (m)		Nutrient concentrations (%)				
					N	P	K	Ca	Mg
Tubeling	Light	S	0.44-0.99		1.014	0.119	0.473	0.408	0.088
		M	1.00-1.56		0.890	0.139	0.511	0.369	0.095
		L	1.57-2.12		0.833	0.120	0.417	0.273	0.075
				$\overline{X}$	0.912	0.126	0.467	0.350	0.086
Tubeling	Heavy	S	0.55-0.91		1.081	0.122	0.497	0.443	0.093
		M	0.92-1.29		0.980	0.136	0.462	0.318	0.090
		L	1.30-1.65		1.040	0.133	0.466	0.309	0.089
				$\overline{X}$	1.034	0.130	0.475	0.357	0.091
Plug	Light	S	1.28-1.50		1.050	0.129	0.361	0.563	0.077
		M	1.51-1.67		0.887	0.100	0.305	0.454	0.080
		L	1.68-2.37		0.937	0.106	0.387	0.332	0.063
				$\overline{X}$	0.958	0.112	0.351	0.450	0.073
Plug	Heavy	S	0.52-0.89		0.873	0.134	0.552	0.419	0.109
		M	0.90-1.27		0.940	0.126	0.481	0.381	0.105
		L	1.28-1.65		0.973	0.131	0.447	0.387	0.099
				$\overline{X}$	0.929	0.130	0.493	0.396	0.104
3+0 Bare-root	Moderate	S	1.67-2.19		0.887	0.103	0.449	0.450	0.078
		M	2.20-2.75		0.917	0.119	0.501	0.300	0.062
		L	2.76-3.24		1.070	0.108	0.521	0.495	0.077
				$\overline{X}$	0.958	0.110	0.490	0.415	0.072
Natural		S	0.98-3.02		0.903	0.120	0.503	0.423	0.088
		M	3.03-3.56		0.910	0.099	0.377	0.350	0.081
		L	3.57-4.10		0.880	0.101	0.408	0.315	0.081
				$\overline{X}$	0.898	0.106	0.438	0.362	0.083

to late fall, which is often the recommended time for sampling (Lowry 1970, Morrison 1974). For purposes of estimating relative nutrition, sampling can be carried out at other times and, if necessary, seasonal adjustment curves can be employed to allow for differences (Lowry and Avard 1969). In this study, sampling was carried out during early May, a period of relative nutrient stability (Salonius 1977).

Foliar nutrient concentrations are presented in Table 3 for the small, medium, and large trees from the five main stand types.

In general, nutrient concentrations revealed little consistent information which might be related to stand type, competition level, or size of tree. Nitrogen, phosphorus, and, in general, magnesium fall within the range of moderate deficiency (Swan 1970). The concentrations of potassium and calcium, however, were within the ranges of sufficiency and luxurious consumption, respectively (Swan 1970). It is of interest to note that, with few exceptions, the mean concentrations of N, P and K for natural trees were less than those for the planted trees. Concentrations of Ca and Mg were comparable.

DISCUSSION

Growth Performance

Although initially conceived to supplement the existing reforestation program, production of containerized trees in Ontario has expanded for economic as much as for biological reasons. With this expansion it has been asked (Barnett 1974) whether or not containers can do a better job than bare-root stock. The future direction of the container stock program hinges on this simple but important question. The results from recent field trials, e.g., Arnott (1974), Gutzwiler and Winjum (1974), Johnson (1974), Hite (1974) and Walker and Johnson (1974), leave one with the impression that this question cannot be answered categorically but depends largely on circumstances of site quality, site preparation, species, cultural treatment, time of planting, tending, etc. With exceptions, container stock does not generally outperform bare-root stock under similar conditions.

Despite the one year difference in plantation age between the bare-root and the tubeling/plug plantations, the results of the present study do not lend support to the hypothesis that--at least for black spruce--Ontario tubelings and plugs grow as well as 3+0 bare-root stock. Eleven years after planting, mean height of bare-root stock was 104% and 69% greater than mean heights of 10-year-old plantations of tubelings and plugs (competition levels combined), respectively. Because the height differences are substantial, it is unlikely that they are due wholly to the difference in plantation age, but are in fact an expression of the inherent growth potential of bare-root tubelings and plugs.

The level of competition had a more pronounced effect on the mean annual height growth of tubelings than of plug trees. From 1974 to 1980 the difference in mean annual height increment between light and heavy competition was 39.8% and 9.3% for tubelings and plug trees, respectively. This substantiates the results of Scarratt (1974), which suggest that tubeling stock is suitable for a narrower range of less competitive sites than bare-root stock. This is further borne out when it is considered that in this study, bare-root stock under moderate competition exhibited an overall mean growth rate (1974-1980) 85.4% and 40.0% greater than that of tubelings and plug trees, respectively. In 1980, plug trees grew comparatively well, i.e., 30.8 cm vs 33.3 cm for bare-root trees, but in all probability, basic differences in total height between stand types will be maintained. This conjecture is supported by the observation of Armson (1975) that small and large black spruce trees at the time of planting remain small and large after the tenth growing season. Scarratt (1974) also noted that performance of container stock is very dependent on tree size and that many early failures can be related directly to this factor. Small trees with small crowns presumably are unable to compete vigorously with other vegetation and gain prominence, but instead become suppressed and grow relative to their size or die.

Root Development

Rapid root growth into the surrounding soil to tap needed supplies of moisture and nutrients is critical for survival of planted trees. Any factor or combination of factors that inhibits early rapid root growth can, at the outset, condition future growth. Although the root system of bare-root stock is often deformed by planting, water absorption can take place at a reduced rate until new root growth occurs. Apart from water and nutrients supplied from within the tube, there are similar delays in absorption of these elements by tubelings, but the presence of the rigid walled container is an added obstacle to the outward growth of roots (McClain 1978) and delays access to moisture and nutrients even further. Observations made in 1972, one year after the tubelings and plugs were planted operationally (Anon. 1971), revealed that those tubelings not heaved by frost were easily pulled from the ground and that plug seedlings could be removed from the soil only by breaking roots. The tube had obviously prevented early normal root growth necessary for anchorage and rapid future growth.

Adventitious root development is an important silvical characteristic of black spruce and is an obvious feature in the development of its root system (McClain 1978). While early rapid root growth was noted to be critical for survival it is the development of a new root system that eventually meets the requirements for anchorage and absorption. With some exceptions, the original roots, regardless of stock type, cease to function as a major component of the root system (e.g., Fig. 10), a fact which is substantiated by the ranges in root ages noted for tubelings, plugs, and 3+0 bare-root stock. Since no single major root was found to be as old as the tree, root system development for at least 10 years after planting is indeed a dynamic process in black spruce.

The conditions which prevailed at the time of adventitious root development can only be assumed, but deep planting or planting on a slant may have caused soil and organic debris to surround the stem, providing the suitably moist conditions for adventitious root development. The frequency of adventitious roots in black spruce suggests the need for this characteristic to be expressed if tree growth is to proceed normally. Unfortunately, silvical characteristics of species are often neglected in the development of containers.

Nutrition

The lack of any clear relationship between nutrient concentration and stand type indicates that, if nutritional differences between bare-root stock and tubelings were present at the time of planting, they have since subsided. Deficiency levels noted for nitrogen, phosphorus and, in general, magnesium, are not unlike values recorded for black spruce stands elsewhere (van Nostrand and Bhure 1973). Despite moderate nutrient deficiencies, however, growth (Fig. 2) was not significantly affected except where heavy competition was present, in which case interacting factors were probably responsible for reduced growth.

SUMMARY AND CONCLUSIONS

The results of the present study were obtained from sample plots located in operationally planted plantations of Ontario tubelings, plugs and 3+0 bare-root black spruce. Although the bare-root plantation was one year older than the tubeling and plug plantations its growth advantage after 11 years was clearly indicated. It was attributed principally to the original tree size and the respective ability of each stock type to develop its root system and crown under a given level of overhead competition. Interestingly, the height growth of plug trees after 10 years was similar to the height growth of bare-root stock after 11 years. Examination of the nutritional status of each stock type clearly indicated deficiencies in some nutrient elements, notably nitrogen, but this was not reflected in suppressed growth or in the coloration of tree foliage.

While the present study is based on regeneration methods of diminishing use, the results are important because they direct our attention to the silvics, stock type (bare-root, containers) and growth of various species in relation to environment. These are significant components of a successful regeneration system and should be considered in the design and choice of future regeneration systems. Specifically:

1. Production of black spruce as bare-root, tubeling and plug stock creates planting stock with inherent morphological and physiological differences. These differences precondition stock to achieve a given level of performance under similar environments. It appears that older, larger and heavier stock will outperform younger, smaller, lighter tubeling and plug stock.
2. It is an inherent characteristic of black spruce to produce adventitious roots. This process is critical to secure establishment and, therefore, must not be impeded. Slower growth of black spruce tubelings can be related to the fact that the tube restricts the early natural form of root development of the species.

ACKNOWLEDGMENT

I wish to thank Terry Casella, Senior Unit Technician, Northern Forest Research Unit, who undertook the field and laboratory work, and Larry Spence, Chemical Analyst, Ontario Tree Improvement and Forest Biomass Institute, Maple, for his assistance in analyzing tree foliage samples.

LITERATURE CITED

Anon.
1971. Dog River silvicultural report. Ont. Min. Nat. Resour., Thunder Bay District. File Rep.

Armson, K.A.
1975. Establishment and early development of black spruce. p. 45-56 in Black Spruce Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symposium Proc. O-P-4.

Arnott, J.T.
1974. Performance in British Columbia. p. 283-290 in R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Barnett, S.
1974. Field performance: Does container stock do a better job? p. 275 in R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Fraser, J.W. and Wahl, W.W.
1969. Frost and tubed seedlings. Dep. Fish. For., Chalk River, Ont. Inf. Rep. PS-X-12. 13 p.

Gutzwiler, J.R. and Winjum, J.K.
1974. Performance of containerized coniferous seedlings in recent forest regeneration trials in Oregon and Washington. p. 291-297 in R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric.Counc. Publ. No. 68.

Hite, W.A.
1974. Container field performance in the Rockies and Plains. p. 306-309 in R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Johnson, H.J.
1974. Canadian Forestry Service container planting trials in Alberta, Saskatchewan and Manitoba. p. 298-305 in R.W. Tinus, W.I. Stein and W.E.Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Lowry, G.L.
1970. Variations in nutrients of black spruce needles. p. 235-259 in C.T. Youngberg and C.B. Davey, *Ed.* Tree Growth and Forest Soils. The North American Forest Soils Conference. Oregon State Univ. Press.

Lowry, G.L. and Avard, P.M.
1969. Nutrient content of black spruce and jack pine needles. III. Seasonal variations and recommended sampling procedures. Pulp Pap. Res. Inst. Can. Woodlands Pap. No. 10.

MacKinnon, G.E.
1974. Survival and growth of tree plantations on crown lands in Ontario. Ont. Min. Nat. Resour., Div. For., For. Manage. Br. 17 p.

McClain, K.M.
1978. Black spruce seedlings grown in Ontario tubes can grow well. p. 166-171 in E. van Eerden and J.M. Kinghorn, *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8.

McLean, M.M.
1959. Experimental planting of tubed seedlings 1958. Ont. Dep. Lands For., Div. Res., Tech. Series Res. Rep. No. 39. 13 p.

Morrison, I.K.
1974. Mineral nutrition of conifers with special reference to nutrient status interpretation: A review of literature. Dep. Environ., Can. For. Serv., Ottawa, Ont. Publ. No. 1343. 74 p.

Mullin, R.E.
1978. Plantation performance averages for black spruce. Ont. Min. Nat. Resour., For. Res. Note No. 19. 2 p.

Reese, R.H.
1974. Container production in Ontario. P. 29-37 in R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seed ling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Salonius, P.O.
1977. Nutrient concentrations in black spruce foliage immediately following fertilization. Soil Sci. Soc. Am. J. 41:136-139.

Scarratt, J.B.
1974. Performance of tubed seedlings in Ontario. p. 310-320 in R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric.Counc. Publ. No. 68.

Swan, H.S.D.
1970. Relationships between nutrient supply, growth and nutrient concentrations in the foliage of black spruce and jack pine. Pulp Pap. Res. Inst. Can. Woodlands Pap. No. 19.

Van Eerden, E. and Kinghorn, J.M., *Ed.*
1978. Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./ Can. For. Serv. Joint Rep. No. 8. 357 p.

van Nostrand, R.S. and Bhure, N.D.
1973. Growth response of black spruce to fertilization in Newfoundland. Dep. Environ., Can. For. Serv., St. John's, Nfld. Inf. Rep. N-X-95. 20 p.

Walker, N.R. and Johnson, H.J.
1974. Field performance of pine and spruce reared in the BC/CFS styroblock - Alberta. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-84. 12 p.

CONTAINER STOCK SPECIFICATIONS FOR NORTHERN ONTARIO

J.B. Scarratt[1]

Abstract.--The size of containerized seedling currently produced for use in northern Ontario generally confines container planting to the easier site conditions with a minimum of competing vegetation. Studies initiated in 1978 compare the performance of various sizes and grades of paperpot and bare-root planting stock over a range of sites, and attempt to define desirable container stock specifications for a broader range of site conditions. Third-year growth data from the first plantings of black spruce *(Picea mariana* [Mill.] B.S.P.) and jack pine *(Pinus banksiana* Lamb.) are presented and discussed.

Résumé.--En raison de la dimension des semis en mottes emballées qui sont couramment utilisés dans le nord de l'Ontario, ces derniers sont généralement plantés dans des stations assez favorables où la concurrence de la végétation est la moins forte. Les études entreprises en 1978 comparent les résultats obtenus dans différentes stations avec des plants de dimensions et de qualité diverses, à racines nues et en récipients de papier, et essaient de définir les caractéristiques souhaitables d'un matériel de reproduction en récipients à planter dans une gamme plus large de conditions stationnelles. On présente les résultats obtenus trois ans après la plantation ainsi qu'une discussion sur le sujet.

INTRODUCTION

It has been estimated that production of containerized planting stock in Ontario will reach 25 million seedlings by 1983 (Heeney 1982), at which time container planting will account for 27% of all planting in the province. In view of the importance of container planting to the overall regeneration program, and in order to justify the substantial capital investments in seedling production facilities, it is clearly essential that containerized planting stock be of such size and quality that it can become fully established and free to grow within a reasonably short time (3-5 years) after outplanting. Unfortunately, current operational experience shows that, while containerized jack pine *(Pinus banksiana* Lamb.) generally performs well in Ontario, field performance of container-grown spruces is frequently less than satisfactory, and is rarely comparable to that of bare-root stock.

Although numerous factors besides planting stock influence plantation success, there can be little doubt that, with current planting stock specifications, container planting in Ontario is still suited primarily to the easier, drier sites, supporting light to moderate vegetation of low competitive vigor. While this has not been particularly restrictive for the planting of jack pine, it means that the risk of suppression by competing vegetation excludes use of the spruces from the more fertile, upland sites. Consequently, for these species, the spectrum of sites currently suitable for container planting is considerably narrower than that for bare-root stock. Clearly, this situation must change if the burgeoning government and industry container planting programs are to

---

[1] Research Scientist, Great Lakes Forest Research Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario.

be made more universally applicable, in terms of range of sites to be reforested, while still retaining operational flexibility.

Many of the disappointing results of the past can be attributed to the use of excessively small stock and/or planting on too difficult sites. Small seedlings not only suffer higher mortality, but also produce trees of lower average quality and poorer growth rates (Scarratt 1974). Several writers have pointed to the importance of seedling size at planting in determining subsequent plantation performance (Dobbs 1976, Roller 1977, Walker and Johnson 1980, Walker and Ball 1981), although little attention has been given to the optimization of stock size for different site conditions.

Container stock specifications suggested by Scarratt and Reese (1976) were an early attempt to relate stock grade to preliminary standards for field performance, and were based on the need to achieve free to grow status within three years of planting on easier sites. However, in many instances containerized seedlings continue to be planted on sites to which they are morphologically unsuited. Obviously, this is neither biologically nor economically acceptable. In order to increase the overall effectiveness of container planting and extend its use to more fertile, upland sites larger stock and specific site treatments are needed if the spruces especially are to perform adequately and reliably under the more difficult conditions that such sites present. To be realistic, two or three grades of stock may be needed to match sites of differing severity.

Studies aimed at the development of seedling specifications and associated growing schedules necessary to extend the effective application of container planting to a broader range of site conditions were initiated in 1978. The work described here is concerned with the preliminary testing and screening of an extended range of container stock grades on a limited number of sites. It attempts to identify a small number of promising seedling grades, with performance comparable to that of bare-root stock, for more extensive testing over a wider range of sites subjected to different pre- and post-planting treatments. Third-year results of the first year's planting of black spruce *(Picea mariana* [Mill.] B.S.P.) and jack pine are reported. All container stock was grown in the Japanese paperpot, the principal container currently used in northern Ontario.

STUDY DESCRIPTION

Planting Stock

This series of studies is concerned primarily with comparing the growth performance of various grades of bare-root and paperpot planting stock. However, in 1978 jack pine tubelings (T) grown in the 1.9 x 7.6 cm Ontario split-plastic tube and direct sowing treatments (SD) of jack pine were included on a limited basis because these were the principal options being considered for operationally regenerating some of the sites concerned.

Bare-root stock was supplied by the Ontario Ministry of Natural Resources' Swastika nursery, adjacent to the study sites. All stock was fresh-lifted on 2 May and was cool-stored (1.6 - 4.4 °C) at the nursery for 2-4 weeks until time of planting. Only one grade (2-0) of jack pine bare-root stock was planted, whereas small (3-0), medium (1.5-1.5) and large (1.5-2.5) grades of black spruce were used.

Paperpot seedlings were grown in the greenhouses of the Great Lakes Forest Research Centre in Sault Ste. Marie. In order to produce the required range in grade of planting stock, crops were started at three different times, viz: 28 May 1976, 14 February 1977, and 27 May 1977. Four sizes of paperpot were used, depending on the crop, to accommodate the different grades of seedling and to avoid inter-rooting between containers of seedlings on the longer growing schedules. Specific crop codes identify the resulting seven crop date/container size treatment combinations:

Crop code	Stock description	
	Date sown	Container size
76-2-5	28 May 1976	FH 508
76-2-6	"	FH 608
77-1-4	14 Feb 1977	FH 408
77-1-5	"	FH 508
77-1-6	"	FH 608
77-2-3	27 May 1977	FH 308
77-2-4	"	FH 408

Each crop was overwintered at least once, and presumably all stock was in a comparable physiological condition at time of planting in the spring of 1978.

Seed for the paperpot stock, supplied by the Ontario Ministry of Natural Resources, was of the same site region provenance (3200) as the bare-root stock, but not from the same seedlot. Although the different crop start dates necessitated minor variations in growing regime, cultural methods were essentially the same for each crop. Water-soluble fertilizers were applied two or three times per week, depending on the stage of seedling development, and, during the main growing period, consisted principally of 20-20-20 at 200-300 ppm N applied through the irrigation water. For two weeks at the beginning and end of the growing period in the greenhouse 10-52-10 at 100-150 ppm N was used. Seedlings remained in the greenhouse for about 12 weeks (jack pine) or 16 weeks (black spruce) of their total growing period; all seedlings were overwintered in Sault Ste. Marie under good snow cover, but were moved north to the Swastika nursery in early spring of the year of planting to avoid premature budbreak. The jack pine tubelings (T) were supplied by the Swastika nursery; they had been sown in early July 1977, and were consequently quite small at time of planting. Morphological characteristics of all planting stock at time of planting are given in Table 1.

Study Area

The 1978 plantings were established in the Englehart Management Unit (EMU) approximately 30 km east of Kirkland Lake, Ontario, within the Missinaibi-Cahonga section (B.7) of the boreal forest region (Rowe 1972). The five planting sites (Table 2) are situated in the townships of Gross and Bompas, all within a few kilometres of the Swastika nursery (48°02'N, 80°22'W).

The EMU is characterized by flat to gently undulating topography, and the elevation of the experimental sites ranges from 300 to 450 m above sea level. Most soils of the area are developed either from glacial till deposits on the upland sites or from outwash, deltaic sands, silts and windblown sands over silt or silt loam on the lower, flatter areas. They are mostly podsolized with a thick, poorly developed LFH layer and well developed Ae and Bf horizons where not disturbed by logging or scarification.

Table 1. Morphological characteristics of black spruce and jack pine planting stock (n = 50).

Stock type/ grade	Shoot height (cm)		Root-collar diam (mm)		Height/ diam ratio		Total dry weight (g)		Shoot/ root ratio		Root area index[a] $(cm)^2$	
	bS	jP[b]	bS	jP	bS	jP	bS	jP	bS	jP	bS	jP
Paperpots												
76-2-5	25.7	29.6	3.9	4.4	6.6	6.8	3.30	3.54	2.2	2.1	48.3	49.7
76-2-6	22.0	36.1	4.3	5.3	5.1	6.8	3.94	5.42	2.2	2.2	69.2	67.5
77-1-4	15.1	9.8	2.9	2.4	5.0	4.0	1.42	1.61	1.4	2.0	33.4	34.4
77-1-5	18.2	22.3	3.7	3.4	4.7	6.7	2.29	2.64	2.3	2.1	37.9	45.6
77-1-6	15.5	15.6	3.6	5.1	4.1	3.1	1.63	4.22	1.7	1.9	37.4	63.1
77-2-3	8.1	12.8	1.0	1.2	8.1	10.5	0.33	0.32	1.2	1.7	2.8	4.8
77-2-4	9.4	14.8	1.0	1.5	9.4	9.7	0.38	0.53	1.4	1.5	2.5	9.5
Tubelings												
T	-	7.8	-	1.5	-	5.2	-	0.15	-	2.0	-	5.8
Bare-root												
2-0	-	18.5	-	4.1	-	4.6	-	3.98	-	4.3	-	44.5
3-0	24.2	-	3.5	-	7.0	-	2.55	-	3.3	-	23.6	-
1.5-1.5	28.0	-	4.7	-	6.1	-	5.15	-	2.3	-	62.3	-
1.5-2.5	25.6	-	6.9	-	3.8	-	8.38	-	2.3	-	68.8	-

[a] Morrison and Armson (1968)

[b] bS/jP = black spruce/jack pine

Table 2. Description of experimental planting sites, Engelhart Management Unit, 1978.

Site number	Township	Description
1	Gross	Terrain flat; deep, fresh, well drained, fine silty sand. Original stand jack pine and trembling aspen; logged in 1974; site prepared with Marttiini plow in 1975. Jack pine tubelings planted in 1976; failed. High competition potential; aspen regrowth cut by hand in October 1977. Planted with black spruce and jack pine 10 May 1978.
2	Gross	Terrain rolling; deep, excessively drained, windblown sand. Site prepared with barrels in 1975. Other details as for site 1. Low competition potential. Planted with jack pine only on 17 May, 1978.
3	Bompas	Lower slope on rolling terrain beside Bompas Lake; deep, fresh, well drained sandy loam till with silt and boulders. Original mixed stand of black spruce, white spruce, trembling aspen and white birch with some jack pine. Logged in 1977 leaving heavy slash and residual birch; site prepared with Young's teeth in October 1977. Heavy competition potential (especially aspen). Planted with black spruce and jack pine 2 June 1978.
4	Bompas	Ridge top on rolling terrain; soil similar to that of site 3, but more shallow with some exposed bedrock. Smaller birch component in original stand, hence less residual slash. Heavy competition potential. Other details as for site 3. Planted with black spruce and jack pine 26 May 1978.
5	Bompas	Upper slope on rolling terrain; shallow, excessively drained sandy loam till over shattered, and frequently exposed, bedrock. Original stand jack pine and black spruce with some birch and poplar. Logged and site prepared as site 3. Low competition potential. Planted with jack pine only on 30 May 1978.

The area has a modified continental climate (Chapman and Thomas 1968), characterized by low winter and high summer precipitation, a wide annual temperature range, and large variation in daily temperature. Average annual precipitation for Kirkland Lake during the period 1951-1980 was 86.6 cm of which 34.0 cm (39%) fell between May and August (Anon. 1982). The mean annual growing season (5.5°C base) is 162 days, and the average length of frost-free period 80 days (Chapman and Thomas 1968).

Experimental Method

At each site an experiment was laid out in a randomized block design with six replications. Each block consisted of one row of 25 trees from each of the planting stock treatments. Black spruce and jack pine, when planted on the same site, were located in separate plots.

Planting was carried out during the latter part of May and early June (Table 2). Bare-root stock was slit-planted with a shovel. Paperpot seedlings were planted either with a Pottiputki (FH 308 and FH 408) or with a tool that removed a plug of soil (FH 508 and FH 608). A dibble was used to plant the tubelings. On site 1 trees were planted along the shoulder of the furrow made by the Marttiini plow; elsewhere they were planted in rows approximately 1.8 m apart parallel to the direction of scarification. Where a direct sowing treatment (SD) of jack pine was included, seedspots of minimum diameter 0.3 m were made with a Sandvik hoe and about 10 seeds were sown per spot. The resulting seedlings were thinned to one per spot at the end of the second growing season. All stock on sites 1, 3 and 4 was hand-released in 1979.

All experiments were assessed for survival, seedling condition and shoot growth at the end of the first, second and third (1980) growing seasons. Only the results of the latter assessment are reported here. The data were subjected to analysis of variance and significant treatment effects identified by Tukey's multiple range test.

RESULTS AND DISCUSSION

Survival

The weather at time of planting was good, with adequate rainfall, and even after three growing seasons all types and grades of planting stock showed exceptionally good survival on all sites (Table 3). However, total survival figures, by ignoring differences in seedling condition, may give an unrealistically optimistic view of seedling condition (Scarratt 1974). The fact that a seedling is able to survive does not necessarily mean that it will grow well.

If we consider the proportion of seedlings with a class 1 or class 2 condition rating[2] (Table 3) treatment differences are revealed that are not evident from the data for total survival. Over all stock types and grades, a higher proportion of jack pine seedlings (67% and 84% on sites 1 and 3, respectively) fell into the combined class 1+2 category than was the case with black spruce (15% and 42% on sites 1 and 3), reflecting the more aggressive growth habit of the pine. However, none of the differences between stock types or grades were significant in 1980, even though, in spruce particularly, a substantially larger proportion of poorer quality seedlings had been enumerated in the smaller grades of planting stock at earlier assessments. This apparent discrepancy may derive from the fact that by the end of the third growing season all seedlings had settled into a similar pattern of development unrelated to stock treatment. This situation will be discussed later in relation to height growth. By contrast, the distinct differences between sites in proportion of class 1+2 surviving seedlings would seem to reflect real differences in site quality. It may be noted that black spruce planted on site 1 has suffered recurrent damage from spring frosts, accounting for the lower quality assessment of spruce at this site in comparison with sites 3 and 4.

Height Growth

Provided that the stocking of healthy, vigorous trees is adequate, growth rates are the primary expression of plantation success. From a practical viewpoint, height growth is usually of greatest concern in young plantations because of the risk of suppression by competing vegetation. Seedlings which are able to keep ahead of weed growth during the first few years after outplanting are more likely to become firmly established and form part of the final crop. Therefore height growth performance only is discussed here.

In comparing the performance of containerized and bare-root planting stock, it is

Table 3. Survival (%) of black spruce and jack pine planting stock after three growing seasons (1978-1980).

	Black spruce						Jack pine					
	Site 1		Site 3		Site 4		Site 1		Site 2		Site 3	
Stock type/ grade	Total surv- ival	Class 1+2	Total surv- ival	Class 1+2	Total surv- ival	Class 1+2	Total surv- ival	Class 1+2	Total surv- ival	Class 1+2	Total surv- ival	Class 1+2
76-2-5	98	10	99	33	99	30	99	73	98	49	98	82
76-2-6	99	12	100	50	100	39	99	68	100	58	100	85
77-1-4	100	16	91	44	100	35	97	65	98	62	-	-
77-1-5	94	16	94	45	98	26	97	59	100	66	98	88
77-1-6	96	19	95	39	96	29	99	70	100	67	100	89
77-2-3	90	21	94	35	97	36	93	70	94	48	96	87
77-2-4	-	-	88	46	96	30	98	71	100	63	100	79
T	-	-	-	-	-	-	89	68	90	50	99	81
2-0	-	-	-	-	-	-	91	56	92	59	99	82
3-0	90	10	95	46	98	28	-	-	-	-	-	-
1.5-1.5	95	13	97	40	99	41	-	-	-	-	-	-
1.5-2.5	92	21	96	39	93	41	-	-	-	-	-	-

---

[2] Classes 1 and 2: seedlings of at least moderate vigor, healthy, and with only minor morphological abnormalities (Scarratt 1974).

clear that the latter, being considerably older, usually has a substantial advantage in terms of both initial height and mass at time of planting (Table 1). For this reason, performance comparisons between the two stock types are sometimes criticized for comparing "apples and oranges". However, from the practical viewpoint of regenerating a given site such comparisons are fully justified by the fact that we are concerned with the relative performance impact of different planting options over a given period of time irrespective of their age or origin.

Clearly, if containerized stock is to have the same performance impact as bare-root on a given site, it must first grow faster until height equivalence is achieved, and then continue to match the height growth of bare-root stock until it is free to grow. However, while superior initial growth rates have long been claimed for container-grown stock, operational experience has frequently shown a lag in total height equivalent to one or more years' growth in comparison with bareroot stock. Although such a growth lag may be acceptable on easier site conditions, it may mean the difference between success and failure on more difficult sites.

Data for shoot height, current (1980) height increment and current height increment percent (CHI%) (current height increment expressed as a percentage of 1979 total height -- i.e. rate of height increment) are illustrated in Figures 1 to 3 (black dots indicate equivalents to current operational paperpot grades).

Jack pine

In jack pine, both stock type/grade and site had a significant effect on height growth, although their interaction was significant only for CHI%. Clearly, the larger paperpot stock produced the largest trees over the three-year period, with several grades surpassing the performance of 2-0 bare-root stock, especially on the better sites 1, 3 and 4. However, Figures 2 and 3 suggest an overall levelling off in the effects of stock grade upon height increment, contrasting with the strong, continuing response to site. This parallels the situation with class 1+2 survival, and points to a progressive stabilization of growth rates at the five sites. Total height and height increment of all stock types were poorest on the drier sites 2 and 5.

In terms of total height, tubelings (T) and 77-2-3 paperpots still lagged considerably behind 2-0 bare-root stock after three growing seasons. The sturdier 77-2-4 paperpot stock, comparable with current operational grades, was a somewhat better choice, although the data indicate that larger container stock would be needed to reliably achieve height parity with bare-root stock. However, this would necessitate either the use of a larger container or a longer growing period in the FH 408 paperpot. Neither is a desirable choice; the larger container would drastically reduce greenhouse production capacities, while an extended growing period with the FH 408 paperpot could well lead to severe inter-rooting problems and a reduction in morphological seedling quality (e.g. tall, spindly seedlings).

While current height increments (Fig. 2) were still positively related to seedling size at planting, differences in rate of height increment (Fig. 3) were beginning to level off. This is confirmed by Figure 4, which demonstrates the extent to which rates of height increment of both stock types had evened out on site 4. A similar response was noted on other sites also. Stabilization of growth rates implies that the benefits of containerization had been outgrown by the end of the third growing season. Henceforth height growth may be expected to increase at a steady rate, irrespective of stock origin, in direct relation to individual tree size and site potential. It is now unlikely that the smaller grades of container stock will catch up to the bare-root stock.

The high relative rate of height increment in direct sown jack pine is noteworthy, for it typifies the early vigor of this species on good sites. However, most seedlings were still quite small (<20 cm) in 1980 (Fig. 1) and are likely to have increasing difficulty coping with the prolific vegetation of sites 3 and 4 unless they are released a second time. Consequently, it is concluded that direct sowing would not have been a satisfactory regeneration method for these sites, although it would have been a reasonable choice, given the difficulties experienced in planting seedlings, on the shallower and drier site 5. By comparison, it should be pointed out that, with the exception of tubelings on sites 3 and 4, all other stock types and grades had achieved free to grow status by 1980.

On balance, it appears that the current specifications for jack pine seedlings grown in FH 408 paperpots (12-14 weeks old, 10-15 cm shoot height, 500-700 mg dry weight) were generally adequate for the sites on which this species was planted. However, the data indicate a one-year lag in height growth compared with bare-root stock. For the majority

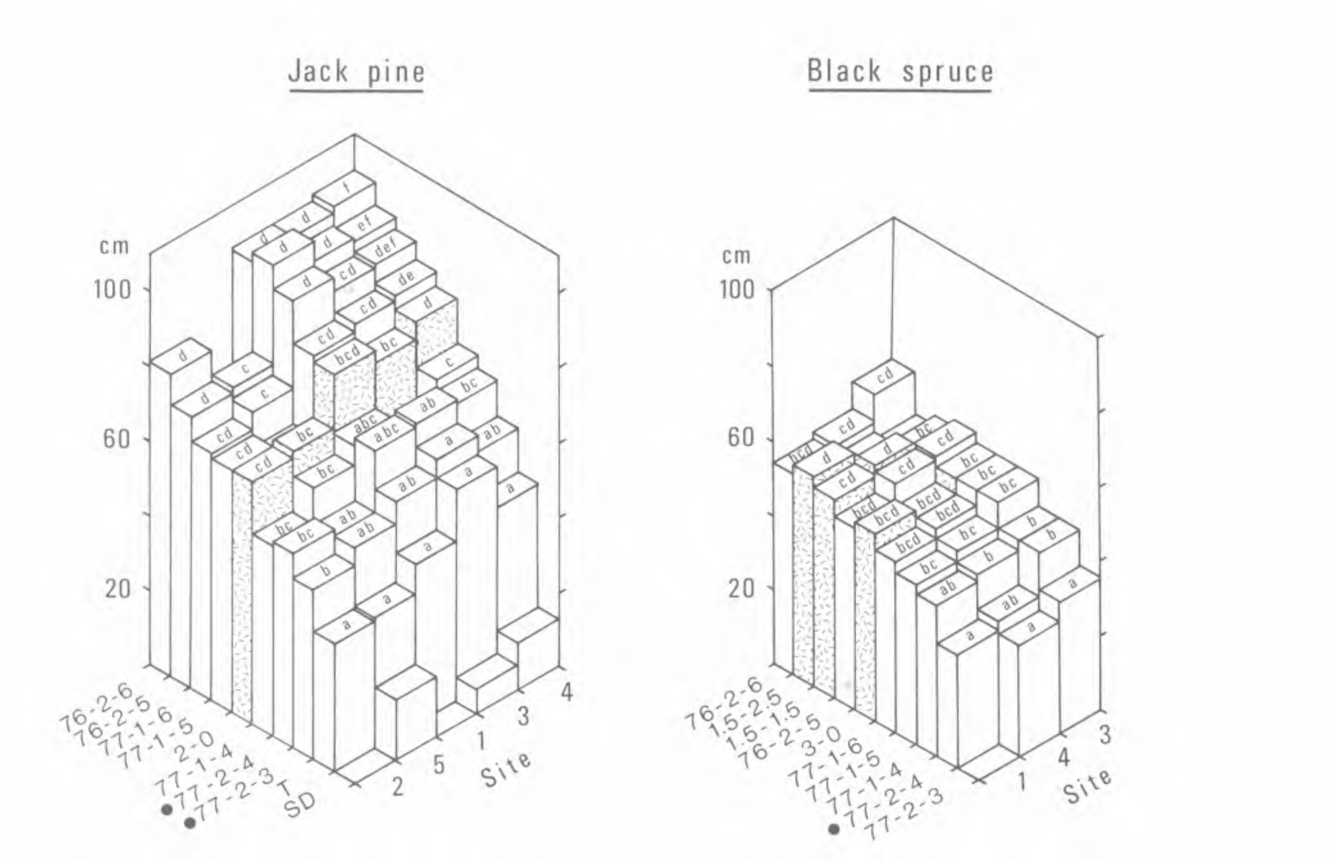


Figure 1. Total shoot height (1980) of bare-root and containerized planting stock grades. (Within sites, treatments with the same letter do not differ significantly: p = 0.05)

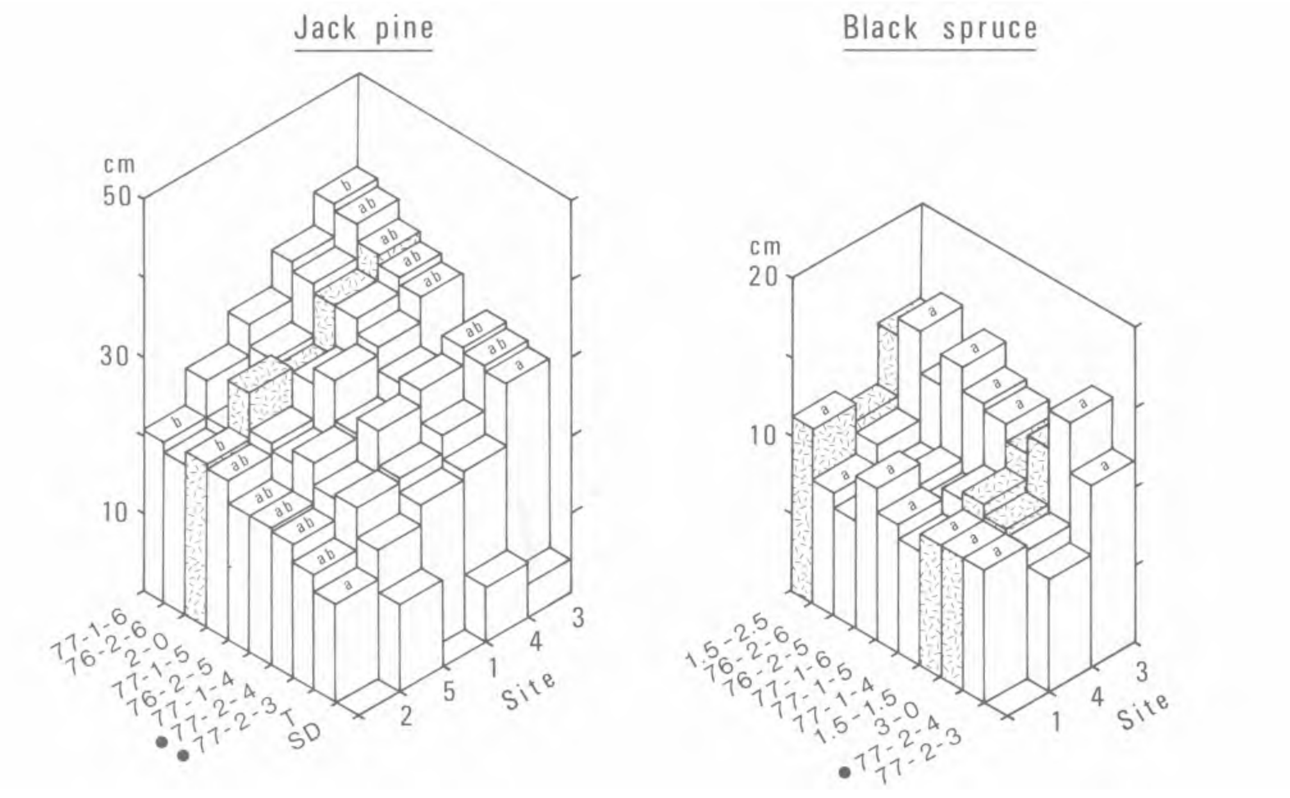


Figure 2. Current height increment (1980) of bare-root and containerized planting stock grades. (Within sites, treatments with the same letter do not differ significantly: p = 0.05)

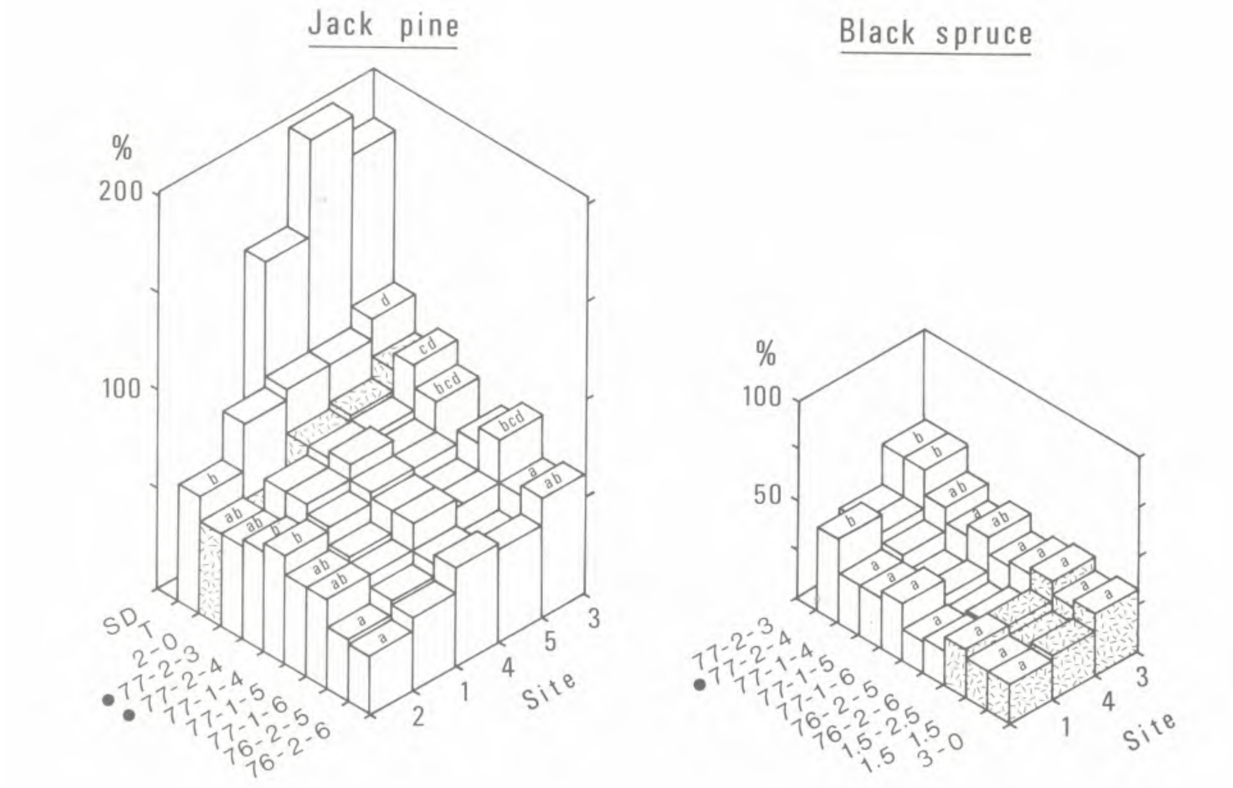


Figure 3. Current height increment % (1980) of bare-root and containerized planting stock grades. (Within sites, treatments with the same letter do not differ significantly: p = 0.05)

of sites, such as sites 2 and 5, on which jack pine is planted, a one-year growth lag with container stock would be of little consequence. But on sites with heavier vegetation competition, larger container stock, or at least the maximum of the specifications set out above may be desirable. This does not exclude the possibility that release from competition may also be required, for it will be recalled that sites 2, 3 and 4 were hand-released in 1979.

Black spruce

In black spruce, as in jack pine, both stock type/grade and site had significant effects upon all height growth parameters, although in this case only shoot height showed any significant interaction. The overall response of shoot height to site differences was not as pronounced as in pine, despite the lower proportion of class 1+2 seedlings that resulted on site 1 from the recurrent frost damage noted earlier. All stock grades had substantially greater current height increment on site 3 than on site 4. Since there was no corresponding difference between sites in total heights, and in view of the heavier weed competition (aspen especially) to which trees were subjected on site 3, it is not unreasonable to suppose that the greater height increment reflects a stronger response to the hand release carried out in 1979.

In relation to competing vegetation, none of the black spruce treatments, bare-root or container-grown, could be considered especially successful. On sites 3 and 4 even the larger stock grades (bare-root included) were barely adequate to keep ahead of the vegetation, emphasizing the need to include competition control as an essential element in regeneration prescriptions for spruce plantations.

If typical, the weak performance of bare-root stock on the moderately severe sites 3 and 4 suggests that comparability of growth with bare-root stock may be too conservative a criterion by which to judge the performance of container-grown stock, especially on more competitive sites. Clearly, if conventional grades of bare-root stock experience difficulty in achieving early, effective establishment of spruce on such sites, we should require better growth rates from both container-grown and bare-root stock in order to ensure reliable plantation

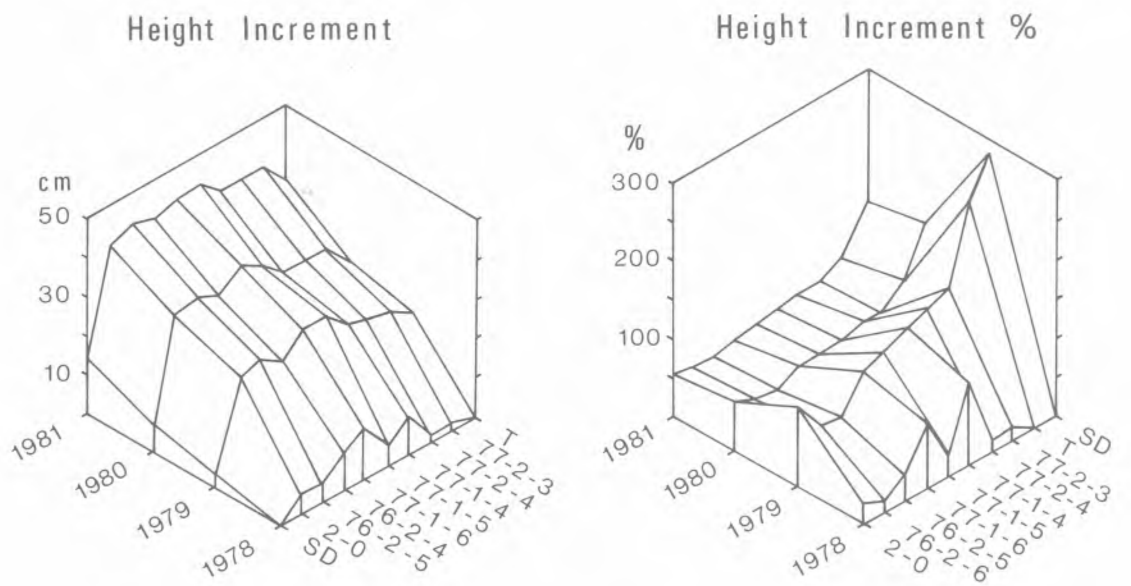


Figure 4. Comparative progression of jack pine height increment on site 4.

establishment. While it is too early to make a final judgment, the question should be borne in mind when considering the present results with containerized spruce.

Although, in general, the larger grades of planting stock grew best, on none of the sites was there any significant difference in height increment or shoot height between bare-root grades. This is somewhat surprising in view of the substantial differences in tree mass at time of planting, and contrasts with the long-term findings of Mullin (1980) regarding the relative performance of seedling and transplant stock. Height increment on site 4 is now (1981) practically identical for all three bare-root grades (Fig. 5), which indicates that the total height relationship is unlikely to change in the future.

Larger seedlings have clearly been of significant benefit in promoting shoot heights of container-grown stock to match those of bare-root material. It is equally evident that the growth performance of the current grade of black spruce paperpot stock (i.e., 77-2-4) was significantly poorer than that of other types and grades and failed to match even the growth of 3-0 bare-root stock. In fact, on sites 3 and 4 many of the 77-2-3 and 77-2-4 seedlings were already being suppressed by weed competition. In all grades of paperpot stock, differences in height increment had levelled off by 1980 and seedlings were now growing at the same relative rate as bare-root stock, indicating, as with jack pine, that the benefits of containerization had been outgrown. This stabilization of height relationships between stock types and grades means that the smaller grades of paperpot stock are not now likely to catch up, and may fall progressively further behind as they succumb to the competition.

Since the current grade of black spruce paperpot was inadequate even for the conditions presented by sites 3 and 4, what size of stock should be used for these and for more difficult site conditions? It is obviously too early in this study to provide definitive specifications. However, as a preliminary working recommendation, it appears that black spruce container stock should, at least, have a shoot height of 20 cm and a minimum dry weight of 1.0 g in order to match the height growth performance of 1.5-1.5 bare-root stock. Seedlings of these dimensions will require one season to grow, and might be sown in late March/early April, grown in a greenhouse for 14-16 weeks, and then grown on outdoors for overwintering and planting the following spring. (Other production schedules could be used to achieve the same results, but will not be discussed here.) Stock of these dimensions should be looked upon as the *minimum* requirement for sites with light to moderate competition potential. This assumes that, for most situations under which black spruce container stock is planted, a one or two year growth lag is unacceptable if the risk of suppression by competing vegetation and/or high re-

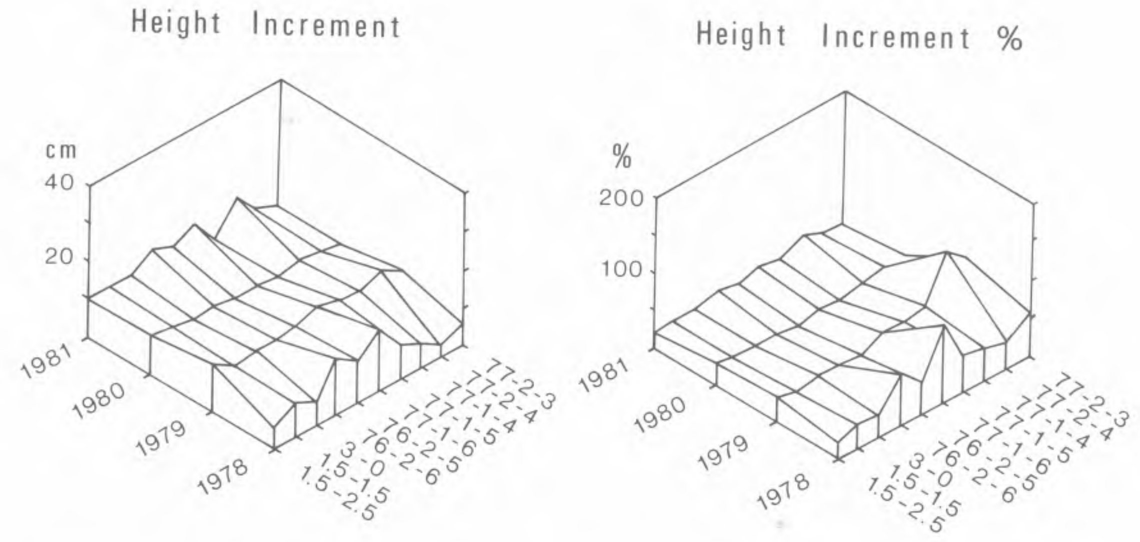


Figure 5. Comparative progression of black spruce height increment on site 4.

lease costs are to be avoided, and that seedlings must perform at least as well as 1.5-1.5 bare-root stock.

In view of the short period over which the growth benefits of containerization prevail, it is clear that, if container stock is to achieve parity of shoot height with bare-root stock, this must occur within three years of outplanting, and before vegetation dominates the site. For this reason, even larger, older stock (up to 1.5 years old and perhaps equivalent to the experimental grade 76-2-5) will undoubtedly be necessary in order to extend the application of container planting to more fertile, upland sites. Although considerably more testing is required to define the optimum grade of seedling for such sites, it is evident that we must also be prepared to apply routine vegetation control treatments in conjunction with these larger grades to ensure early and effective establishment.

While spruce can be grown in the FH 408 paperpot for up to one year without difficulty, seedlings of greater specifications than those set out above should preferably not be grown in this size of container, especially if they are to be grown on into the second growing season. Even with black spruce, some inter-rooting between pots will almost certainly occur after such seedlings have been overwintered. Furthermore, the combination of restricted aerial growing space and extended growing period will produce a seedling that is out of balance with its pot and of impaired morphological quality (e.g. tall, spindly seedlings with few side branches and low photosynthetic area), as well as increasing the risk of disease within the dense foliage. For periods longer than one growing season an FH 508 paperpot or other container of equivalent size is recommended; the data do not indicate that anything larger is necessary. Because these longer growing cycles would allow the development of a well-knit root mass, plug-type containers (e.g., multipot) become a viable alternative to the paperpot for producing larger containerized black spruce.

The production of larger container stock on longer growing cycles will obviously increase production costs, particularly if a larger container is also employed. Planting costs may also increase slightly because larger seedlings are often more difficult to handle. However, these additional costs must be looked at in relation to the total cost of plantation establishment up to the point when seedlings are free to grow, not, as is the case now, simply in terms of nursery production costs. Continued use of the small grade spruce paperpot stock currently produced in Ontario on a 16-18 week rotation vitiates the objective of establishing a new crop as quickly and as cheaply as possible, even on the easier site conditions. The use of larger containerized planting stock, though more expensive in terms of nursery production, shipping and perhaps planting costs, must be balanced against its better growth performance after outplanting, the greater probability of successful establishment, and the probable reduced need for competition release before a free to grow status is achieved. The additional investment may be more than justified by more rapid and reliable plantation establishment, as well as by the prospect of extending the effective use of container planting to more difficult sites.

SUMMARY AND CONCLUSIONS

1. The study reported here is concerned primarily with the screening of comparative growth in a range of bare-root and overwintered experimental paperpot stock grades. It attempts to identify promising grades of containerized seedling for more extensive testing, with the objective of increasing the reliability of container planting as a reforestation method, and extending its application to a broader, often more difficult range of site conditions.

2. The results indicate that, in both jack pine and black spruce, the benefits of containerization, in terms of increased survival and early growth, were outgrown by the end of the third growing season. Beyond this, height growth and seedling condition stabilized in relation to stock type and grade. Henceforth, height increases are likely to depend upon individual tree size and site quality rather than upon stock origin. Thus, if container stock is to match or improve upon the performance impact of bare-root stock on a given site, seedlings must be of sufficiently large grade that this status is achieved within two, or at most three years from planting. This period coincides with the average three-year establishment "window" that exists following site preparation before weed competition begins to dominate most planting sites (Scarratt and Reese 1976).

3. The current grade of jack pine paperpot stock is considered adequate for most planting situations, provided that a one-year lag in height growth in comparison with bare-root stock is acceptable. Somewhat larger stock may be desirable for the most difficult sites on which jack pine is planted, although the need might be offset through the judicious use of herbicides.

4. In comparison with bare-root stock, the current grade of black spruce paperpot seedling, produced on a 16-18 week production cycle, suffered at least a two-year lag in height growth on sites with light to moderate competition growth, with many seedlings in imminent danger of suppression. This is an unacceptable level of performance. Substantially larger seedlings, grown for about one year in the FH 408 paperpot, are recommended as the minimum requirement for such sites to ensure at least parity of height growth with bare-root stock. However, even larger seedlings, preferably grown in an FH 508 paperpot or equivalent container for perhaps 1.5 years, are considered necessary in order to establish black spruce container stock successfully on the more fertile upland sites with heavy competition potential.

5. Planting stock is but one of a number of interacting factors which collectively constitute a regeneration prescription. While the preliminary results of this study indicate the need for two or more grades of black spruce container stock to match site conditions of differing severity, it is evident that their growth response will be conditioned by other factors besides site. Logging practices, the degree and method of site preparation, rate of competition ingrowth, time of planting, planting method, and especially the adequacy of post-planting tending may all substantially modify the response of planting stock grade on a given site. Ultimately, the interaction of all these factors must be taken into consideration when specifications for containerized planting stock are being defined.

ACKNOWLEDGMENTS

The author is indebted to the staff of the Kirkland Lake District and Swastika nursery, Ontario Ministry of Natural Resources for their continued encouragement and support in the conduct of these studies. Technical assistance was provided by B.R. Canning of the Great Lakes Forest Research Centre.

LITERATURE CITED

Anon.
1982. Canadian climatic normals, Volume 2. Precipitation. 1951-1980. Dep. Environ., Atmosph. Environ. Serv., Ottawa, Ont. 602 p.

Chapman, L.J. and Thomas, M.K.
1968. The climate of northern Ontario. Can. Dep. Transp., Meteorol. Br., Ottawa, Ont. Climatological Studies No. 6. 58 p.

Dobbs, R.C.
1976. Effect of initial mass of white spruce and lodgepole pine planting stock on field performance in British Columbia. Dep. Environ., Can. For. Serv., Victoria, B.C. Inf. Rep. BC-X-149. 14 p.

Heeney, C.J.
1982. The status of container planting programs in Canada. 5. Ontario. p. 35-39 in J.B. Scarratt, C. Glerum and C.A. Plexman, *Ed.* Proceedings of the Canadian Containerized Tree Seedling Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. 0-P-10.

Morrison, I.K. and Armson, K.A.
1968. The rhizometer--a device for measuring roots of tree seedlings. For. Chron. 44:21-23.

Mullin, R.E.
1980. Comparison of seedling and transplant performance following 15 years growth. For. Chron. 56:231-232.

Roller, J.R.
1977. Suggested minimum standards for containerized seedlings in Nova Scotia. Dep. Environ., Can. For. Serv., Fredericton, N.B. Inf. Rep. M-X-69. 18 p.

Rowe, J.S.
1972. Forest regions of Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Publ. 1300. 172 p.

Scarratt, J.B.
1974. Performance of tubed seedlings in Ontario. p. 310-320 in R.W. Tinus, W.I. Stein and W.E. Balmer *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Scarratt, J.B. and Reese, K.H.
1976. Objectives and criteria for planting stock production in Ontario. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. 0-X-253. 17 p.

Walker, N.R. and Ball, W.J.
1981. Larger cavity size and longer rearing time improve container seedling field performance. Dep. Environ., Can. For. Serv., Edmonton, Alta. For. Manage. Note No. 6. 2 p.

Walker, N.R. and Johnson, H.J.
1980. Containerized conifer seedling field performance in Alberta and the Northwest Territories. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-218. 32 p.

EARLY GROWTH OF BARE-ROOT AND PAPERPOT PLANTATIONS AT VARIOUS LOCATIONS IN NEW BRUNSWICK

H.H. Krause[1]

Abstract.--Jack pine *(Pinus banksiana* Lamb.) and black spruce *(Picea mariana* [Mill.] B.S.P.) planting stock were graded and their growth was monitored during the first few years after planting. Bare-root (2-0) jack pine has shown faster height development and biomass accretion than paperpot jack pine on similar sites, but paperpot black spruce was superior to bare-root (3-0 and 2-0) black spruce.

Résumé.--Des semis de pin gris *(Pinus banksiana* Lamb.) et d'épinette noire *(Picea mariana* [Mill.] B.S.P.) ont été classés, puis leur croissance a été contrôlée au cours des premières années après le plantage. Chez le pin gris planté à racines nues (2-0), la croissance verticale et celle de la biomasse ont été plus rapides que chez les sujets de même essence cultivés en tubes de papier et plantés dans des endroits semblables; cependant, c'est l'inverse qui s'est produit pour l'épinette noire (3-0 et 2-0).

INTRODUCTION

During the 1977 and 1978 planting seasons samples of different planting stock types were obtained at the planting site or as the stock was shipped from the provincial forest nursery at Kingsclear, New Brunswick for field planting. The samples included bare-root and containerized (2-0) jack pine *(Pinus banksiana* Lamb.) and bare-root and containerized (2-0 and 3-0) black spruce *(Picea mariana* [Mill.] B.S.P.) seedlings. Containers were FH 408 Japanese paperpots. The planting stock was evaluated according to morphological criteria and status of mineral nutrition.

The planted seedlings were sampled and subjected to similar measurements in the spring of 1978, 1979 and 1981 in an attempt to determine the effects of type and quality of planting stock on early plantation growth. Although the observations have shown striking differences in rates and patterns of early growth, the results do not lend themselves to rigorous mathematical analysis since the study was a survey rather than a controlled experiment.

METHODS

Selection of Planting Stock Samples

In 1977, with the assistance of personnel from the New Brunswick Department of Natural Resources (DNR), principal planting areas in the province were selected and stock in the process of being planted was sampled. The samples were taken without undue delay to the Forest Soils Laboratory of the University of New Brunswick. In 1978, samples were obtained directly from the provincial nursery at Kingsclear, as the stock was being prepared for shipment to known planting sites.

Each sample contained a minimum of 32 plants. Shoot lengths and root collar diameters were measured and total and component dry weights were determined. On the basis of mean shoot:root and height:root collar ratios, and seedling dry weight, a quality index (Dickson et al. 1960) was calculated. Each batch of planting stock was then rated according to provisional standards defined on the basis of published information (Scarratt and Reese 1976, Roller 1977, Armson and Sadreika 1979) and experience gained in the province (Table 1).

---

[1] Professor of Forest Soils, Dept. of Forest Resources, University of New Brunswick, Fredericton, New Brunswick.

The needles of seedlings were analyzed to determine macro-nutrient contents. Planting stock types used and stock evaluation results are summarized in Table 2. The jack pine paperpot stock was small to intermediate in size, and identified as grades 1 and 2. Bare-root jack pine was of a low grade in 1977, but a top grade was produced in 1978. Poor morphological balance was the reason for the low rating in 1977.

The quality of black spruce stock was extremely variable. A morphologically imbalanced, low-grade bare-root stock was produced in both years. In contrast, top and intermediate grade paperpot stock was shipped to the field in 1977 and 1978, respectively.

Sampling of Plantations

The plantations (Table 3) were sampled as early as possible in the spring of each growing season except 1980. Eight of the numerous plots established earlier by DNR to determine survival were randomly chosen for sampling in each plantation. In the peripheral zone of each plot, four trees were randomly selected, 32 trees from each plantation.

Growth Measurements

The trees were taken to the laboratory for determination of height, root collar diameter and component dry weights.

Height and biomass data for the average tree from plantations of different ages were extrapolated to a common age by use of polynomial equations with the following general form:

$$y = a + bx + cx^2$$

where "y" is either the height or total biomass of the tree and "x" the number of completed growing seasons since planting; the intercept "a" gives the height or biomass of the tree at time of planting, and the coefficients "b" and "c" are reflections of site and type of planting stock.

Intercepts and coefficients for all but the bare-root black spruce plantations are given in Table 4. The listed standard errors indicate a moderately high accuracy for estimates of height in most plantations, but estimates of tree biomass were less reliable.

Table 1. Provisional standards for the evaluation of planting stock.

Type of stock	Grade	Shoot length (cm)	Root collar diam (mm)	Dry weight (g) Top	Dry weight (g) Root	Dry weight (g) Total	Ratios Shoot/diam	Ratios Shoot/root	Quality index (QI)[a]
Jack pine									
bare-root	1	< 6	< 0.9	< 0.150	< 0.075	< 0.225	< 6.7	< 2.0	< 0.026
	2 lower	6	0.9	0.150	0.075	0.225	6.7	2.0	0.026
	upper	12	1.8	0.414	0.136	0.550		3.99	0.057
	3	> 12	> 1.8	> 0.414	> 1.36	> 0.550	> 6.7	3.0 – > 3.5	> 0.057
paperpot	1	< 12	< 2.5	< 1.2	< 0.6	< 1.8	< 4.8	< 2.0	< 0.264
	2 lower	12	2.5	1.2	0.6	1.8	4.8	2.0	0.264
	upper	20	4.0	1.95	0.65	2.6	5.0	3.0	0.325
	3	> 20	> 4.0	> 1.95	> 0.65	> 2.6	> 5.0	> 3.5	> 0.325
Black spruce									
bare-root	1	< 7.5	< 1.0	< 0.233	< 0.117	< 0.35	< 7.5	< 2.0	< 0.036
	2 lower	7.5	1.0	0.233	0.117	0.35	7.5	2.0	0.036
	upper	15	2.0	0.526	0.174	0.70		3.0	0.078
	3	> 15	> 2.0	> 0.526	> 0.174	> 0.70	> 7.5	3.0 – > 3.5	> 0.078
paperpot	1	< 15	< 3.5	< 2.14	< 0.86	< 3.0	< 4.3	< 2.5	< 0.441
	2 lower	15	3.5	2.14	0.86	3.0	4.3	2.5	0.441
	upper	25	5.5	5.83	1.67	7.5	4.5	3.5	0.937
	3	> 25	> 5.5	> 5.83	> 1.67	> 7.5	> 4.5	3.5 – > 4.5	> 0.937

[a] QI = Mean seedling dry weight (g)/$\dfrac{\text{shoot(g)}}{\text{root (g)}} + \dfrac{\text{shoot (cm)}}{\text{diam (mm)}}$

Table 2. Type, morphological characteristics and grade of jack pine and black spruce planting stock used.

No. of sample	Species and type	Age	Shoot length (cm)	Root collar diam (mm)	Mean seedling dry weight (g)	Ratios		Quality index	Grade
						Shoot/diam	Shoot/root		
1	jP[a], br[b]	2-0	18.8	2.4	1.90	7.7	5.5	0.142	1
2	" , "	"	21.8	3.3	2.50	6.6	6.0	0.191	1
3	" , "	"	16.0	2.4	1.60	6.7	5.1	0.136	1
4	" , "	"	19.3	3.7	4.50	5.2	4.1	0.459	3
5	" , "	"	18.0	5.2	5.02	3.5	3.8	0.690	3
6	jP,pp[b]	8 weeks[c]	5.7	1.1	0.226	5.2	3.1	0.026	2
7	" , "	9 "	4.3	1.0	0.159	4.4	2.0	0.025	1
8	" , "	10 "	11.8	1.7	0.430	6.9	4.9	0.037	2
9	" , "	7 "	4.5	0.7	0.088	6.7	1.3	0.011	1
10	" , "	6 "	3.0	0.9	0.094	3.5	1.3	0.020	1
11	" , "	10 months	2.9	0.9	0.125	3.3	4.3	0.016	1
12	" , "	1 year	6.6	1.5	0.370	4.4	3.3	0.048	2
13	bS[a], "	28 weeks	19.2	2.6	1.264	7.4	3.1	0.119	3
14	" , "	30 "	22.1	2.6	1.362	8.5	3.3	0.114	3
15	" , "	23 "	22.8	2.1	1.130	10.0	5.1	0.071	2
16	" , "	20 "	20.4	2.0	0.700	10.1	4.2	0.052	2
17	" , br	2-0	13.9	2.0	0.67	7.7	4.8	0.053	1
18	" , "	3-0	33.8	3.5	3.30	9.7	5.7	0.212	1
19	" , "	3-0	45.1	4.2	5.74	10.6	6.9	0.328	1

[a] jP = jack pine, bS = black spruce
[b] br = bare-root, pp = paperpot
[c] Counted from germination

Table 3. Time of planting, first-year survival, site preparation and some site characteristics of monitored plantations.

Plantation No.	DNR designation	Time of planting	Survival[a] (%)	Type of site preparation	Soil		Competition	
					Texture[b]	Drainage class[c]	Degree[d]	Type
1	P-12-77	15-20/5/77	89	Disc trencher	sL/lS	2	1	Eric.-elderberry
2	P- 9-77	24/5-25/6/77	71	Wildfire	lS	2/1	2/3	Eric.
3	P-11-77	1-10/6/77	81	Sharkfin barrels	lS	2/1	2	Eric.-intol hardw.
4	P-16-78	17/5-7/6/78	97	Finnish plow	L	3	1	Eric.-grasses
5	P -3-78	6/5-16/6/78	91	Sharkfin barrels	sL	2	1/2	Eric.-brack. fern
6	TP-31-77	3-10/8/77	96	Disc trencher	lS	1/2	2/3	Eric.
7	TP-15-77	2/8-7/9/77	98	Sharkfin barrels	sL/lS	2	1/2	Eric.
8	TP-32-78	20/8-10/9/78	76	Crusher	sL	2	1/2	Eric.-brack. fern
9	TP-14-78	8-20/9/77	88	Sharkfin barrels	lS	2/3	2/3	" "
10	"	"/"/"	89	Bräcke	lS/sL	2/3	2/3	" "
11	TP- 1-77	20/5-15/6/77	82	Burned, Bräcke	sL	2	2/3	" "
12	TP-22-78	10-15/7/78	-	Finnish plow	lS/sL	1/2	2/3	Eric.
13	TP-11-77	20-30/6/77	96	Sharkfin barrels	lS	2	2	Eric.-sweetfern
14	TP-20-77	10-20/7/77	84	"	l/sL	2/3	2/3	Rasp.-grasses
15	TP-35-78	20/6-28/7/78	83	"	L	2	2/3	Rasp.-b. fir
16	TP- 1-78	10/7-14/8/78	85	Disc trencher	L/sL	2/3	2/3	" "

[a] Determined on DNR plots
[b] L(l) = loam (loamy)
S(s) = sand (sandy)
[c] As defined by Canada Soil Survey Committee
[d] 1 = mild, 2 = moderate, 3 = strong

RESULTS

Jack Pine Bare-root Stock

The growth of 2-0 stock was monitored after outplanting at five different locations (Tables 2 and 3). Mean tree heights (measured or estimated annually) (Fig. 1) showed strongly divergent patterns of growth with the expected mean height at age 5 years differing by more than 100%. The difference in plantation performance is revealed more dramatically when biomass production is examined (Fig. 2). The estimated 5-year biomass gives plantation 1 a more than sevenfold lead over plantation 2.

Grade of planting stock may have affected survival, but there are no indications that it has contributed significantly to variation in early plantation growth. Site and method of site preparation appear to be of greater importance.

Plantation 1, which has performed best, was established on well drained sandy loam prepared for planting by a disc trencher. After one year, 89% of the planted trees had survived. Sparse growth of elderberry *(Sambucus* sp.), blueberry *(Vaccinium angustifolium* Ait.) and raspberry *(Rebus idaeus* L.) offered little competition to the planted trees. Foliar nitrogen was high after three growing seasons in the field (Table 5), and this indicates moderately high soil fertility.

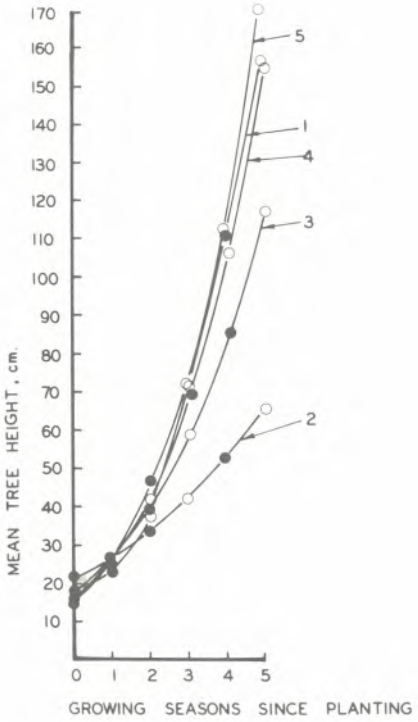


Figure 1. Height development of jack pine plantations established with 2-0 bare-root stock. (Dots and open circles represent measured and calculated mean heights, respectively.)

Table 4. Intercept a, coefficients b and c and standard error of the estimate (SE) of polynomial equations used to extrapolate heights and biomass to age 5 years. Also shown are projected height (Δh_5) and biomass (Δm_5) increments for the fifth year.

Plantation No.	Height growth					Biomass accretion				
	a	b	c	SE (%)	h_5 (cm)	a	b	c	SE (%)	m_5 (g)
1	18.1	4.03	4.78	± 2.9	43.8	7.85	-56.8	41.3	±16.6	356
2	21.7	3.76	1.01	± 0.7	13.9	2.69	- 1.7	4.1	± 3.2	39
3	16.1	5.87	2.88	± 0.6	34.7	3.31	-11.9	10.9	±15.1	97
4	19.8	-0.25	5.54	± 5.2	55.2	6.60	-17.8	18.4	±21.3	166
5	18.6	-3.81	6.85	± 7.2	64.7	7.78	-27.4	19.7	±34.8	170
6	5.9	-2.01	2.93	± 0.1	27.3	1.08	- 7.3	4.4	±26.1	37
7	4.8	-0.41	2.06	±11.3	21.0	0.82	- 5.1	3.3	±25.8	27
8	12.4	-7.17	4.85	±13.5	41.3	1.35	-11.0	7.5	±37.1	64
9	4.0	-4.96	3.89	±21.1	34.0	1.24	- 9.4	5.3	±35.2	43
10	4.9	-3.53	2.64	±11.3	22.9	0.49	- 3.3	2.0	±28.6	16
11	3.6	-1.97	2.16	±12.4	23.5	1.24	- 9.5	6.2	±22.8	53
12	6.7	-3.75	3.13	± 2.1	27.5	0.51	- 1.5	1.4	±20.6	12
13	18.8	3.77	0.43	± 5.5	8.1	1.77	- 4.0	3.8	±12.5	33
14	21.1	-0.52	2.21	±11.1	21.6	2.57	-12.3	8.1	±18.0	69
15	22.8	2.35	2.30	± 0.1	28.0	1.18	1.8	3.1	± 2.9	26
16	20.7	-6.12	4.76	± 4.4	41.5	0.90	- 3.2	3.7	± 8.3	34

RESULTS

Jack Pine Bare-root Stock

The growth of 2-0 stock was monitored after outplanting at five different locations (Tables 2 and 3). Mean tree heights (measured or estimated annually) (Fig. 1) showed strongly divergent patterns of growth with the expected mean height at age 5 years differing by more than 100%. The difference in plantation performance is revealed more dramatically when biomass production is examined (Fig. 2). The estimated 5-year biomass gives plantation 1 a more than sevenfold lead over plantation 2.

Grade of planting stock may have affected survival, but there are no indications that it has contributed significantly to variation in early plantation growth. Site and method of site preparation appear to be of greater importance.

Plantation 1, which has performed best, was established on well drained sandy loam prepared for planting by a disc trencher. After one year, 89% of the planted trees had survived. Sparse growth of elderberry *(Sambucus* sp.), blueberry *(Vaccinium angustifolium* Ait.) and raspberry*(Rubus idaeus*L.) offered little competition to the planted trees. Foliar nitrogen was high after three growing seasons in the field (Table 5), and this indicates moderately high soil fertility.

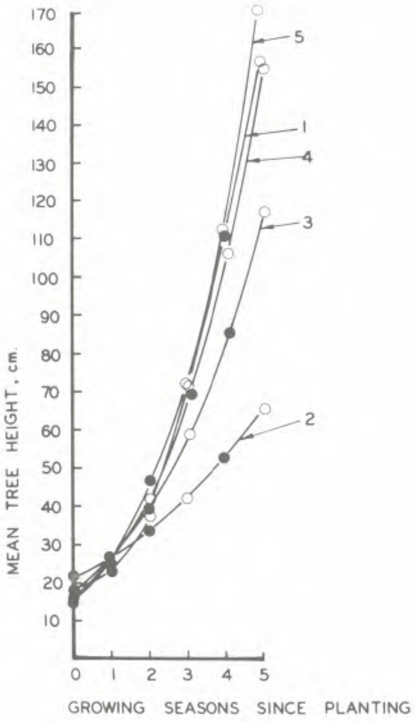


Figure 1. Height development of jack pine plantations established with 2-0 bare-root stock. (Dots and open circles represent measured and calculated mean heights, respectively.)

Table 4. Intercept a, coefficients b and c and standard error of the estimate (SE) of polynomial equations used to extrapolate heights and biomass to age 5 years. Also shown are projected height (Δh_5) and biomass (Δm_5) increments for the fifth year.

Plantation No.	Height growth					Biomass accretion				
	a	b	c	SE (%)	h_5 (cm)	a	b	c	SE (%)	m_5 (g)
1	18.1	4.03	4.78	± 2.9	43.8	7.85	-56.8	41.3	±16.6	356
2	21.7	3.76	1.01	± 0.7	13.9	2.69	- 1.7	4.1	± 3.2	39
3	16.1	5.87	2.88	± 0.6	34.7	3.31	-11.9	10.9	±15.1	97
4	19.8	-0.25	5.54	± 5.2	55.2	6.60	-17.8	18.4	±21.3	166
5	18.6	-3.81	6.85	± 7.2	64.7	7.78	-27.4	19.7	±34.8	170
6	5.9	-2.01	2.93	± 0.1	27.3	1.08	- 7.3	4.4	±26.1	37
7	4.8	-0.41	2.06	±11.3	21.0	0.82	- 5.1	3.3	±25.8	27
8	12.4	-7.17	4.85	±13.5	41.3	1.35	-11.0	7.5	±37.1	64
9	4.0	-4.96	3.89	±21.1	34.0	1.24	- 9.4	5.3	±35.2	43
10	4.9	-3.53	2.64	±11.3	22.9	0.49	- 3.3	2.0	±28.6	16
11	3.6	-1.97	2.16	±12.4	23.5	1.24	- 9.5	6.2	±22.8	53
12	6.7	-3.75	3.13	± 2.1	27.5	0.51	- 1.5	1.4	±20.6	12
13	18.8	3.77	0.43	± 5.5	8.1	1.77	- 4.0	3.8	±12.5	33
14	21.1	-0.52	2.21	±11.1	21.6	2.57	-12.3	8.1	±18.0	69
15	22.8	2.35	2.30	± 0.1	28.0	1.18	1.8	3.1	± 2.9	26
16	20.7	-6.12	4.76	± 4.4	41.5	0.90	- 3.2	3.7	± 8.3	34

Plantation 2, close to stagnation since the time of planting, was established on well to rapidly drained soil varying in texture from loamy sand to sandy loam. The site supported jack pine previously and was intensively burned by a wildfire, after which a dense ericaceous ground vegetation developed. Planting stock was morphologically similar to that used in plantation 1, but apparently had suffered while kept in storage for delayed planting in June. The use of the impaired plants may explain their high rate of mortality. Only 71% of the planted trees survived the first winter and 67% the second winter. The condition of the plants may also have contributed to their poor growth over the first two years, but is not believed to be responsible for continued unsatisfactory performance. More likely, this is the result of low native fertility of the soil, aggravated by the burn and severe competition from the ericaceous vegetation. The tree foliage sampled in the fall of 1979 contained only 1.51% nitrogen as compared with 1.91% in plantation 1.

Plantation 3, which grew at an intermediate rate (Fig. 1 and 2), was established in the first half of June with plants exhibiting morphological conditions similar to those used at the other two sites. Soil conditions were generally comparable with those of plantation 2, but the area had not been burnt. This may have helped to conserve the small nutrient reservoirs of this sandy site. The results of foliar analysis (Table 5) indicate noticeably better nitrogen nutrition than in trees of plantation 2.

The 1978 plantations showed rapid height development and intermediate rates of biomass accretion. They were established on moderately well drained to well drained medium-textured soils of intermediate fertility. Groundcover plants including bracken fern (*Pteridium aquilinum* L.), blueberry, lambkill (*Kalmia angustifolia* L.) and grasses offered light to moderate competition. The 1978 planting stock had received a more favorable rating than the 1977 stock (Table 2). The difference in stock quality is a possible reason for the strong first-year growth observed in 1978 but not in 1977. However, differences in weather, site preparation, and planting time prevent a direct comparison of 1977 and 1978 stock.

Jack Pine Paperpot Stock

At the time of this study the Kingsclear nursery was growing two crops of jack pine paperpot seedlings per year. The first crop was usually sown in late spring, retained in the greenhouses or nursery until midsummer and outplanted before the end of the summer.

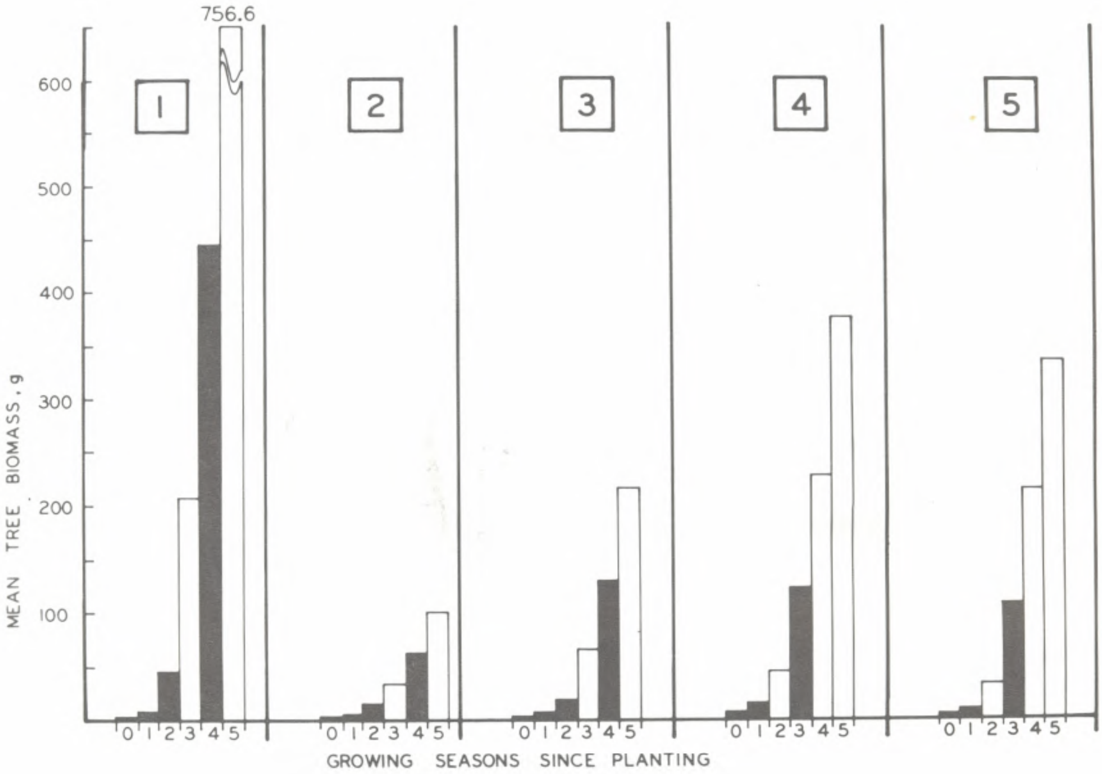


Figure 2. Biomass accretion in jack pine plantations established with 2-0 bare-root stock. (Solid and open bars represent measured and calculated mean biomass, respectively.)

Table 5. Macro-element concentrations in foliage of seedlings at the time of planting and after two or three growing seasons in the field.

Plantation No.	N	P	K	Ca	Mg
			(%)		
			Before planting		
1	2.02	0.20	0.59	0.60	0.13
2	1.82	0.18	0.64	0.56	0.15
3	1.76	0.19	0.79	0.59	0.13
4	1.86	0.19	0.67	0.35	0.13
5	1.80	0.20	0.59	0.41	0.13
6	3.08	0.40	1.39	0.11	0.15
7	2.17	0.39	1.30	0.15	0.19
8	2.62	0.39	1.20	0.23	0.16
9	1.81	0.34	1.07	0.12	0.22
10	1.98	0.34	0.99	0.12	0.16
11	2.68	0.26	0.75	0.16	0.11
12	1.35	0.13	0.57	0.20	0.12
13	2.10	0.25	0.95	0.26	0.11
14	2.97	0.33	1.01	0.44	0.15
15	1.95	0.25	0.98	0.12	0.14
16	1.93	0.23	1.08	0.25	0.15
			After two (three) growing seasons		
1	1.91	0.16	0.50	0.18	0.10
2	1.51	0.15	0.54	0.20	0.11
3	1.76	0.16	0.56	0.25	0.11
4	1.64	0.15	0.53	0.22	0.11
5	1.76	0.16	0.59	0.24	0.10
10	1.83	0.18	0.67	0.20	0.11
11	1.69	0.17	0.60	0.20	0.11
12	1.75	0.18	0.72	0.18	0.12
13	1.73	0.20	0.51	0.68	0.11
14	2.18	0.21	0.55	0.68	0.11
15	2.08	0.21	0.60	0.60	0.10
16	2.39	0.27	0.59	0.64	0.13

The second crop was sown in early summer or midsummer, shipped to the field for late summer planting or retained over winter in the nursery and planted in the spring or early summer of the following year.

Spring-sown, summer-planted

Three plantations, established with grades 1 and 2 stock (Table 2), were monitored.

The plants showed little height growth during the year of planting, but large relative increases in needle, stem, branch, and particularly root biomass. The high shoot: root ratio of the plants as they left the nursery had decreased to approximately 1.0 before the second growing season had begun.

The plants approximately doubled their heights and increased their dry weights by a factor of two or greater in the second year (Fig. 3a and 4). Despite these growth rates, height development and biomass accretion were considerably retarded in paperpot plantations in comparison with bare-root plantations. Mean tree heights, extrapolated to year 5, approached 1.0 m in the best paperpot plantation whereas three of the five bare-root plantations have projected 5-year heights in excess of 1.5 m under similar soil conditions (Fig. 1 and 3a). A similar relationship is revealed when plantations 3 (bare-root) and 6 or 7 (paperpot), all established on sandy soil with ericaceous growth, are compared. However, two of the paperpot plantations are expected to surpass in height the slowly developing bare-root plantation on the burned site and the best performing paperpot plantation (8) may equal in annual height growth the thrifty bare-root plantation 1 by the fifth year (Table 4).

Paperpot and bare-root plantations show even greater differences when biomass accretions are compared (Fig. 2 and 4). The mean tree biomass at five years is expected to vary between 57 and 133 g in paperpot plantations and between 100 and 757 g in bare-root plantations.

Although the somewhat variable quality of paperpot stock used in the above plantations may have influenced rates of survival, it is doubtful that the observed differences in growth are related to the condition of seedlings at the time of planting. Site, particularly soil and competing vegetation, and method of site preparation, are believed to be dominant factors as previously discussed for bare-root plantations.

The most rapidly growing paperpot plantation (8) had been established on a moderately fertile sandy loam after minimal site preparation by a tree crusher. In contrast, plantations 6 and 7 were located on coarser soil (loamy sand) with a heavy ericaceous vegetation. In one case (plantation 6), trees had been planted in infertile sand exposed by deep trenching. Lack of nutrients may explain the slow start of this plantation, although by the fourth year seedling roots had developed well into the ridges of organic matter turned up by the trencher, improving thereby the nutrient supply to the trees.

Plantation 7 was established after site preparation with sharkfin barrels which presumably created microsites richer in nutrients than those created by trenching. However, the plants in this plantation which were growing well initially fell behind those

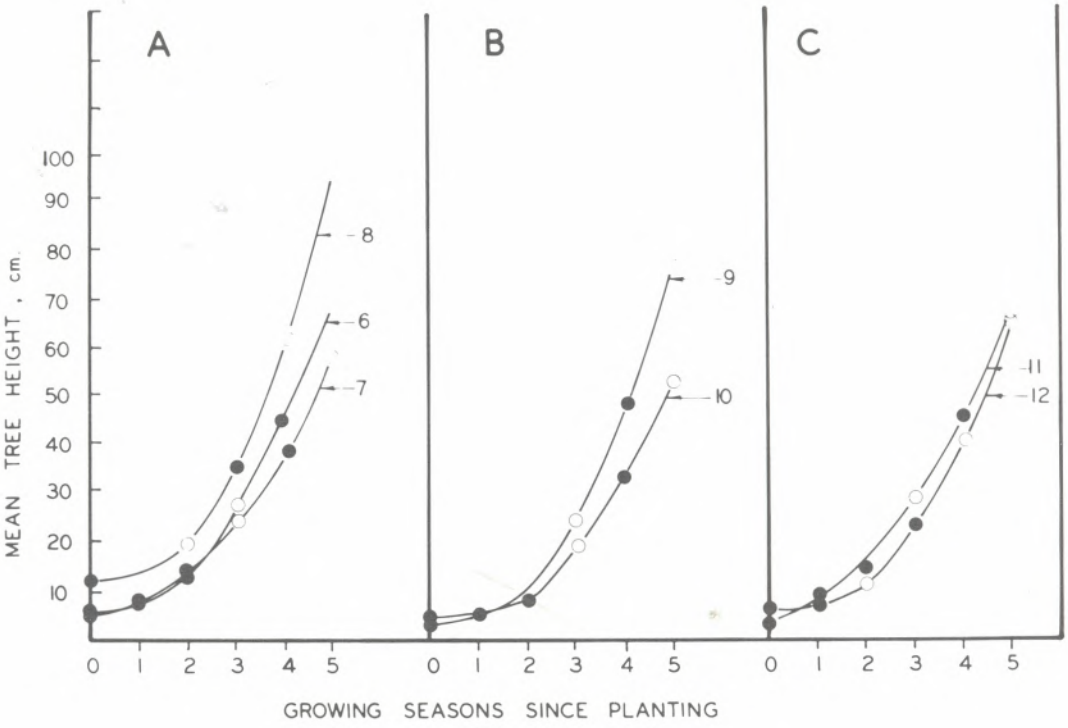


Figure 3. Height development of jack pine plantations established with paperpot stock A) sown in spring and planted in summer, B) sown in midsummer and planted in late summer, or C) sown and planted in the year following overwintering in the nursery. (Dots and open circles represent measured and calculated mean heights, respectively.)

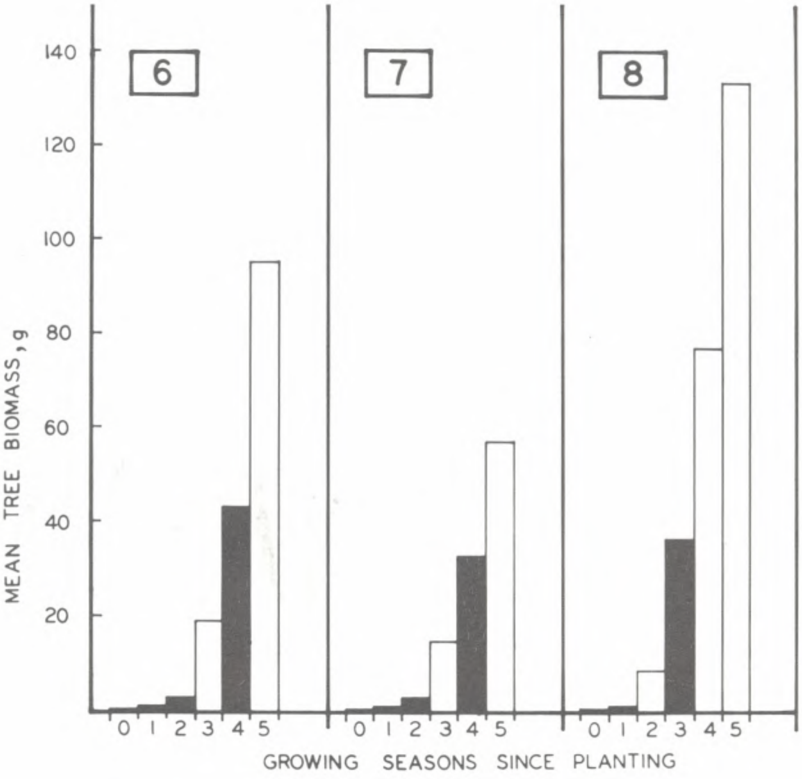


Figure 4. Biomass accretion in jack pine plantations established with paperpot stock sown in spring and planted in summer. (Solid and open bars represent measured and calculated mean biomass, respectively.)

of plantation 6, possibly because of increasing competition from the ericaceous growth.

Summer-sown, late summer-planted

Two plantations (9 and 10) were established with very small planting stock (Table 2) in mid-September.

Survival after the first winter was noticeably lower than in the plantations established during the same year with spring-sown stock (Table 3). The surviving plants showed some gain in biomass and shoot elongation between the time of planting and sampling the following spring. In contrast with summer-planted stock, which showed a strong root development during the first few months in the field, the late-planted seedlings exhibited some shoot development but little gain in roots.

In the second year, mean seedling dry weight was increased by factors of 6.7 (plantation 9) and 3.5 (plantation 10). This amounted to only minor absolute gains since the original weight of seedlings was very small. However, with continued high relative growth rates, plantation 9 may display, by the fifth year, a mean tree height and biomass comparable with what is expected in summer planted stock (Fig. 3, 4 and 5a).

Several factors are believed to be responsible for the slow development of plantation 10. It could be a consequence of very late planting, but the effects of improperly chosen microsites appear more likely to be responsible. Many of the trees had been planted in holes created by the Bracke cultivator rather than on prepared mounds. At the time of sampling in spring, the holes were usually filled with water. This problem did not exist in plantation 9 which had been established after site preparation with sharkfin barrels.

Overwintered, spring- or summer-planted

Two plantations were monitored, one that had been established towards the end of May, 1977 (11) and another established in mid-July, 1978 (12).

The two plantations showed similar patterns of height development, but differed dramatically with respect to biomass accretion. Among the possible causes of this difference, variability of planting stock and time of planting are probably the least important.

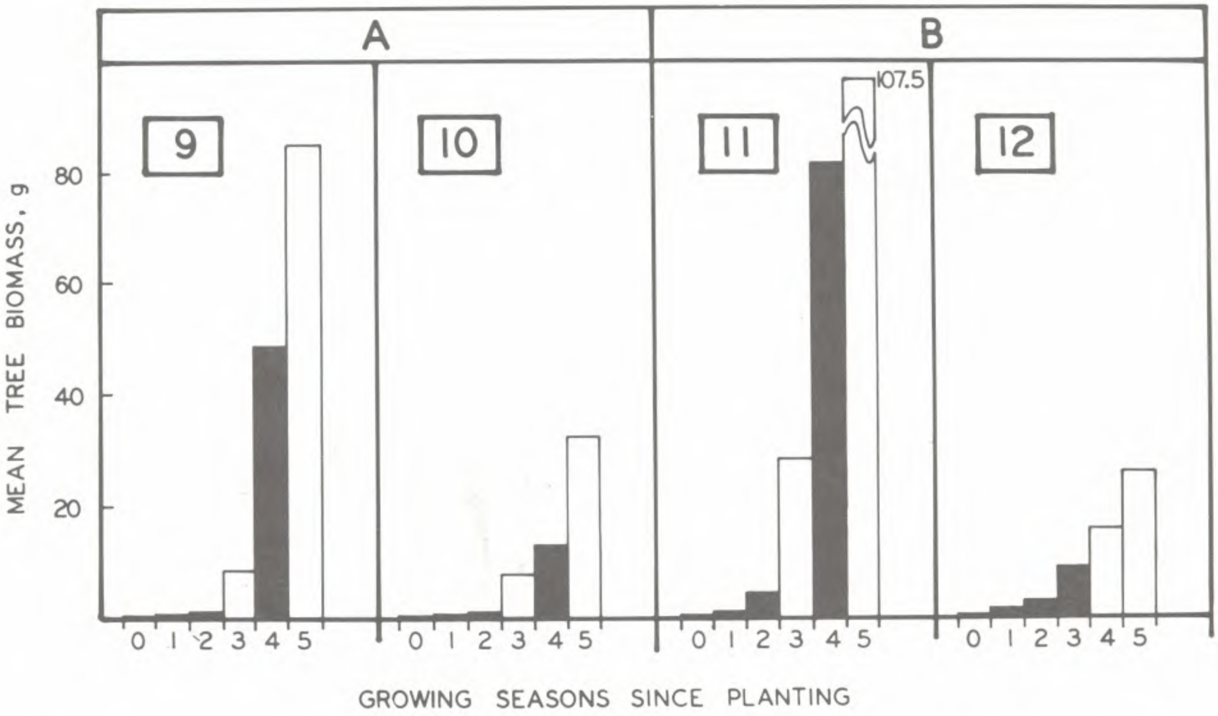


Figure 5. Biomass accretion in jack pine plantations established with paperpot stock A) sown in early or midsummer and planted in late summer, or B) sown and planted in the year following overwintering in the nursery. (Solid and open bars represent measured and calculated mean biomass, respectively.)

Plantation 11 was located on a sandy plain previously supporting jack pine. The area was burned and site-prepared with a Bräcke cultivator. The small plants (Table 2) suffered high mortality, but those that had survived exhibited an approximately sixfold increase in mean dry weight and a threefold increase in height during the first growing season. This rapid rate of growth, presumably supported by a short-term improvement in nutrient supply after the fire, was not maintained through the following years.

The overwintered seedlings planted in 1978 were of a higher morphological grade than those used in the previous spring, but showed very little growth in the first two years (Fig. 3a and 5b). Most of the seedlings had been planted in infertile sandy soil exposed by a Finnish plow. Low nutrient availability in the rooting medium combined with a very low nitrogen content in the seedlings at the time of planting (Table 5) were probably reasons for the poor growth. Additional factors appear to have been shading and competition by volunteer hardwoods and larger jack pine of an unsuccessful earlier planting. Under these conditions, early planting of overwintered stock has not resulted in a more rapid development than was found in plantations established with the same type of stock in late summer or early fall.

Black Spruce Bare-root Stock

Three-year-old seedling stock used in the 1977 fall planting and the 1978 spring planting, as well as 2-0 seedlings planted in 1978, were evaluated.

The bare-root stock had received a low rating at time of planting (Table 2). Plantation survival was very low and the three areas have since been replanted with different stock. The surviving plants exhibited very little growth in the first year. Observations were discontinued thereafter.

Black Spruce Paperpot Stock

Four batches of paperpot stock were sampled, two in 1977 and two in 1978. The 1977 samples had received a top rating whereas those produced in 1978 were of intermediate grade (Table 2). This stock showed moderately high rates of survival (Table 3).

The plantations varied considerably in growth (Fig. 6 and 7), apparently because of differences in soil fertility and competing vegetation. Plantation 13, characterized by its sluggish height development, was established on an ericaceous site with predominantly coarse textured soil. Lack of fertility is suggested by the low foliar nitrogen content (Table 5).

Plantations 14, 15 and 16 were established on moderately rich sites with a vigorous competing vegetation dominated by raspberry. Plantation 14 showed little biomass accretion in the first year when rapidly overtopped by raspberry, but seems to have responded well to a herbicide spray in the second year. Plantation 16 has shown the fastest height development, but trails plantation 14 in biomass accretion. Rapid height growth with a less than normal gain in biomass may be a typical response to shading by faster growing, competing plants.

Black spruce paperpot plantations cover height and biomass ranges similar to those of paperpot jack pine plantations (Fig. 3, 4, 6, and 7).

There are no indications that the observed differences in grade of paperpot planting stock (Table 2) have had or will have a noticeable influence on the 5-year growth of black spruce plantations.

DISCUSSION

Height development in bare-root jack pine plantations followed patterns established by Hamilton (1979) with a larger number of plantations. That study also indicated that jack pine growth in New Brunswick plantations was comparable with, if not superior to, growth in parts of the Great Lakes region (Wilde et al. 1964).

Several studies with other species in various parts of North America have suggested faster juvenile growth in plantations established with containerized stock than in those established with bare-root stock (Aycock 1974, Mann 1977, Stein and Owston 1977). The jack pine paperpot plantations of this study have lagged one to two years behind bare-root plantations. A considerable time lag in the development of jack pine plantations from containerized stock was also evident in one of the early comparisons in Ontario (Scarratt 1974).

Black spruce paperpot stock was judged superior to bare-root stock because of the high mortality in the latter. Because of the heavy losses, it has not been possible to compare the different types of planting stock of this species with respect to early growth. When the results of a previous sur-

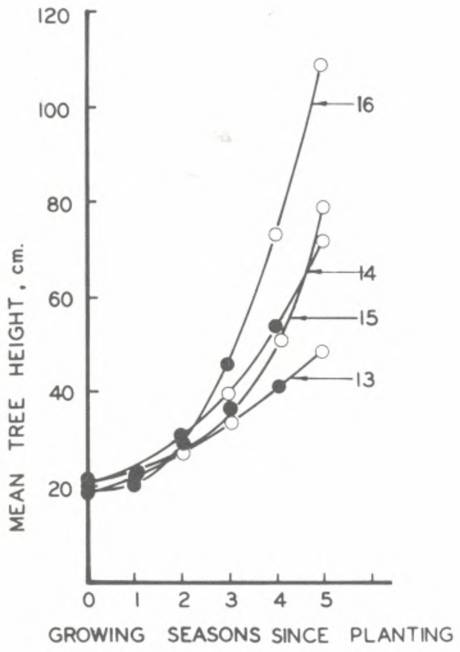


Figure 6. Height development in black spruce plantations established with paperpot stock. (Dots and open circles represent measured and calculated mean heights, respectively.)

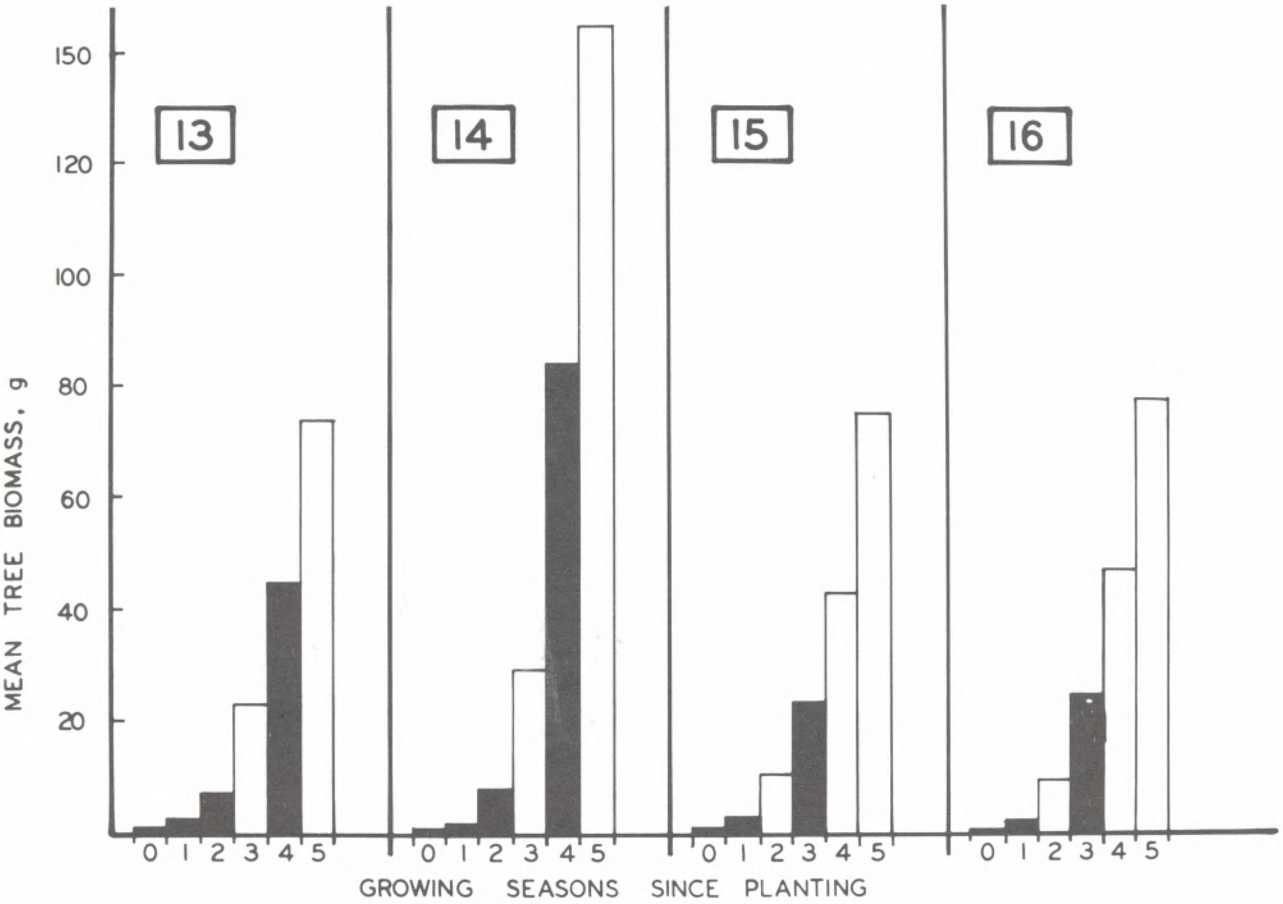


Figure 7. Biomass accretion in black spruce plantations established with paperpot stock. (Solid and open bars represent measured and calculated mean biomass, respectively.)

vey of black spruce plantations established in the province with 2-2 stock[2] are compared it becomes apparent that the development of black spruce paperpot plantations exhibits a time lag similar to that of jack pine paperpot plantations. For example, the expected height of 109 cm at age five years in the best growing paperpot plantation (Fig. 6) was reached by the average bare-root transplant plantation three years after planting, and the slowest growing paperpot plantation would just have surpassed the size of 2-2 planting stock in the fourth year after planting. The lag in paperpot stock plantations would be especially noticeable on sites with heavy shrub competition which require herbicide treatments earlier and more often than plantations established with large stock.

With the results of the present study, it would not be unreasonable to expect that the average paperpot plantation may require an additional one to two years in the rotation to produce a yield comparable with that of the average bare-root plantation. However, the advantage of a shortened juvenile period in bare-root plantations must be weighed against the advantages of the paperpot planting system, including extended planting season, reduced planting cost and improved survival. The problem of root deformation, which appears to be more severe in trees from bare-root than from container-grown stock, should also be mentioned. Scarratt (1974) and Scarratt and Reese (1976) have made a case for an integrated system of planting stock production and field planting in which containerized stock supplements conventional bare-root stock or vice versa.

While the use of different types of planting stock (bare-root vs. containerized) has had an obvious effect on the early growth of jack pine plantations, the influence of grade, as defined in Table 1, was not discernible. For example, bare-root plantations 4 and 5 were established with grades 1 and 2 stock, yet they exhibited comparable patterns of height development. Paperpot plantations 6 and 7 were established with stock that had received a much higher rating than stock used in plantation 9, but the cumulative height of the latter was equal to or greater than that of the former despite the fact that the seedlings were planted late in the season. Plantation 12 has been trailing plantation 11 (Fig. 3c and 5b) because of very slow growth in the former in the first two years. Stock used for plantation 12 was of a higher morphological grade than that of plantation 11, but was low in nitrogen at the time of planting.

The lack of a clear effect of morphological grade on the early growth of plantations used in this study is no justification for relaxing standards of planting stock quality. It has been shown repeatedly that rate of survival, the overriding criterion in judging early plantation performance, is related to those features of the plant that determine its morphological grade (Dobbs 1976, van den Driesche 1980, Mullin and Christie 1981).

Scarratt (1974) has shown that late season planting of tubed seedlings of several conifer species resulted in considerably reduced growth. In the present study, the time of planting of paperpot stock had no clear effect. Plantations 11 and 12, having been established early in the season, were expected to be the most advanced in growth. Instead, the late-summer planted stock of plantations 8 and 9 has shown faster height development than the early planted stock of plantations 11 and 12. However, it should be recalled that jack pine paperpot stock planted late in the season (September) had shown little root growth before the onset of winter. The lack of sufficient new roots to anchor the plant firmly in the ground is usually the reason for frost heaving and reduction in survival.

Observations from this study indicate a strong effect of site and microsite on early plantation development. Most prominent among site factors are type and vigor of competing vegetation and soil fertility. Typically unsuitable microsites were infertile soil and depressions exposed or created by implements used in site preparation. The high incidence of poor growth of planted trees on adverse site or microsite conditions underlines the importance of accurate matching of species and site, and proper choice of site preparation method.

SUMMARY AND CONCLUSIONS

1. Jack pine bare-root plantations have shown highly variable growth, with projected mean tree heights ranging from 0.65 to 1.70 m at the age of five years.
2. Jack pine paperpot plantations exhibited a time lag of one to two years over bareroot plantations on similar sites.
3. Black spruce bare-root seedlings suffered excessive mortality and showed very little growth after planting.

---

[2] H.H. Krause, unpublished data.

4. In comparison with bare-root seedlings, black spruce paperpot seedlings were highly successful; height development and biomass accretion followed patterns similar to those observed with jack pine paperpot plantations.

5. The results of this study have not shown a clear effect of morphological grade of planting stock or time of planting on the early growth of paperpot plantations.

6. Dominant factors determining the rate of growth of seedlings that have survived the first winter in the field appear to be site and microsite.

ACKNOWLEDGMENTS

This study was carried out under contract agreement between the New Brunswick Department of Natural Resources and the University of New Brunswick. Financial support was also received from the block grant of the Canadian Forestry Service to the Faculty of Forestry. I am grateful to Misses M.E. Guptill and L.J. Calder, and Messrs. J. Beyeler, W.N. Hamilton, S.D. Reilly, P.D. Archibald, S. Ramnarine and D.E. Swift for field sampling and work in the laboratory.

LITERATURE CITED

Armson, K.A. and Sadreika, V.
1979. Forest tree nursery soil management and related practices (metric edition). Ont. Min. Nat. Resour., Toronto. 179 p.

Aycock, O.
1974. Field performance of containerized seedlings in the Southern Region, USDA Forest Service. p. 321-323 in R.W. Tinus, W.I. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Dickson, A., Leaf, A.L. and Hosner, J.F.
1960. Quality appraisal of white spruce and white pine seeding stock in nurseries. For. Chron. 36:10-13.

Dobbs, R.C.
1976. Effect of initial mass of white spruce and loblolly pine on field performance in the B.C. interior. Dep. Environ., Can. For. Serv., Victoria, B.C.Inf. Rep. BC-X-149. 14 p.

Hamilton, W.N.
1979. Early development of jack pine plantations in New Brunswick. M.Sc.F. Thesis, Univ. New Brunswick, Fredericton.

Mann, W.F. Jr.
1977. Status and outlook of containerization in the south. J. For. 75:579-581.

Mullin, R.E. and Christie, C.
1981. Morphological grading of white spruce nursery stock. For. Chron. 57:126-130.

Roller, K.J.
1977. Suggested minimum standards for containerized seedlings in Nova Scotia. Dep. Environ., Can. For. Serv., Fredericton, N.B. Inf. Rep. M-X-69. 18 p.

Scarratt, J.B.
1974. Performance of tubed seedlings in Ontario. p. 310-320 *in* R.W. Tinus, W.I. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Scarratt, J.B. and Reese, K.H.
1976. Objectives and criteria for planting stock production in Ontario. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Report 0-X-253. 17 p.

Stein, W.I. and Owston, P.W.
1977. Containerized seedlings in western reforestation. J. For. 75:557-578.

van den Driessche, R.
1980. Effects of nitrogen and phosphorus fertilization on Douglas-fir nursery growth and survival after outplanting. Can. J. For. Res. 10:65-70.

Wilde, S.A., Iyer, J.G., Tanzer, C.H., Trautmann, W.L., and Watterson, K.G.
1964. Growth of jack pine *(Pinus banksiana* Lamb.) plantations in relation to fertility of non-phreatic sandy soils. Soil Sci. 98:162-169.

SURVIVAL AND GROWTH OF SOME PAPERPOT SEEDLING PLANTATIONS IN QUEBEC

R.J. Hatcher'

Abstract.--Survival, growth, rabbit damage and hardwood competition in 20 FH 408 paperpot container plantations of conifers established in Quebec from 1974 to 1979 were studied in the summer of 1980 on 340 1/100-ha plots. Survival and growth were as good as or better than those reported recently for other such plantations in eastern Canada.

Résumé.--La survie, la croissance, les dégâts causés par les lapins et la concurrence des feuillus dans 20 plantations de semis de conifères en tubes de papier FH 408, établies au Québec de 1974 à 1979, ont été étudiés pendant l'été 1980 dans 340 placettes d'un hectare chacune. La survie et la croissance étaient égales ou supérieures à celles qui ont récemment été observées dans d'autres plantations de ce genre, dans l'est du Canada.

INTRODUCTION

The use of containerized seedlings in Canada has increased dramatically since the early 1970s, from 16 million seedlings or 8% of all planting stock in 1971, to 124 million seedlings or 35% of the total in 1980 (Smyth 1980). Quebec declined to embrace any of the container systems being refined and undertook to develop its own system based on an extruded cylinder of peat with a biodegradeable paper container (Bonin 1972).

Since the inception of development work, research by the provincial government and the Laurentian Forest Research Centre (LFRC) has concentrated on solving problems associated with paper quality, container size, peat extrusion, and greenhouse production techniques.

Until recently, very little research had been carried out in Quebec on the performance of outplanted containerized seedlings. Consequently, in May 1980, LFRC initiated research in container plantations. This report presents the results of a 1980 study of 20 container plantations, 15 of which are on freehold land of Consolidated-Bathurst Inc. at Grand'Mére. With a few exceptions, survival and growth have been comparable with those recently reported for eastern Canada (Carrier and Bissonnette 1980, Forcier 1980, Marceau 1980).

DESCRIPTIONS OF PLANTED AREAS

1. Grand'Mere

The container plantations at Grand'Mére were planted following clearfelling of white spruce (*Picea glauca* [Moench] Voss) and Scots pine (*Pines sylvestris* L.) plantations that had been established on abandoned farmland between 1913 and 1932. Surface soils are mostly excessively drained, loamy, fine sands of poor productivity underlain by 5 m deposits of coarse sand over impervious blue clay (Gagnon 1969). Pockets of richer surface soil are scattered throughout the plantations and on these soils deciduous trees have become established and are growing faster than planted conifers. Where the dominant competition is trembling aspen (*Populus tremuloides* Michx.), the company is reducing this competition by felling aspen with Brushmaster mechanical saws.

---

[1] Research Scientist, Laurentian Forest Research Centre, Canadian Forestry Service, Ste-Foy, Quebec.

Except for the 1974 plantings, all sites were prepared for planting with a Bracke scarifier. FH 408 paperpot seedlings were planted in spring with a Pottiputki at the top of soil scalps near the junction of the organic and mineral soil horizons. By far the most frequently planted species is jack pine *(Pinus banksiana* Lamb.), followed by Scots pine, black spruce *(Picea mariana* [Mill.] B.S.P.) and European larch *(Larix decidua Mill.).*

2. Pembina

Four plantations were established near Pembina Depot, 75 km northwest of Grand Mere, in 1974 (three jack pine, one Scots pine) following clearfelling of mature jack pine stands. Soils are of fluvio-glacial origin and consist of varying depths of medium sand overlying bedrock. Slopes range from nil to gentle and drainage is excessive. The almost total lack of competing vegetation six years after planting suggests that these sites are poorer than those at Grand Mere. Two of the four study stands were scarified with the Bracke prior to spring planting of FH 408 paperpots.

3. Dolbeau

In 1975 jack pine seedlings in FH 408 paperpots were planted on a level site 80 km north of Dolbeau on fluvio-glacial deposits of medium sands overlying bedrock. Drainage is excessive and the humus horizon is almost nonexistent as a result of the burning of logging slash from the parent jack pine stand in 1962. Without doubt this was the poorest site studied; vegetation is limited to cladonia mosses, a few lichens and some patches of *Vaccinium* spp.

STUDY METHODS

At Grand Mere, the long narrow farms, typical of much of Quebec, influenced both the planting row direction and the study method. The original plantations that are being replanted with containerized stock were established on a farm lot basis and subsequently are being harvested on the same basis, usually with the main haul road running lengthwise down the middle of the lot or farm. In turn, scarification was carried out lengthwise on the lots, parallel to the main haul roads, in order to avoid the necessity for making frequent turns.

To sample as many plantations as possible, contiguous 1/100 ha sample plots (4 m x 25 m) were established along cruise lines whose starting points were established at random along the main haul road. Plot lines were run across the scarification rows because preliminary sampling strongly suggested that plots on lines parallel to the scarifier direction were overestimating stocking.

For each plot, the following information was recorded: species planted, survival, number of living seedlings damaged by rabbit browsing, and, on one half of the plot, the total height (nearest cm) of each planted seedling. Each sample plot was classified by ocular estimate into three vegetation competition classes: light, medium and dense. In the 20 plantations studied, 340 plots were established. Data were compared by analysis of variance.

RESULTS AND DISCUSSION

Seedling survival has been excellent up to five years after planting (Table 1). Only one 1976 larch plantation and a 1977 white pine *(Pinus strobus* L.) plantation did not have acceptable levels of stocking. In both plantations the soils were better than average, and competition from shrub and herbaceous vegetation was greater; consequently rabbits were numerous and damaged almost every white pine, and nine of ten larch (Table 1).

At Grand Mere, rabbit damage was serious. In three 1978 plantations 23% of the Scots pine, 36% of the jack pine and 25% of the larch were damaged, although few seedlings were killed (Table 1). Damage consisted of severed leaders, which resulted in multi-leadered seedlings, or severed lateral branches, which reduced subsequent height growth. Both types of damage seldom occurred on the same seedling. In two other 1978 plantations, damage was very light.

Height growth of the four main species was excellent, and five years after planting the annual average growth rate of undamaged trees varied from 25 to 55 cm. However, the rabbit-damaged trees have not done nearly as well (Fig. 1).

Efforts to relate conifer height growth to shrub and hardwood competition were unsuccessful (Table 2). Similarly, an analysis to relate degree of rabbit damage to year of planting (age) and degree of competition (rabbit habitat) also failed to reveal any consistent relationships (Table 3).

Table 1. Seedling survival and incidence of rabbit damage in spring plantations of FH 408 paperpots in Quebec, 1980.

Location	Year of planting	Surviving trees per ha (1980)	Percent survival by species: Scots pine	Jack pine	White pine	European larch	Black spruce
Grand'Mère	1976	1940	88(10)[a]	85(22)	-	-	-
		1945	-	90(3)	-	-	-
		1320	-	-	-	65(90)	-
	1977	2218	94(16)	-	-	-	-
		1820	-	93(12)	-	-	-
		993	-	-	50(97)	-	-
	1978	2642	-	98(36)	-	-	-
		2640	-	-	-	-	99(2)
		2317	91(23)	-	-	96(25)	-
		2410	96(3)	-	-	-	-
	1979	2125	92(1)	-	-	-	-
		2183	-	88(1)	-	-	-
		1595	-	-	-	-	67(<1)
		2300	-	-	-	92(10)	89(2)
Average all years and plots[b]			93(8)	90(15)	48(97)	78(42)	80(1)
Pembina	1974	1740	-	70(9)	-	-	-
		1346	73(0)	-	-	-	-
Dolbeau	1975	1675	-	81	-	-	-

[a] Percentage of living trees damaged by rabbits given in parentheses
[b] Calculated on the basis of 1/100 ha plots

Table 2. Seedling heights by year of planting and competition class, Grand'Mère, 1980.

Year planted	Height[a] (cm) by species and competition class[b,c]: Black spruce L	M	D	European larch L	M	D	Jack pine L	M	D	Scots pine L	M	D
1974	-	-	-	74	111	-	-	223	179	-	-	-
1976	-	-	-	97	72	-	134	115	91	77	-	101
1977	-	-	-	-	-	-	108	92	86	71	74	-
1978	-	35	31	-	-	50	36	47	50	44	47	45
1979	-	20	26	21	22	-	27	23	-	21	21	-

[a] Undamaged trees only
[b] L = light, M = moderate, D = dense
[c] Means underlined by the same line are not significantly different at 5% level

Table 3. Incidence of rabbit-damaged trees, by competition class and year of planting, Grand'Mère, 1980.

Competition class	Percentage of damaged trees by year of planting, all species[a]					All years[b,c]	Jack and Scots pine[c]	European larch and Black spruce[c]
	1974	1976	1977	1978	1979			
Light	0	26	12	26	1	17	8	57
Moderate	24	44	15	13	5	22	19	27
Dense	-	34	28	15	1	12	17	6

[a]Means underlined by same line are not significantly different at 5% level
[b]Calculated on the basis of 1/100 ha plots
[c]Means bordered by the same line are not significantly different at 5% level

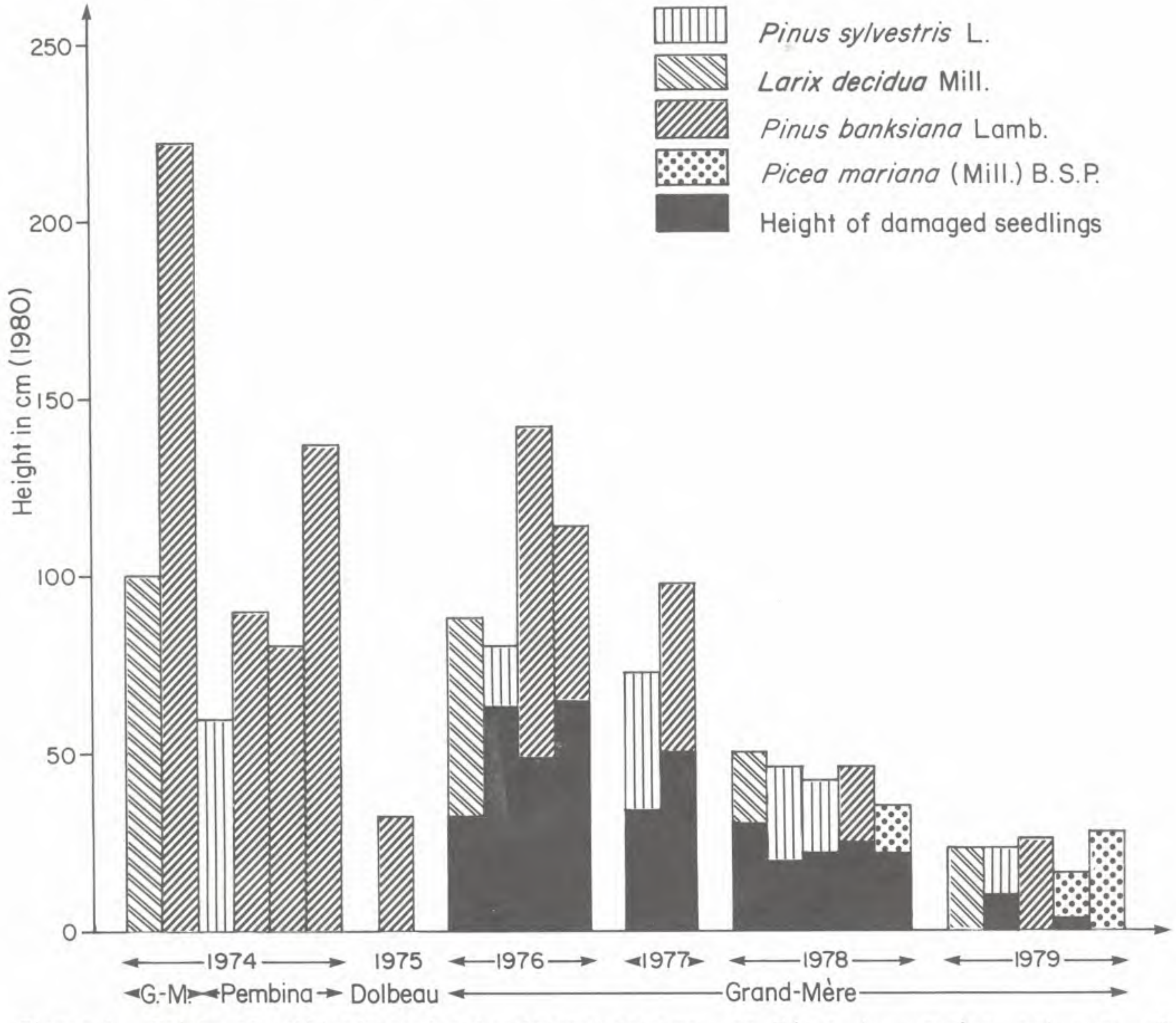


Figure 1. Height of rabbit-damaged and undamaged paperpot seedlings by species and year of planting, 1980.

In each of the three areas several containerized and natural seedlings were excavated and their roots were examined. Without exception the paperpot seedlings had balled and spiralled roots with tissue fusion occurring after five years. None of the natural seedlings exhibited similar characteristics.

In conclusion, the data show that survival and height growth of jack and Scots pine grown in FH 408 paperpots have been excellent up to five years after outplanting. However, there are two causes for concern: 1) the frequency and degree of damage caused by rabbits, and 2) the balled root system produced by containers that do not degrade in these sandy soils within five years.

There is little doubt that frequency and degree of rabbit damage are related to vegetation density but the 1/100 ha plot was too large a study unit to reveal the relationship. Smaller permanent sample plots wherein individual trees are followed need to be established. These same plots will also permit quantification of the effect of competition on height growth and assessment of the long-term effects of balled roots on tree survival and stability.

LITERATURE CITED

Bonin, P.
1972. La culture des plants en recipients: nouveau procede preconise par le Service de la Restauration forestiere du Quebec. For. Conser. 38:6-7.

Carrier, C., and Bissonnette, R.
1980. Evolution de la culture des plants en recipients au M.E.R. p. 84-102 in Proceedings: Atelier de travail sur la culture des semis en recipients. Centre de recherches forestieres des Laurentides, Environnement Canada, Ministere de l'Energie et des Ressources, L'Ordre des Ingenieurs forestiers du Quebec.

Forcier, L.
1980. La culture des semis en recipients en Ontario. p. 156-183 in Proceedings: Atelier de travail sur la culture des semis en recipients. Centre de recherches forestieres des Laurentides, Environnement Canada, Ministere de l'Energie et des Ressources, L'Ordre des Ingenieurs forestiers du Quebec.

Gagnon, J.D.
1969. Soil improvement trials using scarification and fertilization in stagnant white spruce plantations, Quebec, Canada. Plant and Soil 30:23-33.

Marceau, J.-P.
1980. Le reboisement chez J.D. Irving au Nouveau-Brunswick. p. 184-193 in Proceedings: Atelier de travail sur la culture des semis en recipients. Centre de recherches forestieres des Laurentides, Environnement Canada, Ministere de l'Energie et des Ressources, L'Ordre des Ingenieurs forestiers du Quebec.

Smyth, J.H.
1980. A directory of forest tree nurseries in Canada. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Report 0-X-305. 51 p.

PERFORMANCE OF CONTAINER-GROWN DOUGLAS-FIR ON DROUGHTY SITES IN SOUTHWEST OREGON

Stephen D. Hobbs[1], Denis P. Lavender[2], and Kenneth A. Wearstler[3]

Abstract.--First-year growth and survival data from two plantations of container-grown and bare-root Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) seedlings on hot, dry sites in southwest Oregon are discussed. The container-grown plants demonstrated better shoot and root growth and had higher survival than the bare-root seedlings in both plantations.

Résumé.--La croissance et la survie de semis de Douglas taxifoliés cultivés en récipients ou à racines nues dans deux plantations au climat chaud et aride du sud-ouest de l'Oregon sont discutées. Dans les deux cas, la croissance de pousses et des racines et la survie des semis en récipients sont plus grandes que chez les semis à racines nues.

INTRODUCTION

Southwest Oregon is an area of diverse environments and complex geology. Its flora combines elements from northern California, eastern Oregon, and the Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) forests to the north as well as many indigenous species (Franklin and Dyrness 1973). The climate is moderate; winters, during which most of the precipitation occurs, are mild, and summers are hot and dry. An exception is a narrow coastal belt where the climate is characteristically cool and moist. The region itself has a land area of 3,296,985 ha, of which approximately 2,480,327 ha are considered commercial forest land (Bassett 1979).

The Siskiyou Mountains, occupying the western half of the region, have severe regeneration problems. The ecology of these mountains has been described in detail by Whittaker (1960), Waring (1969), and Franklin and Dyrness (1973). Summer drought can be particularly prolonged, with only 18% of the annual precipitation occurring between April and September (Gratkowski 1961) and mean maximum air temperatures for July in excess of 29°C (Anon. 1960). The topography is characterized by steep mountains whose slopes range from 40 to 80% and elevations up to 2,296 m. Many of the soils are typically shallow (< 1 m); coarse fragment contents account for over 35% of the soil volume. Competition for moisture from a variety of sclerophyll brush and grass species is intense, and site-prepared areas are rapidly dominated by unwanted vegetation if newly planted trees fail during the first 5 years. Sites with southern exposures in steep terrain are particularly resistant; repeated operational plantings with the widely used 2-0 bare-root Douglas-fir seedling on such sites have produced disappointing results. A matter of increasing concern is that this regeneration failure has caused the recent withdrawal of more than 68,300 ha of commercial forest land from the timber production base (Anon. 1978, 1979b).

Poor seedling survival can be attributed to a wide variety of causes ranging from poor nursery practices to inadequate site preparation. Recently, however, it has been suggested that 2-0 bare-root Douglas-fir seedlings may not be the most appropriate stock type for the environments normally associated with droughty sites in southwest Oregon. This paper reports on the preliminary results of two separate Douglas-fir stock type comparisons involving bare-root, container-grown, and pulp-pot seedlings on droughty sites in southwest Oregon.

---

[1] Assistant Professor and [2] Professor, Department of Forest Science, Oregon State University, Corvallis, Oregon; [3] Silviculturist, Boise Cascade Corporation, Medford, Oregon.

BARE-ROOT, CONTAINER-GROWN, AND PLUG-1 COMPARISON

Three Douglas-fir stock types were outplanted in a randomized complete block experimental design with five replications on a severe site at Soldier's Camp Saddle in March 1980. Located at an elevation of 1,067 m, with a southeast exposure and a 75% slope, the test site is typical of many hard-to-regenerate areas in the Siskiyou Mountains. Mean annual precipitation is from 178 to 203 cm (Anon. 1979a). The soil is a loamy-skeletal, mixed, mesic Dystric Xerochrept (Anon. 1975) with a surface mantle of loose rock, gravels, and vegetative debris; soil depth is <1 m. Logged in the early 1970s, the site had been planted several times with 2-0 bare-root Douglas-fir and spot-seeded once with sugar pine *(Pinus lambertiana* Dougl.), but in 1980 remained unstocked.

Dominated by several species of sclerophyll brush, the test site was handslashed with chainsaws to prepare it for planting. Stock types planted were: (1) 2-0 bare-root seedlings, (2) 1-0 container seedlings grown in 164-cm^3 Leach single cells, and (3) plug-1 seedlings initially grown in 66-cm^3 Leach single cells and then transplanted to the nursery bed as bare-root seedlings for an additional year. Two hundred seedlings per stock type were hoe planted and protected from deer browsing by flexible Vexar tubes. Seedling height and diameter were measured immediately after outplanting and again in November 1980.

Half of the seedlings were subsequently used for plant moisture-stress measurements. Every 3 weeks over a 4-month period in the summer of 1980, predawn measurements for each stock type were taken with a Pressure Bomb (Waring and Cleary 1967) according to a method developed by Scholander et al. (1965). On each measurement date, 10 seedlings per stock type were selected at random and destructively sampled to determine plant moisture stress.

Survival of container-grown and plug-1 seedlings was significantly greater than that of bare-root stock (chi-square = 48.62, 2 d.f.) in July 1981 (Table 1). Bare-root seedlings suffered 37% mortality during the first year whereas container-grown and plug-1 seedlings had losses of only 5 and 7%, respectively. During the first half of 1981, population levels of all stock types showed signs of stabilization.

First-year growth performance of 2-0 bare-root seedlings was poor; average height increased only 4.44 cm. The 1-0 container-grown seedlings gained an average of 6.72 cm and plug-1 seedlings an average of 7.24 cm (Table 2). Diameter increases of 0.48, 0.70, and 0.42 mm for 2-0 bare-root, 1-0 container, and plug-1 seedlings were recorded during 1980. On a relative basis, the percentage increases in height and diameter of 1-0 container-grown seedlings far exceeded those of the other two stock types, although both were larger in terms of total height and diameter.

Table 1. Percent survival of three Douglas-fir stock types at Soldier's Camp Saddle.

Stock type	1980		1981	
	August	November	May	July
2-0 bare-root	74	63	57	57
1-0 container	100	95	93	92
Plug-1 bare-root	97	93	91	91

Predawn plant moisture stress was consistently lower in 1-0 container seedlings from May through September except for one measurement period in which weather conditions were unusual (Table 3). Mean plant moisture stress in 2-0 bare-root seedlings was higher than that of 1-0 container or plug-1 seedlings except as previously noted. Higher levels of plant moisture stress in 2-0 bare-root seedlings, particularly from May through July, were reflected in poorer survival and growth.

BARE-ROOT, CONTAINER-GROWN, AND PULP-POT COMPARISON

In 1978, three Douglas-fir stock types were outplanted at Brummet Creek, approximately 80 km north of Soldier's Camp Saddle. In 1977 a prescribed burn was carried out on the test site, which was located on a 6.47 ha clearcut. Characterized by a southeast aspect and 30% slopes at an elevation of 396 m, the site has deep soils (>1 m) classified as either a fine-loamy mixed, mesic Typic Haplumbrept or a fine-loamy mixed, mesic Umbric Dystrochrept (Anon. 1975). Mean annual precipitation is between 203 and 254 cm (personal communication from Craig Garland, Coos Bay District, USDI, Bureau of Land Management).

Over 2,000 seedlings of each of three stock types were planted in randomly assigned parallel rows that ran across contours. The stock types were: (1) 2-0 bare-root seedlings, (2) 1-0 container seedlings grown in 164-cm^3 Leach single cells, and (3) 1-0 seed-

Table 2. Mean height and diameter of three Douglas-fir stock types 1 year after outplanting at Soldier's Camp Saddle.

Stock type	Mean ht, 1980 (cm) March	Mean ht, 1980 (cm) November	Height increase (cm)	Mean diam, 1980 (mm) March	Mean diam, 1980 (mm) November	Diam increase (mm)
2-0 bare-root	19.13(±5.10)[a]	23.57(±6.01)	4.44	5.48(±1.43)	5.96(±1.30)	0.48
1-0 container	14.27(±3.10)	20.99(±3.81)	6.72	2.71(±0.60)	3.41(±0.64)	0.70
Plug-1 bare-root	33.10(±6.53)	40.34(±7.43)	7.24	6.71(±1.06)	7.13(±1.03)	0.42

[a] Standard deviations within parentheses.

Table 3. Mean predawn plant moisture stress of three Douglas-fir stock types at Soldier's Camp Saddle (May through September, 1980).

Stock type	Measurement date 28 May	8 July	29 July	19 Aug	9 Sep	30 Sep
2-0 bare-root	13.15(±7.93)[a]	9.41(±5.83)	20.11(±13.83)	11.74(±3.85)	20.56(±13.87)	19.35(±11.42)
1-0 container	5.98(±1.03)	5.46(±1.02)	8.85(±0.96)	13.08(±7.32)	13.29(±6.23)	16.90(±7.71)
Plug-1 bare-root	9.74(±3.61)	8.04(±2.99)	13.61(±10.20)	13.96(±7.23)	17.08(±9.49)	18.97(±9.84)

[a] Standard deviations within parentheses.

Table 4. Survival and mean height of three Douglas-fir stock types one growing season after outplanting at Brummet Creek.[a]

Stock type	Survival, September 1978 (%)	Mean ht, 1978 (cm) March	Mean ht, 1978 (cm) September	Height increase (cm)
2-0 bare-root	82	29.51(±6.86)[b]	37.31(±10.16)	7.8
1-0 container	95	16.28(±3.28)	29.34(±7.39)	13.06
1-0 pulp-pot	100	14.17(±3.61)	32.89(±11.58)	18.72

[a] Data provided courtesy of the Coos Bay District, USDI Bureau of Land Management.
[b] Standard deviations within parentheses.

Zings grown in biodegradable pulp-pots fabricated from papier mache. The pulp-pots were approximately 30 cm long, had a tapered cylindrical shape and an upper diameter of 8 cm; the bottom end of each pot was perforated for drainage. Seedling growth and survival data were collected by examining one randomly selected row of 125 seedlings for each stock type.

Survival of all three stock types was high at the end of the first growing season after outplanting (Table 4), although significant differences in survival did exist (chi-square = 31.9, 2 d.f.). Seedlings grown in pulp-pots outperformed 1-0 container and 2-0 bare-root seedlings in terms of survival and increase in height growth (Table 4). The 2-0 bare-root seedlings had the lowest survival rate (82%) and the smallest height increase (7.8 cm) even though they were the largest seedlings outplanted.

DISCUSSION

Douglas-fir 2-0 bare-root seedlings, a stock type frequently planted on dry sites in southwest Oregon, did not perform as well as other stock types the first year after outplanting in two separate trials. Survival and growth of all seedlings at Soldier's Camp Saddle, a site characterized by a thin, skeletal soil, were poorer than those of the seedlings planted at Brummet Creek, evidence that the former is a more stressful site. The much poorer growth and survival of the 2-0 seedlings at Soldier's Camp Saddle suggest that this stock type is less resistant to extreme site conditions in southwest Oregon than container-grown seedlings. This may reflect the poorer physiological condition of 2-0 seedlings, as manifested by significantly reduced needle length on 1978 shoots, or the relatively poor root growth of 2-0 stock compared with that of container-grown seedlings.

When excavating seedlings for plant moisture-stress measurements at Soldier's Camp Saddle, we found that the 2-0 bare-root stock did not produce new root growth to the same extent as the 1-0 container-grown and plug-1 stock types. Although this growth was not quantified, the difference in the number and length of actively growing root tips among stock types was profound. Even at the time of planting, root systems of both the 1-0 container-grown and plug-1 seedlings were obviously better developed than those of the 2-0 bare-root stock. Only a few seedlings were excavated at Brummet Creek, and these were dug in fall during a period of low root activity. Nonetheless, the relative superiority of root development in container-grown seedlings was equally evident in this plantation. Undoubtedly, the stock types with more vigorous root growth were able, as Schubert (1977) suggests, to use deeper sources of soil moisture, particularly as soil dried with advancing summer drought. This point is reinforced by the higher plant moisture-stress values generally encountered in the 2-0 bare-root seedlings (Table 3). Other data collected from four test sites near Soldier's Camp Saddle with 1-0 container-grown Douglas-fir support this hypothesis (S.D. Hobbs, unpublished data).

These preliminary results, which support data reported for the Sierra in California (McDonald and Cosens 1980), indicate that seedlings grown initially in containers may be better adapted to loamy soils than 2-0 bare-root seedlings on southerly sites in southwest Oregon, where moisture is a limiting factor. A well developed, fibrous root system capable of rapid growth seems to be a major factor governing seedling success on well drained, dry sites. Substantial root growth should occur during the first year to meet the high moisture demands placed upon the seedling during prolonged periods of high temperature and little precipitation. In this respect, 2-0 bare-root Douglas-fir seedlings have not done as well as other stock types, particularly on droughty, skeletal soils. These data are in agreement with data on the general performance of bare-root Douglas-fir seedlings, and strongly support the hypothesis that current bare-root nursery regimes do not produce seedlings of the highest vigor.

LITERATURE CITED

Anon.
1960. Climates of the states, Oregon. Climatography of the United States 60-35. U.S. Weather Bur. 20 p., illus.

Anon.
1975. Soil taxonomy. USDA Soil Conserv. Serv. Agric. Handb. 436. 754 p.

Anon.
1978. Final timber management and environmental statement: Josephine sustained yield unit. USDI Bur. Land Manage., Portland, Oreg. 691 p.

Anon.
1979a. Final environmental statement: Rogue-Illinois planning unit. USDA Pac. Northwest Reg., Siskiyou Natl. Forest, Portland, Oreg. 370 p.

Anon.
1979b. Final timber management and environmental statement: Jackson-Klamath sustained yield unit. USDI Bur. Land Manage., Portland, Oreg. 400 p.

Bassett, P.M.
1979. Timber resources of southwest Oregon. USDA For. Serv., Pac. Northwest For. and Range Exp. Stn. Res. Bull. PNW-72.

Franklin, J.F., and Dyrness, C.T.
1973. Natural vegetation of Oregon and Washington. USDA For. Serv., Pac. North west For. and Range Exp. Stn. Gen. Tech. Rep. PNW-8. 417 p.

Gratkowski, H.
1961. Brush problems in southwestern Oregon. USDA For. Serv., Pac. Northwest For. and Range Exp. Stn. Unnumbered Rep. 53 p.

McDonald, P.M., and Cosens, R.D.
1980. Survival and height growth of bareroot and container-grown seedlings in northern California. p. 75 in Executive Summaries, Proc., 1980 West. For. Conf. West. For. and Conserv. Assoc., Portland, Oreg.

Scholander, P.F., Hammel, H.T., Bradstreet, E.D. and Hemmingsen, E.A.
1965. Sap pressure in vascular plants. Science 148:339-346.

Schubert, G.H.
1977. Forest regeneration of arid lands. p. 82-87 in Forests For People. Proc., Soc. Am. For., Washington, D.C.

Waring, R.H.
1969. Forest plants of the eastern Siskiyous: their environmental and vegetational distribution. Northwest Sci. 43(1):1-17.

Waring, R.H. and Cleary, B.D.
1967. Plant moisture stress: evaluation by pressure bomb. Science 155(3767): 1248-1254.

Whittaker, R.H.
1960. Vegetation of the Siskiyou Mountains, Oregon and California. Ecol. Monogr. 30:279-338.

EFFECTS OF NURSERY NUTRITIONAL SCHEDULES ON DEVELOPMENT OF WESTERN HEMLOCK SEEDLINGS IN THE FIELD

W.C. Carlson[1] and G.D. Shaw[2]

Abstract.--Western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) seedlings were cultured with five different nutritional schedules used in the Pacific Northwest. Seedling shoot and root development were compared after the nursery culture period and after the first year in the field. Differences in shoot development were increased whereas differences in root development were decreased during the first year after outplanting.

Résumé.--Des plants de pruche occidentale (*Tsuga heterophylla* [Raf.] Sarg.) ont été cultivés en étant soumis à cinq régimes d'alimentation en usage dans le nord-ouest du Pacifique. La croissance des pousses et des racines de ces plants a été comparée à la fin de la période de culture en pépinières et un an après la plantation. Les différences de développement des pousses se sont accrues tandis que les différences de développement des racines ont diminué au cours de la première année après la transplantation.

INTRODUCTION

Nutritional schedules for the culture of forest tree seedlings have been the subject of much research. Brix and van den Driessche (1974) reviewed this work with regard to the greenhouse culture of tree seedlings in containers. Larson (1974) suggested that application of research knowledge was more of a problem than lack of knowledge in the mineral nutrition of cultured tree seedlings. Inspection of seedlings cultured by many different growers around the Pacific Northwest indicated a surprising diversity of seedling gross morphology which could be attributed in part to differences in nutritional schedules used by these nurseries. The studies reported here were initiated to distinguish quantitatively the differences among the nutritional schedules in common use for the culture of western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) in the Pacific Northwest.

MATERIALS AND METHODS

Stratified seeds of western hemlock from two seed lots, one from Sekiu, Washington (365 m elevation) and the other from the Seaside, Oregon area (182 m elevation) were sown in mid-February 1977 in 60-cm^3 styroblock-4 quarterblock containers filled with 1:1 peat/vermiculite growing medium. These containers were arranged in 152.4- x 182.9-cm rectangles of 1800 trees each. Half of each rectangle was sown with each seed source. Four greenhouse benches were oriented north-south, each holding five of the seedling blocks 122 cm apart. Each of the five seedling blocks on a particular bench was assigned a nutritional treatment at random. The assigned nutritional schedules included one utilized by the British Columbia Forest Service's (BCFS) Koksilah Forest Nursery at Duncan, B.C., Hoagland's solution, and one utilized by the Crown Zellerbach (CZ) Corporation Nursery near Aurora, Oregon (Table 1). We recognize that managers often alter nutritional schedules during the growing season; therefore, our schedules only approximate those used in any one year.

---

[1] Weyerhaeuser Co., Southern Forestry Research Center, Hot Springs, Arkansas

[2] 23745 Third NE Butteville, Aurora, Oregon

Table 1. Composition of three liquid nutritional schedules used.

(A) Nutritional schedule based on that of the BCFS

Week	NPK Ratio	Rate (g/1000 L)
5	10-51-16	625
8-24	20-20-20	500
25-26	0-52-34	625
27-34	10-51-16	625
35	0-0-0	
36+	10-51-16	625

(B) Hoagland's Solution

Stock solutions (diluted 1:200 to make final solution). Applied at 6 ml/cavity/ week until midsummer, then as needed.

		mg/gal
(a)	NH_4Cl	244
	KNO_3	458
	KH_2PO_4	124
	$MgSO_4 \cdot 7H_2O$	462
	H_3BO_4	5.2
	$CuCl_2 \cdot 2H_2O$	0.1
	$MnCl_2 \cdot 4H_2O$	3.28
	$Zn(NO_3)_2 \cdot 6H_2O$	0.42
	MoO_3	0.013
(b)	$Ca(NO_3)_2$	848
	Sequestrene	148

(C) CZ 1976 nutritional schedule

Week	NPK Ratio	Rate (ppm)
5-18	1-2-1	25
9-13	1-2-1	50
14	2-1-1	75
15-24	3-1-1	100
25-34	1-2-1	50
35-37	0-0-0	
38+	2-50-25	25

Stock solution used for 1:200 injection into irrigant	NH_3SO_4 g/L	KNO_3 g/L	H_3PO_4 (85%) ml/L
1-2-1 @ 25 ppm	16	11.5	7.9
1-2-1 @ 50 ppm	32	23	15.8
2-1-1 @ 75 ppm	59.5	17	5.95
3-1-1 @ 100 ppm	84.0	15	5.3
2-50-25 @ 25 ppm	0	11.5	7.9

Two other nutritional schedules used were BCFS schedule plus 2.34 kg/m^3 Osmocote 117 (17-5-11) and BCFS schedule plus Scott Progrow (24-9-9) at 1.79 kg/m^3.

In mid-December 12 seedlings were chosen at random from each replicate block and measured for total height, root-collar diameter, shoot dry weight and root dry weight. The number of unsuberized root tips per root system was counted on seedlings sampled from the Sekiu seed source.

The remaining seedlings were then put into storage at 2-4 °C until late January 1978 when 100 trees were sampled randomly from each seed source and each nutritional treatment and outplanted. Sekiu source seedlings were planted on a northeast aspect at 365 m elevation near Sekiu, Washington. Seaside source seedlings were planted near 182 m elevation in the Charlie Creek subdrainage of the Necanicum River near Seaside, Oregon. At each site the seedlings were individually tagged and planted in a completely randomized design. At the Charlie Creek site seedlings were protected from animal damage with Vexar tubing.

In January, 1979, total height, height growth and groundline diameter were measured on each seedling. On the Sekiu plantation, 25 trees were randomly sampled for root system structure from each treatment except the BCFS plus Scott Progrow treatment. The trees chosen were marked on the uphill side of the stem at groundline, then excavated 15 cm from the stem and a minimum of 25 cm deep. The excavated seedlings were placed in a 12-zone frame similar to that used by Rischbieter (1978). The number of roots per zone and the diameter of the largest root in each zone were recorded for each of the excavated seedlings. Programs of the Statistical Analysis System (SAS Institute Inc., SAS Circle, Cary, NC. 27511) were used for data analysis.

RESULTS

Seedlings from the various nutritional schedules varied less than 3 cm in mean height at the end of the nursery culture period (Fig. 1). These variations were not strongly related to treatment (a = .2016), but were more related to seed source (a = 0.0848) and position of the replicate within the greenhouse (a = 0.1142). Mean root collar diameter was greatest for seedlings cultured with the BCFS Osmocote 117, and least for seedlings cultured on Hoagland's solution schedule (a = 0.0001) (Fig. 1). The mean weight distribution within seedlings also varied depending on the cultural treatments (Fig. 2). Shoot weight was highest in seedlings cultured with the CZ nutritional schedule, and the other treatments were very similar in weight (overall a = 0.0001). Root weight varied only about 0.14 g and while differences due to treatment were significant (a = 0.0001) the variation due to location in the greenhouse was quite strong (a = 0.0043). Conversely, shoot weight did not vary by greenhouse location (a = 0.9908). Shoot:root ratio was most affected by treatment (a = 0.0001) but was also affected by greenhouse location (a = 0.0043). Over all, seedlings cultured on the CZ schedule had comparatively high shoot:root ratios (Fig. 2).

Nutritional regime had a pronounced effect on the number of active root tips (a = 0.0030) and the number of active root tips per gram dry weight of root (a= 0.0005), although these parameters were also affected by greenhouse location (a = 0.0626 and a = 0.0084, respectively). In general, the BCFS schedule and modifications of it had uniformly high numbers of active root tips per gram dry weight of root while the CZ and Hoagland's solution schedules produced lighter roots with fewer active tips (Fig. 3).

Foliar analysis at the end of the greenhouse culture period indicated that the BCFS nutritional schedule with and without controlled release fertilizer amendments yielded seedlings with higher foliar levels of nitrogen, potassium and phosphorus than the CZ and Hoagland's solution schedules (Table 2).

On the Seaside, Oregon site seedlings from the BCFS plus Osmocote 117 nutritional schedule grew more the first year after outplanting (a= 0.0125) and were also the tallest (a = 0.0192) (Fig. 4). The groundline diameter of these trees was also greater than that of trees from other treatments (a = 0.0001).

Seedling height growth on the Sekiu, Washington test site was not related to nursery cultural treatment (a = 0.7772). Seedlings from BCFS plus Osmocote 117 and Crown Zellerbach nutritional schedules were the tallest (a = 0.0829) because of differences at planting (Fig. 5) and had the largest groundline diameter (a = 0.0147).

Excavation of seedlings at the Sekiu test site showed that, in all treatments, more roots egressed from the, bottom zone of the plug than from the upper zones (Fig. 6). Seedlings from the BCFS plus Osmocote 117 treatment had more roots in the bottom zone than did those of other treatments (a = 0.0004). The upper zone of the plugs from the Hoagland's solution treatment had more roots than did those from other treatments (a = 0.0353).

While maximum root diameter and the number of roots in each of 12 zones varied with treatment (Table 3), the relative values of these factors between zones was similar among treatments (Fig. 7).

Table 2. Foliar nutrition analysis results at the end of the greenhouse culture period for two seed sources.

Nutritional schedule	N	P	K	S	Ca	Mg	Na	Zn	Mn	Cu	Fe
Hoagland's - O[a]	1.64	.296	.90	.107	.48	.257	.045	17	222	4.0	168
Hoagland's - W	1.62	.234	.88	.147	.46	.248	.046	17	212	2.9	160
BCFS + Scott Prog - O	1.72	.449	1.42	.008	.46	.275	.033	40	541	9.0	117
BCFS + Scott Prog - W	2.04	.458	1.61	.008	.41	.283	.037	35	532	6.2	100
Crown Zellerbach - O	1.66	.292	.87	.214	.36	.174	.023	19	177	3.0	108
Crown Zellerbach - W	1.61	.346	1.05	.290	.40	.211	.021	25	208	3.0	128
BCFS - O	2.26	.485	1.35	.046	.42	.268	.032	20	429	4.8	61
BCFS - W	1.97	.496	1.37	.007	.37	.266	.035	22	371	4.9	92
BCFS + Osmo 117 - O	2.16	.508	1.23	.148	.37	.264	.43	21	301	5.4	99
BCFS + Osmo 117 - W	2.00	.463	1.27	.131	.38	.264	.39	19	313	4.9	87

[a] O = Seaside, Oregon seed source
W = Sekiu, Washington seed source

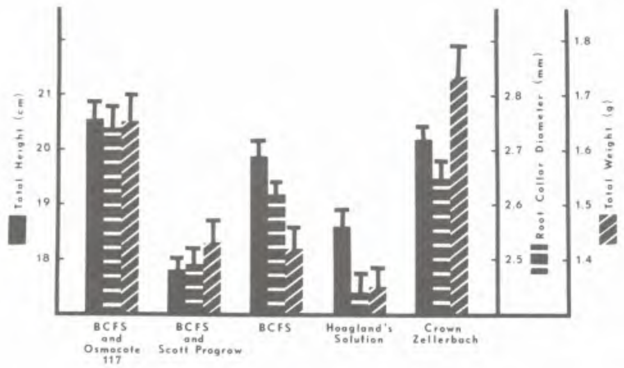


Figure 1. Seedling size parameters for each nutritional schedule. Data were combined for the two seed sources. One standard error of the mean is indicated at the top of each bar.

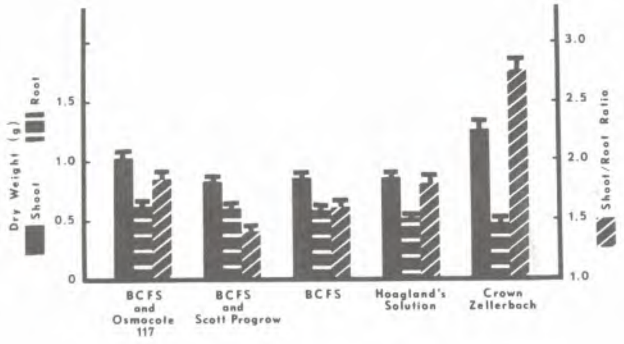


Figure 2. Seedling weight parameters for each nutritional schedule. Data were combined for the two seed sources. One standard error of the mean is indicated at the top of each bar.

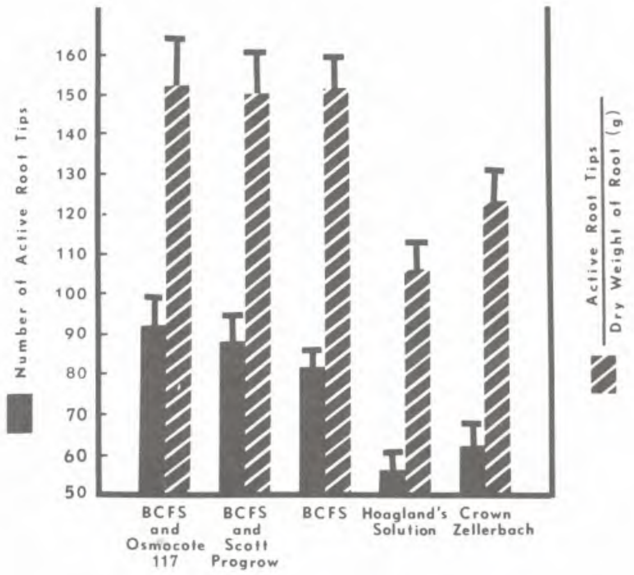


Figure 3. The number of active (unsuberized) root tips per seedling and per gram dry weight of root for seedlings from each nutritional schedule. One standard error of the mean is indicated at the top of each bar.

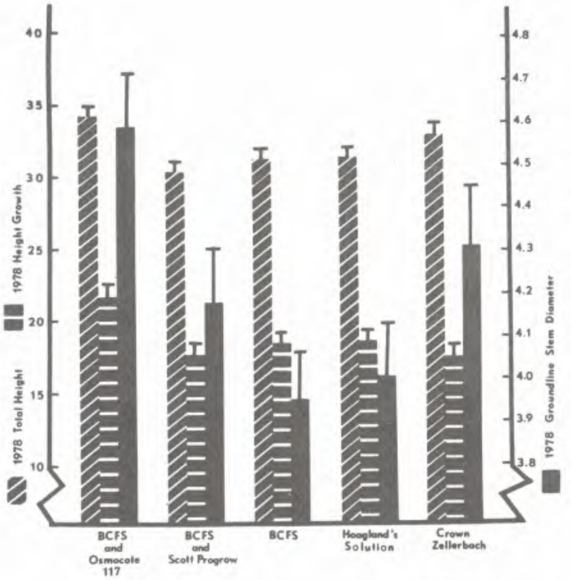


Figure 4. Height, height growth, and groundline diameters one year after outplanting at Seaside, Oregon. One standard error of the mean is indicated at the top of each bar.

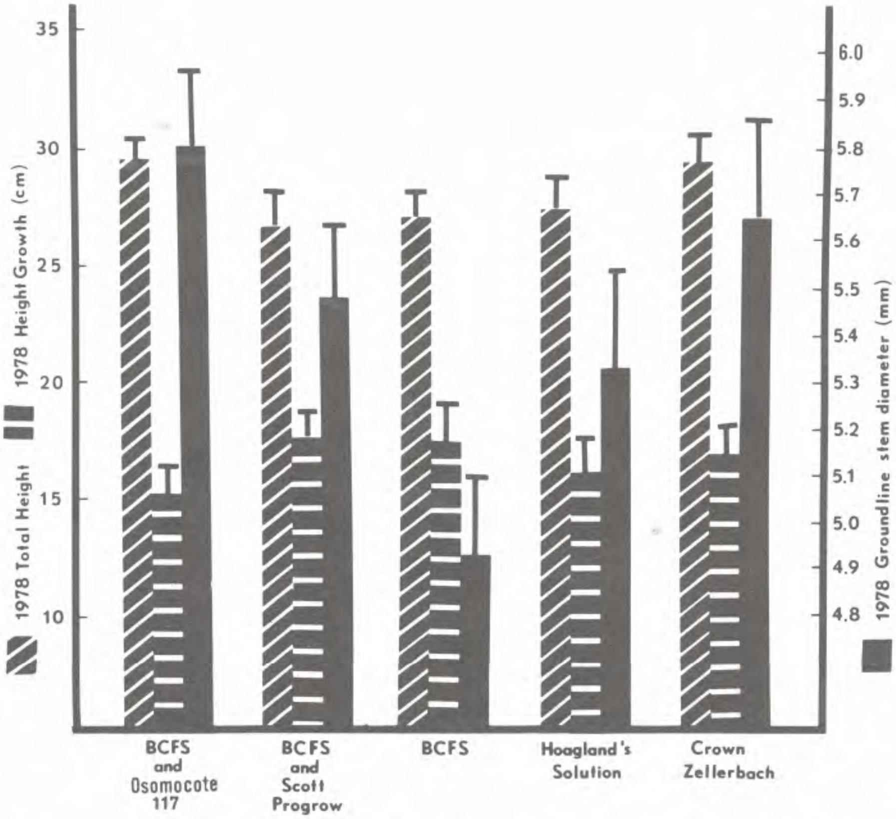


Figure 5. Height, height growth and groundline diameters one year after outplanting at Sekiu, Washington. One standard error of the mean indicated at top of each bar.

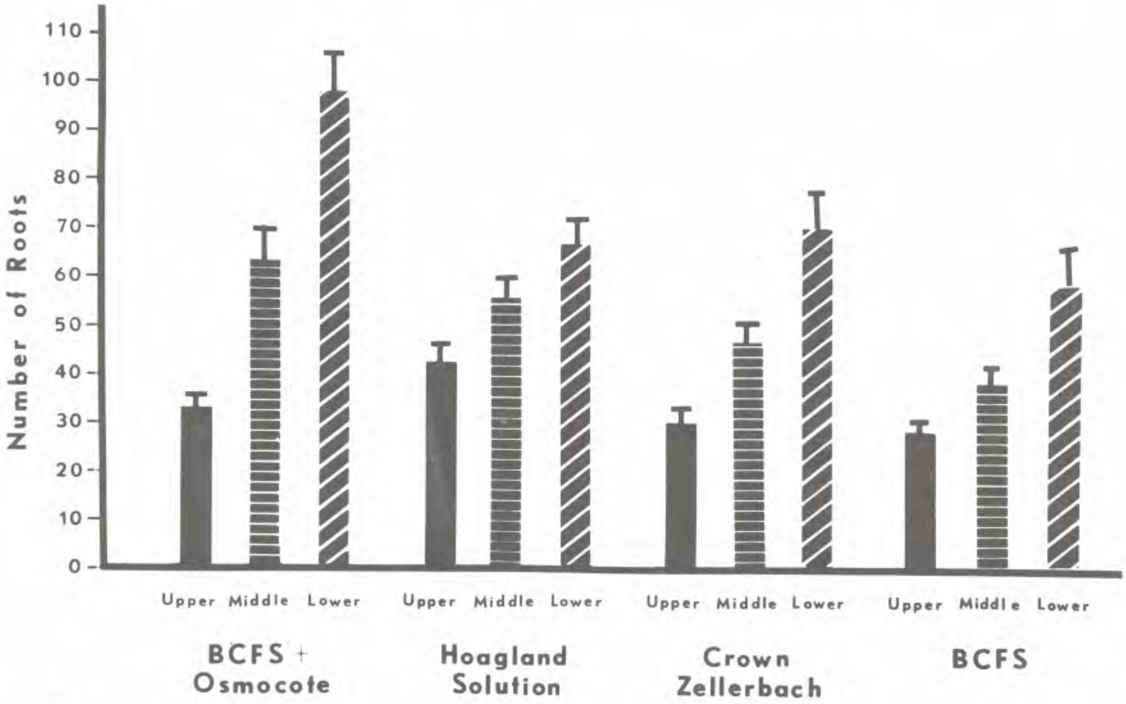


Figure 6. Number of roots egressed from the upper, middle and lower third of the original plug root mass one year after outplanting. One standard error of the mean indicated at top of each bar.

Table 3. Analysis of variance of number of roots per zone and the maximum root diameter (cm) in each zone by treatment.

	Number of roots in zone		Average maximum root diameter in zone	
	Mean square by source*		Mean square by source*	
Root zone	Treatment**	Error	Treatment**	Error
1	$47.87^{0.1204}$	24.20	$0.2744^{0.1885}$	0.1697
2	$67.33^{0.0789}$	29.07	$0.3561^{0.0427}$	0.1268
3	$47.42^{0.1254}$	25.18	$0.2597^{0.0671}$	0.1062
4	$54.51^{0.1697}$	32.02	$0.7212^{0.0431}$	0.2576
5	$54.57^{0.4352}$	59.22	$0.3217^{0.1066}$	0.1550
6	$59.20^{0.4118}$	61.08	$0.0699^{0.6388}$	0.1222
7	$366.35^{0.0011}$	62.52	$0.1553^{0.4727}$	0.1830
8	$498.81^{0.0006}$	78.55	$0.7311^{0.0095}$	0.1814
9	$612.81^{0.0017}$	111.67	$0.2258^{0.4044}$	0.2292
10	$317.34^{0.0422}$	112.64	$0.3048^{0.1196}$	0.1537
11	$794.93^{0.0097}$	198.20	$0.4388^{0.0783}$	0.1890
12	$1110.67^{0.0001}$	137.29	$0.7499^{0.0206}$	0.2192

*There were three degrees of freedom for treatment and 102 for error.
**The superscript on the mean square is the probability of a type I error.

DISCUSSION

Western hemlock seedlings cultured under different but commonly used nutritional schedules generally differed more at the end of the nursery culture period (1 year) than at the end of the first field season. Small differences in height at the end of the nursery culture period were, however, increased slightly after planting on the Seaside plot where seedlings from the BCFS plus Osmocote 117 nutritional schedule were tallest. Anderson and Gessel (1966) and Smith et al. (1966) presented data indicating that in Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) plantations such small differences can become much larger as seedlings develop to 5 years of age.

Osmocote 117 is a resin-coated 17-5-11 NPK controlled release fertilizer (Oertli and Lunt 1962) that can effect increased height growth in both the first and second years after application (Carlson and Preisig 1981). The availability of additional NPK to seedlings in this treatment was thereby extended through the first field season. Carlson (1982) has shown that western hemlock responds to higher levels of this fertilizer applied at planting. The height growth response in this treatment was probably due to the combined effects of initially taller seedlings and residual Osmocote 117.

Late season fertilization of bare-root stock in the nursery has improved the survival and growth of Douglas-fir and western hemlock after outplanting (Anderson and Gessel 1966, Smith et al. 1966, Benzian and Freeman 1967). Benzian and Freeman (1967) noted that such nursery treatments raised the foliar nitrogen level of western hemlock from 0.8% to 1.6% in 2-yr-old stock and to 2.0% in 1-yr-old stock. In the study reported here, late season foliar nitrogen levels ranged from 1.61 to 2.26% and hence were all in the range found by Benzian and Freeman (1967) to give better survival, frost hardiness, height and diameter growth than a 0.8% level found in unfertilized stock. It is apparent that all of the nutritional schedules tested here provide foliar nitrogen adequate to support the type of initial growth observed in the field following late season nursery fertilization of bare-root stock.

The root regeneration potential of trees under controlled conditions has often been used as a basis for estimating bare-root seedling quality (Stone 1955). Containerized seedlings have root systems that are less disturbed at planting and can elongate rapidly to produce a greater length of roots on the seedling than is common for bare-root stock (Hahn and Hutchison 1978). It seems reasonable to assume that a major factor in rapid enlargement of containerized seedling root systems following outplanting is the presence of unsuberized root tips. The initiation of new lateral root primordia is more sensitive to physiological stress than is elongation of existing roots (Ritchie and Dunlap 1980).

Our results suggest that the number of unsuberized root tips does not predict the number of roots that will develop after planting under moist forest conditions in western hemlock. Seedlings cultured on Hoagland's solution had fewer unsuberized root tips at the end of the nursery culture period than did those of other treatments, but these seedlings were second only to seedlings cultured with the BCFS and Osmocote 117 nutritional schedule in number of elongated roots after outplanting. This suggests that new root initiation or elongation of lateral root tips not apparent as unsuberized tips is potentially as important as elongation of unsuberized tips to root system enlargement after outplanting.

Seedlings from all treatments had more roots extending from the bottom third of the plug than from upper zones. This agrees with the findings of Long (1978) for western hemlock. Air pruning at the bottom of the container causes many new roots to form in that area of the plug, possibly because of hormonal changes associated with the injury (Carlson and Larson 1977).

The average root systems of hemlock seedlings cultured with any of the nutritional schedules in this study were symmetrical with respect to numbers of roots and the diameter of the largest root in each of the 12 root zones. Arnott (1978) noted that root system structure of containerized western hemlock seedling roots was oriented in a configuration similar to that of naturally seeded trees.

Results reported here support the conclusion that hemlock seedlings grown in styroblock-4 containers with any one of the nutritional schedules tested will develop an adequate root system after outplanting.

ACKNOWLEDGMENTS

The work reported here was completed while the authors were Research Forester and Assistant Research Forester, respectively, with Crown Zellerbach at Wilsonville, Oregon.

LITERATURE CITED

Anderson, H.W. and Gessel, S.P.
1966. Effects of nursery fertilization on outplanted Douglas-fir. J. For. 64:109-112.

Arnott, J.T.
1978. Root development of container-grown and bare-root stock: coastal British Columbia. p. 257-267 *in* E. Van Eerden, and J.M. Kinghorn, *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8.

Benzian, B. and Freeman, S.C.R.
1967. Effect of late-season N and K top-dressings applied to conifer seedlings and transplants, on nutrient concentrations in the whole plant and on growth after transplanting. Comm. Rep. on For. Res. 1967. HMSO, London, p. 135-140.

Brix, H. and van den Driessche, R.
1974. Mineral nutrition of container-grown tree seedlings. p. 77-84 *in* R.W. Tinus, W.I. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Carlson, W.C. and Larson, M.M.
1977. Changes in auxin and cytokinin activity in roots of red oak, *Quercus* rubra, seedlings during lateral root formation. Physiol. Plant. 41:162-166.

Carlson, W.C.
1981. Effects of controlled release fertilizers on shoot and root development of outplanted western hemlock *(Tsuga heterophylla* [Raf.] Sarg.) seedlings. Can. J. For. Res. 11:752-757.

Carlson, W.C. and Preisig, C.L.
1981. Effects of controlled release fertilizers on the shoot and root development of Douglas-fir seedlings. Can. J. For. Res. 11:230-242.

Hahn, P. and Hutchinson, S.
1978. Root form of planted trees and their performance. p. 235-240 in E. Van Eerden and J.M. Kinghorn, *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8.

Larson, P.R.
1974. The upper limit of seedling growth. p. 62-76 in R.W. Tinus, W.I. Stein, and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Long, J.N.
1978. Root system form and its relationship to growth in young planted conifers. p. 222-223 in E. Van Eerden and J.M. Kinghorn, *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8.

Oertli, J.J. and Lunt, O.R.
1962. Controlled release of fertilizer minerals in incapsulating membranes I. Factors influencing the rate of release. Soil Sci. Soc. Proc. 26:579-583.

Rischbieter, N.O.
1978. Root egress from dibble planted containerized Douglas-fir seedlings. p.241-252 in E. Van Eerden and J.M. Kinghorn, *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./ Can. For. Serv. Joint Rep. No. 8.

Ritchie, G.A. and Dunlap, J.R.
1980. Root growth potential: Its development and expression in forest tree seedlings. N. Z. J. For. Sci. 10(1):218-48.

Smith, J.H., Kozak, G.A., Sziklai, O. and Waters, J.
1966. Relative importance of seedbed fertilization, morphological grade, site, provenance and parentage to juvenile growth and survival of Douglas-fir. For. Chron. 42(1):83-86.

Stone, E.C.
1955. Poor survival and the physiological condition of planting stock. For. Sci. 1:90-94.

ROOT EGRESS IN LODGEPOLE PINE SEEDLINGS GROWN IN PEAT AND PLANTED IN SOIL

A.K. Helium'

Abstract.--Seedlings of lodgepole pine *(Pinus contorta* Dougl. var. Zatifolia Engelm.) were grown in 49 cm^3 containers filled with peat or soil and subsequently transplanted into 18 cm diameter pots filled with soils ranging in texture from sandy loam to clay loam. Watering intensity did not significantly influence the growth of transplanted seedlings. Seedlings reared in peat, and held for planting past their optimum size relative to container size, became progressively less able to adapt to soils with increasing clay content the longer they were held. When seedlings were reared in the same soil into which they were to be transplanted, clay content in the soil did not influence root egress at all.

Résumé.--Des semis de pin tordu latifolié *(Pinus contorta* Dougl. var. *latifolia* Engelm.) ont été cultivés dans des récipients de 49 cm^3 contenant de la tourbe ou différents types de sol, et ensuite transplantés dans des récipients de 18 cm de diamètre contenant des sols dont la classe de texture variait du loam sableux au loam argileux. L'intensité de l'arrosage après la transplantation n'a pas beaucoup influé sur la croissance des plants. Ceux qui avaient crû dans la tourbe et dont la transplantation avait été retardée une fois leur dimension optimale atteinte par rapport à la dimension du récipient ont eu d'autant plus de difficulté à s'adapter aux sols de plus en plus argileux que le retard avait été important. La teneur en argile n'a aucunement influé sur le développement des racines dans le cas des semis cultivés dans le même sol que celui dans lequel ils allaient être transplantés.

INTRODUCTION

The advantages of container-grown tree seedlings over bare-root stock are many and varied (Kinghorn 1970, Scarratt and Ketcheson 1974), and range from easier handling of stock and rearing, to more rapid nursery production, to less expensive field planting and higher survival. Techniques for rearing have been detailed at great length (Waldron 1972, Tinus et al. 1974, Kay 1975, Low 1975, Carlson 1979, Tinus and McDonald 1979).

Considerable attention has also been paid to growth of coniferous stock after outplanting although the results are contradictory with respect to growth advantages over bare-root stock (Arnott 1971, 1974, Gillgren 1972, Walker and Johnson 1974, Kormanik et al. 1976, Carlson and Nairn 1977, Hahn and Hutchison 1978, Segaran et al. 1978, Walker 1978).

Root development may be hampered by the container in which the seedling is grown in the nursery (Bergman and Hgggstriim 1976, Van Eerden and Kinghorn 1978). Not only may root form be restricted but this restriction may lead to unbalanced growth (Greene 1978) and to warnings of instability in sapling stands (Tinus 1978). The problem is especially severe for several members of the genus *Pinus* (Stone et al. 1963, Endean 1972, Van Eerden 1978).

It is not only the container, however, which may present problems; the potting medium is also important (Long 1932, Klett et

---

[1] Associate Professor, Department of Forest Science, University of Alberta, Edmonton, Alberta.

al. 1972, Helium 1975, Funk et al. 1980). Peat moss is the principal potting medium used in Canada and elsewhere.

The study reported here addresses the problem of planting seedlings of lodgepole pine *(Pinus contorta* Dougl. var. *latifolia* Engelm.) that have been grown in peat moss in soils of different texture. The problem has received little attention, but may play a major role in determining seedling survival after outplanting. We know that peat has different hygroscopic properties than soil (Buckman and Brady 1960) and that this difference leads to moisture problems (Day and Cary 1974) when roots attempt to traverse the boundary between the peat and the soil.

The study attempts to answer three questions:

1. Does root growth outside the container, after simulated outplanting, vary in relation to available water as suggested by Endean and Hocking (1973)?

2. Does soil texture or soil manipulation (affecting bulk density) affect root egress as suggested by de Champes et al. (1975)?

3. Does the size of the seedling in relation to the volume of the container in which it is grown affect the seedling's growth when it is planted in soils of different soil texture?

METHODS

Three separate greenhouse studies were initiated, one each year from 1978 through 1980. All seedlings in the second and third year were grown in a greenhouse under a 16 hr day and at 20°C. In 1978 the seedlings were donated by North Canadian Forest Industries Ltd. This stock was considered overgrown for the size of the container used, and weighed nearly twice as much as was recommended for a 49 cm^3 rooting volume (Endean and Carlson 1975).

In 1978 and 1979 the seedlings were reared in peat moss and transplanted to flowerpots (18 cm diameter and 10 cm deep) filled with peat, sandy loam (Culp series), silt loam (Breton series), or clay loam (Maywood series) from the Edmonton areal. In 1980 the seedlings were both reared in Spencer-Lemaire Ferdinand containers (49 cm^3) and transplanted into the above three soils (transplanted into same flowerpots). Only in 1979 were the seedlings fertilized with a 10-52-10 fertilizer.

After transplanting, the seedlings were allowed to grow for 10 weeks at 20°C, with a 16 hr photoperiod, before harvesting.

Watering varied between years. In 1978 the transplanted seedlings were watered every 3 1/2, 7 or 14 days, in 1979 they were watered every 7, 14 or 21 days, and in 1980 they were watered every 14, 21 or 28 days.

A total of 75 seedlings were tested each year in 1978 and 1979, and 60 were tested in 1980. Each year, 15 of these seedlings were analyzed before transplanting, and the remaining seedlings were divided equally among the three watering levels and transplant media.

The seed sources for this study were: 1978--seedlot DG 63-3-6-74 from Grande Prairie, Alberta (1060 m above sea level and 54°30'N); 1979 and 1980--seedlot DB 8-4-5-77 from Blairmore, Alberta (1,500 m above sea level and 49°30'N).

The soils and peat were sieved through 6 mm mesh, sterilized (steam-sterilized at 82°C for 30 minutes), and watered daily for 14 days before transplanting to settle the material. Then cores of medium were removed from the centre of each pot to accommodate the 49 cm^3 seedling plug. The cores were removed using a hollow, rectangular dibble made of sheet metal. The bulk density of each of the mineral soils in the pots was measured after the 14 days of watering. A 70 cm^3 core was taken from the centre of each of three pots, in addition to those used in the transplant tests, 24 hr after the last watering when the soils were near field capacity.

At the time of final harvest the seedlings were carefully removed from the pots to ensure that roots were not damaged or cut off and that root egress from the plug form could be identified. Egressed roots were cut off in the laboratory so that the effects of rooting media could be compared.

Seedlings were oven dried at 105°C for 24 hr to determine dry weights.

The following measurements were made at time of transplanting and after the 10-week growing period: seedling height, maximum root length, shoot and root dry weights, root weight outside plug form, root-collar diam-

---

[2] The soils were tested by the Alberta Department of Agriculture and found to be adequately supplied with N and P and well supplied with K.

eter, shoot:root ratios (based on oven-dry weights).

Simple "F" and "t" tests were run and line formulae were calculated for salient data. Percent and ratio values were transformed to ARCSINE before analyses were run.

RESULTS

Seedling characteristics before transplanting are given in Table 1. Note that in 1978 seedlings were too large (by nearly 100%) for the 49 cm^3 container (Endean and Carlson 1975). The 1979 seedlings were too small (by about 30%) and those from 1980 were matched in size to the rooting volume of the container (300-500 mg total dry weight).

No correlation could be established between watering regime after transplanting and seedling growth (95% confidence level). Consequently, watering levels within soil types were considered as three replicates, each consisting of five seedlings, for the analyses in this study. This lack of watering effect on seedling growth must be related to the fact that the 18 cm flowerpots provided such a large reserve of water that infrequent additions of moisture were of no practical consequence. Watering periodicities from 3 1/2 to 28 days were all the same in their effect on growth.

Little or no height growth took place in the 10 weeks following transplanting although there was considerable root extension, some roots nearly doubling their maximum lengths (Table 2).

In contrast, both roots and shoots increased greatly in dry weight. The increases were greatest in the roots of the smaller plants. The 1979 stock increased its root weight an average of 686%, while the average-sized seedlings of 1980 increased their root weight by 397%. On the other hand, the overgrown stock of 1978 increased its root weight by only 272%. The effect was that the 1980 stock, matched to container size, had the heaviest roots (625 mg vs 607 mg and 259 mg averages for 1979 and 1978, respectively).

Shoot weight increases were much more modest, amounting to an average of 247% in the 1979 stock, 223% in 1980 and a mere 89% in 1978. In other words, the greatest increases were found in the smallest stock (at time of transplanting) and the smallest increases were found in the overgrown stock. Seedlings grown in sandy loam in 1980 also produced heavier roots than those grown in silt loam or clay loam (99% confidence level).

Similar trends were observed in root collar diameters and shoot:root ratios. Root collar diameters increased most in the smallest stock (at time of outplanting) and were similar for the large as well as average-sized stock (66 and 64%, respectively). Shoot:root ratios all decreased after transplanting by 35 to 55%. This decrease was a direct result of the large root weight increases over the test period.

When the weight of roots growing from the container (plug) form was analyzed separately from total root weight (Fig. 1) it was found that:

Table 1. Seedling characteristics, by test year, immediately prior to transplanting into 18 cm pots.

	Test year and growing medium				
	1978[a]	1979[b]	1980[c]		
	Peat	Peat	Sandy loam	Silt loam	Clay loam
Shoot (cm)	14.05	7.95	9.71	7.99	8.77
Max. root (cm)	16.24	12.87	11.98	11.69	14.16
Shoot dry weight (mg)	581.00	132.00	287.67	210.67	239.33
Root dry weight (mg)	223.00	65.19	84.67	95.33	93.33
Root-collar diameter (mm)	1.96	0.79	1.37	1.28	1.22
Shoot:root ratio	2.60	2.05	3.71	2.22	2.62

[a] Seedlings were approximately 150 days old at time of transplanting
[b] Seedlings were approximately 90 days old at time of transplanting
[c] Seedlings were approximately 180 days old at time of transplanting

Table 2. Changes in seedling characteristics over the 10-week transplanting test period.

	Test year and growing medium				
			1980		
	1978	1979	Sandy loam	Silt loam	Clay loam
Shoot (cm)	+ 13%	+ 9%	+ 7%	+ 18%	+ 15%
Max. root (cm)	+ 22%	+197%	+131%	+189%	+ 64%
Shoot, oven-dry basis (mg)	+ 89%	+247%	+180%	+233%	+257%
Root, oven-dry basis (mg)	+272%	+686%	+485%	+336%	+369%
Root-collar diameter (mm)	+ 66%	+157%	+ 52%	+ 62%	+ 78%
Shoot:root ratio	- 46%	- 55%	- 56%	- 24%	- 26%

a) oversized seedlings reared in peat (1978) showed a strong negative correlation ($r^2 = 0.75$) with increasing clay content of the surrounding transplant soil ($Y = 75116.6 X$) which was significant at the 99% confidence level (Y = weight of egressed root and X = percent clay in the transplant soil);

b) seedlings reared in peat and undersized for the container (1979) also showed a negative but much weaker correlation ($r^2 = 0.32$) between percent root egress and percent clay in the transplant soil ($Y = 531-10.6 X$) which was also significant at the 99% confidence level;

c) seedlings matched in size to their container and reared in the same soil in which they were to be transplanted showed no correlation ($Y = 150.3$ mg) between root egress and clay content of the transplant soil.

It is probable that the small amount of root egress for seedlings grown in soil (1980) is related to their slower overall growth in comparison with that of seedlings grown in peat.

Regardless of texture, the soils did not vary significantly in bulk density during the transplant period. Therefore, average values of 1.02, 1.08 and 0.94 for the sandy loam, silt loam and clay loam, respectively, suggest that root egress is probably not related to bulk density, at least not directly.

The weight of roots inside the container (plug) form increased over the 10-week transplant period. It doubled in the overgrown seedlings (1978), tripled in the average-sized stock (1980) and quadrupled in the small stock (1979). Texture differences among soils in the 1980 test had no significant effect on root weight inside the container (95% level). Since root egress decreases with increasing clay content of the soil after transplanting, it is essential that measurements of root growth be based on the percentage of egressed roots rather than on total root weight when soil effects on growth are evaluated.

CONCLUSIONS

The results of this study have clear implications for planting programs with containerized stock.

1. Watering frequencies ranging from every 3 1/2 days to every 28 days did not influence seedling growth in these studies. It appears that seedlings need no more water than that which was supplied every 28 days, provided that they do not suffer from competition with other plants and that conditions are similar to those of this study. The study lasted 70 days, or approximately 70% of what would constitute a normal growing season under many forest conditions in Alberta (Longley 1968). This modest use of water by the transplanted stock must be seen in relation to transplant shock, however slight it was in this study and in relation to the fact that stock did not flush and grow in height during the transplant period, something which happens commonly

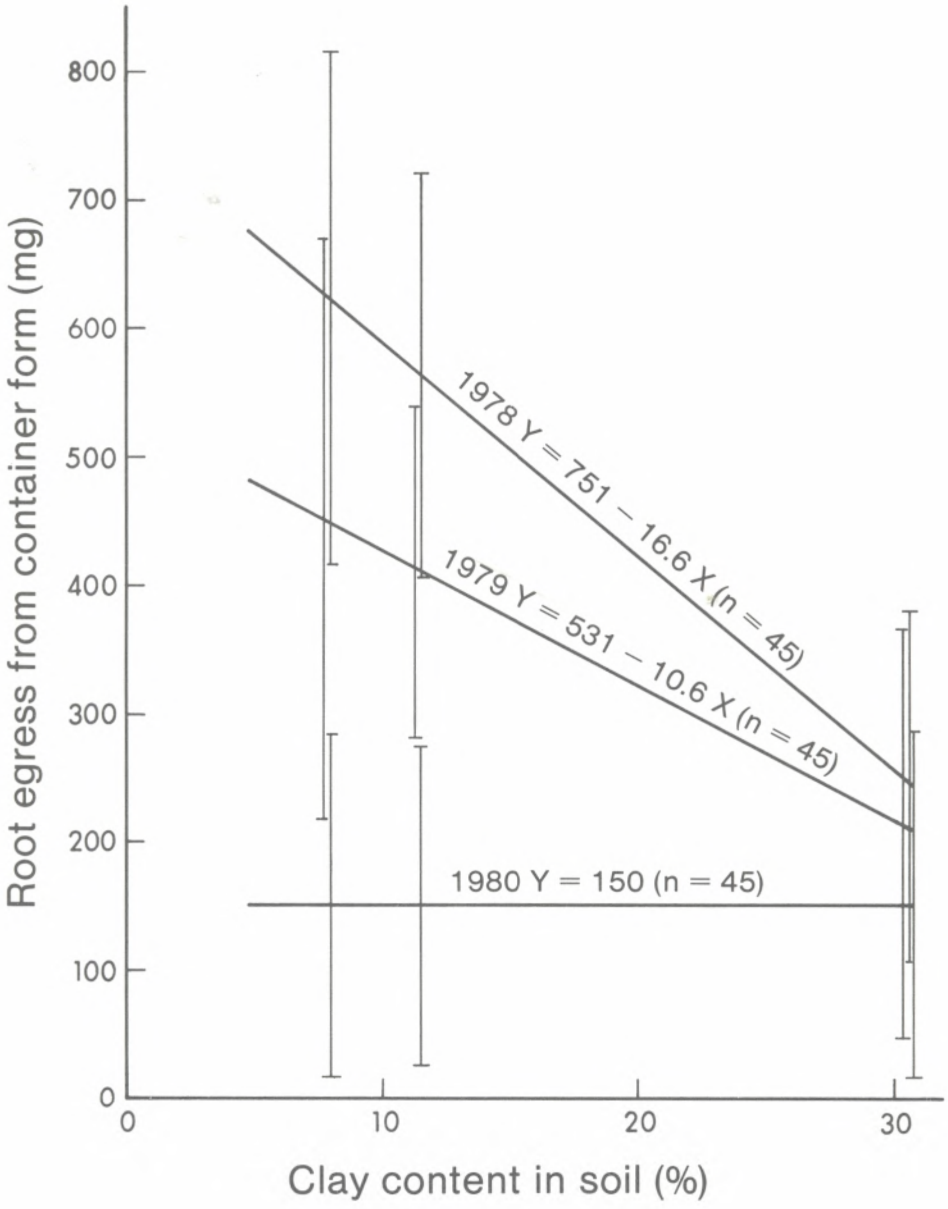


Figure 1. Relationships between root egress and clay content of surrounding soil.

in Alberta when cold stored or overwintered stock is outplanted.

2. The seedlings which were transplanted as peat plugs showed progressively less root egress as the clay content in the surrounding soil increased to a limit of 30% by weight. This agrees with findings by Dosskey and Ballard (1980) and Endean and Hocking (1973), and indirectly with the results of Lähde and Mutka (1975). The effect is interpreted as a response to moisture and texture discontinuities between the peat and soil but not to differences in bulk density.

3. Root-bound and large, overgrown seedlings reared in peat plugs (1978 stock) exhibited a much stronger negative response to transplanting in soil containing clay than did smaller seedlings. This suggests that root binding in lodgepole pine is potentially a serious hindrance to root egress, because egress decreases markedly as the surrounding soil increases in clay content. This points to a need for the use of very vigorous rather than large seedlings for reforestation. Holding container-grown seedlings in a nursery, or in the field, past the optimal time is therefore highly unde-

sirable and may in fact be the single most important factor giving rise to variability among seedlings in subsequent growth and establishment. The conclusion, by Endean and Carlson (1975), that large stock grows more than small stock after outplanting, given one container size for rearing, must be related to amount of rooting volumes matched to seedling size, as well as to seedling size itself. Growth is exponential in the early stages, larger seedlings growing more than smaller seedlings regardless of other factors. The plants in Endean and Hocking's experiment weighed no more than 450 mg at maximum and were therefore not pot-bound (Endean and Carlson 1975).

4. It takes much more time to grow a seedling to a given size in soil than in peat, even when rich agricultural soils are used. It is therefore questionable if it is economically or practically feasible to evade the problems of moisture and texture discontinuities that occur between the seedling plug and the surrounding soil by using soil rather than peat as a growing medium. Soil would also be much heavier than peat for the planters to carry.

5. Alternatives to growing seedlings in peat for outplanting in areas of heavy soils include direct seeding (Helium 1979) and/or extensive site preparation and soil working as suggested by de Champes et al. (1975). Good seedling establishment and growth require that the seedlings be spared severe shock in outplanting. One way to minimize the shock for container-grown seedlings could be to approximate the growing medium with the soil of the planting site, thereby increasing chances for survival and active growth.

LITERATURE CITED

Arnott, J.T.
1971. Progress report on field performance of Douglas-fir and western hemlock container seedlings on Vancouver Island, British Columbia. Dep. Environ., Can. For. Serv. , Victoria, B.C. Inf. Rep. BC-X-63. 59 p.

Arnott, J.T.
1974. Field performance of container-grown and bare root trees in coastal British Columbia. Can. J. For. Res. 5:186-194.

Bergman, F. and Haggström, B.
1976. Some important facts considering planting with rooted forest plants. For.Chron. 52(6):266-273.

Buckman, H.O. and Brady, N.C.
1960. The nature and properties of soils. The Macmillan Co., New York. 567 p.

Carlson, L.W.
1979. Guidelines for rearing containerized conifer seedlings in the Prairie Provinces. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-214. 62 p.

Carlson, L.W. and Nairn, L.P.
1977. Root deformities in some container-grown jack pine in southeastern Manitoba. For. Chron. 53:147-149.

de Champes, J., Marien, J.N., County, A. and Dufour, J.
1975. Etude de l'enracinement en place sur jeunes Douglas. AFOCEL: 251-357.

Day, R.J. and Cary, J.R.
1974. Differences in post-planting soil-mixture relations of container-grown tube and plug stock affect the field survival and growth of black spruce. p. 388-392 in R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No.68.

Dosskey, M.G. and Ballard, T.M.
1980. Resistance to water uptake by Douglas-fir seedlings in soils of different texture. Can. J. For. Res. 10:530-534.

Endean, F.
1972. Assessment of different types of containers for growing seedlings in Alberta. p. 119-128 in Proceedings of a workshop on container planting in Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. DPC-X-2.

Endean, F. and Carlson, L.W.
1975. The effect of rooting volume on the early growth of lodgepole pine seedlings. Can. J. For. Res. 5(1):55-60.

Endean, F. and Hocking, D.
1973. Performance after planting of four types of container-grown lodgepole pine seedlings. Can. J. For. Res. 3(2):185-195.

Funk, D.T., Roth, P.L. and Celmer, C.K.
1980. The influence of container type and potting medium on growth of black walnut seedlings. USDA For. Serv. Res. Note NC253. 4 p.

Gillgren, I.
1972. Rot snurr, deformation och strangulering. Svenska Cellulose A.B. 1972:18-21.

Grene, S.
1978. Root deformations reduce root growth and stability. p. 150-155 in E. Van Eerden and J.M. Kinghorn, *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8.

Hahn, P. and Hutchison, S.
1978. Root form of planted trees and their performance. Georgia Pacific Co. Pap., 7 p.

Helium, A.K.
1975. Selecting peat for rearing coniferous container seedlings. For. Chron. 51 (5):200-201.

Helium, A.K. 1979. Eight plantations of lodgepole pine in West Central Alberta. For. Chron. 55(3):88-90.

Kay, W.C.
1975. ARC container rearing manual. Alta. Res. Counc. Prod. Res. Dev., Edmonton, Alta. 63 p.

Kinghorn, J.M.
1970. The status of container planting in western Canada. For. Chron. 46(6):466-469.

Klett, J.E., Garner, J.B. and Hughes, T.D.
1972. Utilization of hardwood bark in media for growing woody ornamental plants in containers. J. Amer. Soc. Hort. Sci. 97(4):448-450.

Kormanik, P.P., Belanger, R.P. and Belcher, E.W.
1976. Survival and early growth of containerized and bare-root seedlings of cherry bark oak. Tree Plant. Notes 27 (3):9, 10, 23.

Lahde, E. and Mutka, K.
1975. Meddelanden frn Skogsforsknings-institutet i Finland. Vol. 83. No. 3.

Long, J.C.
1932. The influence of rooting media on the character of roots produced by cutting. Am. Soc. Hort. Sci. Proc. 29: 352-355.

Longley, R.W.
1968. Climatic maps for Alberta. Univ. Alta., Dep. Geogr., Alta. Climatol. Comm. 8 p.

Low, A.J.
1975. Production and use of tubed seedlings. For. Comm. Bull. No. 53. 46 p.

Scarratt, J.B. and Ketcheson, D.E.
1974. Japanese paperpots for containerized planting of tree seedlings. II. Preliminary evaluation of planting tools. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. Rep. 0-X-204. 13 p.

Segaran, S., Dojak, J.C. and Rathwell, R.K.
1978. Studies of bare root and container plantations. I. Assessment of root deformities of jack pine *(Pinus banksiana* Lamb.) planted in southeastern Manitoba. Man. Dep. Renew. Resour. Transp. Serv. M.S. Rep. 78-2-85.

Stone, E.C., Schubert, G.H., Benseler, R.W., Baron, F.J. and Krugman, S.L.
1963. Variation in the root regeneration potentials of ponderosa pine from four California nurseries. For. Sci. 9:217-225.

Tinus, R.W.
1978. Root system configuration is important to long tree life. Internatl. Plant Prop. Soc. Proc. 28:58-62.

Tinus, R.W. and McDonald, S.E.
1979. How to grow seedlings in containers in greenhouses. USDA For. Serv., Gen. Tech. Rep. RM-60.

Tinus, R.W., Stein, W.I. and Balmer, W.E., *Ed.*
1974. Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68, 458 p.

Van Eerden, E.
1978. Roots of planted trees in central British Columbia. p. 201-208 in E. Van Eerden, and J.M. Kinghorn, *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8.

Van Eerden, E. and Kinghorn, J.M., *Ed.*
1978. Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8. 357 p.

Waldron, R.M., *Ed.*
1972. Proceedings of a workshop on container planting in Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Inf. Rep. DPC-X-2. 168 p.

Walker, N.R.
1978. Field performance of Spencer-Lemaire container seedlings in west-central Alberta. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-207. 14 p.

Walker, N.R. and Johnson, J.H.
1974. Field performance of pine and spruce reared in the BC/CFS Styroblock - Alberta. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-84. 12 p.

SURFACE PLANTING SYSTEMS

Anders Lindström and Kart-Anders Hogberg[1]

Abstract.--The history of surface planting methods in Sweden, and the development of the Peat-Pillow concept, are reviewed and discussed, together with the problems which research attempts to address.

Résumé.--On fait l'historique des méthodes de plantation en surface en Suède. On analyse et on discute de ces méthodes, de la progression de l'idée de la motte de tourbe, et des problèmes que la recherche essaie de résoudre.

INTRODUCTION

In Sweden considerable effort is being made to solve some of the problems involved in the mechanization of reforestation. This effort should be viewed against a background of increasing costs for manual reforestation activities and a reduction in the permanent labor force available for planting.

Up to now, "deep" planting with either bare-root or containerized seedlings has been the principal means of artificial regeneration. In the planting operation, this involves placing the seedling roots in a hole dug into the ground. One of the reasons for developing other planting principles is that, with mechanized deep planting, it is difficult to achieve a suitable environment for the plant.

In recent years, a new planting principle has attracted great interest in Swedish forestry circles because of its strong potential for mechanization. This is known as surface planting and involves a specially designed container with the seedling being placed directly on the prepared ground surface. From a technical point of view, surface planting has several advantages over deep planting (e.g., it is easier and faster). Biologically there is a good possibility of obtaining rapid establishment with this method, as the roots of the plant start growing in the warm top layer of the soil.

The first step toward mechanization of surface planting involves a machine which scarifies the planting patch and delivers a container to each patch. At the present time, the choice of planting point and exact positioning of the container within a scarified patch is done manually from the ground. With completely mechanized planting, the choice of planting position and adjustment of the container will be made from the machine.

THE PEAT PILLOW:
AN APPLICATION OF THE SURFACE PLANTING METHOD

The Peat-Pillow is the first example of a containerized planting system developed on the principle of surface planting, and is almost ready for operational use (Fig. 1). The pillow concept had already been tried in the late 1960s as a method for direct sowing (Remröd 1971), but met with little success. The Peat Pillow discussed here is essentially the same, but with it the seedlings are grown in the nursery before being planted in the forest. It consists of a block of compressed peat, enclosed in an envelope of black polyethylene (7 x 7 cm) which holds the peat together and restricts moisture loss in the nursery and field. A hole 5 cm in diameter in the polyethylene at the bottom of the

---

[1] Research Foresters, Department of Reforestation, Swedish University of Agricultural Sciences, Garpenberg, Sweden.

Figure 1. The Peat-Pillow planted on the surface.

pillow allows seedling roots to grow down into the soil after outplanting.

In the nursery, seedlings are grown outdoors on frames which permit air-root pruning. The Peat-Pillow is relatively space-demanding in the nursery in comparison with other container planting systems (about 180 seedlings/m^2); however, greenhouse facilities are not needed.

The Peat-Pillow is placed directly on scarified ground for surface planting. Equipment for manual planting has been developed and the further development of a partially or completely mechanized system for distributing and positioning the Peat-Pillow is well advanced (Lindstrom and Hakansson 1980).

CURRENT RESEARCH

Research into the use of surface planting is being carried out both at the Logging Research Foundation and at the Swedish University of Agricultural Sciences in Garpenberg. At the latter, two projects are under way, one concerned with basic surface planting principles and the other a biological follow-up of Peat-Pillow plantations (Lilliehbök and Nyström 1981). Current investigations in the first project are described briefly below.

After an introductory phase, the project has concentrated on the resolution of a number of key biological and technical problems. The purpose is to increase our knowledge of the surface planting technique and to develop broad guidelines for developing future systems. The experimental studies are directly concerned with the establishment phase for surface planted seedlings, which may be divided into three distinct stages (Fig. 2), viz.:

1. Seedling roots have not yet established themselves in the surface soil.
2. Seedling roots are becoming established in the surface soil.
3. Seedling roots are fully established in the surface soil, and the tree is large enough to depend upon its root system for support and stability.

Stage 1--Roots Still in Container

During this first stage the seedling may be subjected to a great deal of stress. This stress places heavy demands on the container and the method of planting:

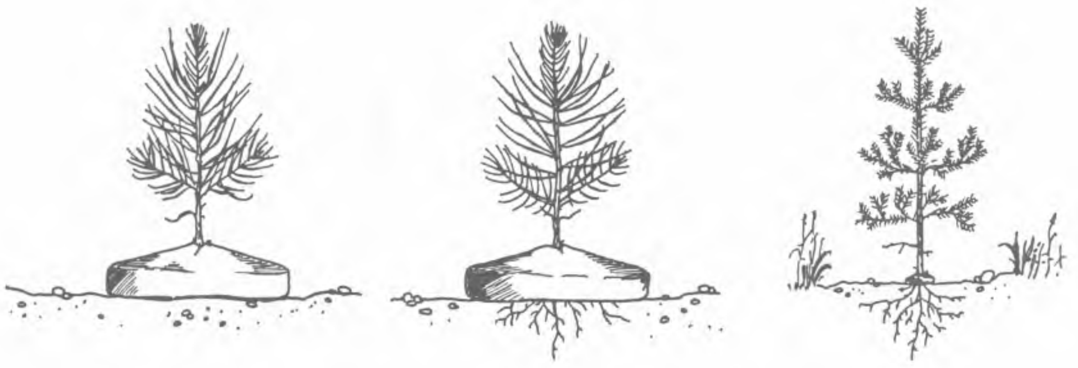


Figure 2. The three periods of the establishment phase.

- The container should restrict drying of the substrate, both from the top and from the bottom. The study emphasis is on the design of the container and protection against evaporation.
- The container should be designed and planted so that good hydraulic conductivity is established between the ground surface and the container substrate. This study focuses on the criteria for establishing such moisture conditions.
- The container should be sufficiently stable that, until seedling roots are fully established, it will not be overturned by wind, etc. Here we are concerned with the relationship between container size, seedling characteristics and the tendency for the Peat-Pillow to overturn (Hogberg and Lindström 1980). This involves artificial methods for stabilizing the continer (e.g., pins), and the identification and assessment of site factors which may contribute to the overturning of seedling and container.
- The container should protect against injuries from insects. This study investigates the possibility of combining container design with a protective function, especially against the pine weevil *(Hylobius abietus* L.) (Lindström and Mattson 1980).

Stage 2--Root Establishment

In this stage, seedling roots penetrate into the surface soil, from which they obtain water and nutrients. The fact that roots grow into the soil signifies that the seedling is becoming stabilized on the scarified patch, and the risk of seedling dehydration diminishes as the roots become established.

During this second stage the principal requirement is that the container should allow good root penetration. The aim of the studies is to obtain knowledge of the effects of root penetration on the stability and water supply of the plant (Hogberg 1981).

Stage 3--Roots Established

In the third stage, the seedling is often so large that it is exposed to the destabilizing effects of wind and snow. The larger the seedling the greater are the demands placed on the stabilizing function of the root system. Also during this stage, the protective function of the container (restricting drying of the substrate and protecting against insects) decreases in importance as the seedling roots become firmly established in the soil.

The main requirement of the container during this third period is that its design should not lead to root deformations which might cause stability problems for the tree. An unsuitable container design and/or improper growing conditions may initiate root deformations in the nursery. This study therefore focuses on the relationship between container design, nursery methods and planting techniques on the one hand and root development and seedling stability on the other.

CONCLUSION

Knowledge in the area of surface planting is at present limited. A number of fundamental technical and biological studies must be undertaken before we can define the potential value and limitations of surface planting. The knowledge acquired will lay the foundation for technical development in this field.

LITERATURE CITED

Hogberg, K-A.
1981. Fixering vid ytplantering. (Stabilizing containers on the planting point when using surface planting.) Institutionen for skogsproduktion, Sveriges lantbruksuniversitet, Garpenberg. Stencil 12.

Högberg, K-A. and Lindström, A.
1980. Valtningsbengenhet for odlingsenheter anpassade till ytplantering. [Overturning tendencies for containers designed for surface planting]. Institutionen för skogsproduktion, Sveriges lantbruksuniversitet, Garpenberg. Stencil 6.

Lilliehoök, L. and Nystrom , C.
1981. Inventeringsresultat fran provodling med odlingsplattan. [Biological follow-up of Peat-Pillow plantations] Institutionen för skogsproduktion, Sveriges lantbruksuniversitet, Garpenberg. Stencil 10.

Lindström, A. and Hakansson , L.
1980. Odlingsplattan - paperpot FH408. En jämforande studie i plantskola och fält. [The Peat-Pillow-Paperpot FH408. A study of comparison in the nursery and the field.] Institutionen för skogsproduktion, Sveriges lantbruksuniversitet, Garpenberg. Stencil 7.

Lindström, A. and Mattsson, A.
1980. Plastkragar mot snytbaggeangrepp. [Plastic collars against pine weevil attacks.] Skogen nr 12.

Remrod, J.
1971. Resultat fran försok med saddplattor. [Trials with seed "plates".] Sveriges skogsvrdsforbund Tidskrift, sid 247-279.

ROOT FORM OF PLANTED TREES

E. Van Eerden[1]

Abstract.-- The degree of root deformation of newly planted trees is governed by nursery practice, container design, planting method and quality, and site conditions. Evidence suggests that root systems of planted trees become increasingly "normal", and that toppling of planted trees will not be a major problem in Canadian forests.

Résumé.--Chez les arbres nouvellement plantés, le degré de déformation des racines dépend des pratiques utilisées en pépinière, de la forme des contenants, de la méthode de plantation et de sa qualité ainsi que des conditions de l'emplacement. D'après certains indices, le système racinaire des arbres plantés devient de plus en plus "normal", et la perte de vitalité des arbres plantés ne représentera pas un problème majeur dans les forêts canadiennes.

INTRODUCTION

Root form of planted trees is a topic of recurring interest. The current cycle of interest and debate on this topic appears to have been precipitated by the rapid expansion in production and planting of container-grown stock.

Root systems of planted trees initially differ substantially in form from those of naturally established trees, regardless of environmental conditions at time of establishment or the nursery practices and planting techniques employed. Alteration of the "natural" or "normal" root form clearly originates in the nursery with both bare-root and container stock. Although the form and size of root system can be manipulated in both stock types through various nursery practices (such as undercutting, air-pruning, mechanical or chemical pruning, wrenching, transplanting, fertilization and irrigation regimes) the nature of root deformation in the two stock types is essentially different. Root deformation in bare-root stock is attributable primarily to deficiencies in quality control in the nursery or at outplanting, as a result of human error and/or constraints imposed by soil and site conditions. The root form of container stock, on the other hand, is governed mainly by nursery factors, principally container design, since the potential for poor planting is minimized as a result of the consistency in shape and size of the root system.

ROOT DEVELOPMENT IN PLUG STOCK

The development and testing of the Walters bullet system, which was undertaken by the Canadian Forestry Service and the British Columbia Ministry of Forests in the late 1960s, had as one of its long-term objectives the evaluation of the root morphology and development of variously grown and planted trees. Results of those studies were first reported by Van Eerden and Arnott (1974) at the North American Containerized Forest Tree Seedling Symposium in Denver and, more recently, at the Root Form Symposium in Victoria (Van Eerden 1978).

The Walters bullet system was designed specifically to improve planting productivity through manual and, ultimately, mechanized injection planting. To assess the effects of the bullet container on root development and morphology, seedlings were planted with and

---

[1] Container Systems Coordinator, Silviculture Branch, Ministry of Forests, Victoria, British Columbia.

without the container, the latter being called "bullet-plugs". Survival and growth of the relatively small bullet stock compared favorably with those of larger bare-root stock, and some of these early bullet plantations have grown into excellent stands, in spite of juvenile root deformation. Nonetheless, bullet seedling planting has not been widely accepted. This lack of acceptance is associated primarily with concern over the potentially constricting influence of the bullet container on the root system. Although the performance of bullet-plugs generally resulted in only marginal improvements in survival and growth in comparison with that of seedlings planted with the bullet container intact, the "plug" concept found wide acceptance.

Because the Walters bullet was not designed to produce plugs it had some obvious shortcomings as a plug container. As a result, a new container, the BC/CFS styroblock, was designed and developed in 1969/70 specifically for the production of plug stock. The basic design features of the Walters bullet, the tapered tip to the drainage hole at the bottom of the bullet and the provision for air-root pruning, were retained in the design of the styroblock cavities. To control cross-over and inter-twining of primary laterals, vertical ribs were later incorporated into the design of the styroblock.

About the same time that the BC/CFS styroblock was being developed, the multipot or K-pot was being introduced in Sweden. Although the British Columbia and Swedish plug containers were identical in concept, there were two significant differences in design and cultural approach. Unlike the BC/CFS styroblocks, the multipots were patterned after traditional plant pots, having a flat bottom with a central drainage hole and no vertical ribs. It is well known from horticultural experience that such a design inevitably results in extensive coiling of lateral roots in the bottom of the container, commonly referred to as "potbinding". In addition, and probably duplicating the then current paperpot practice, multipot crops were generally grown on the ground, where air-root pruning could not be carried out. The multipot has now been modified to eliminate the flat bottom and include vertical ribs, while more recent cultural practices generally include provision for air-pruning.

Another well known container, the Spencer-Lemaire "Rootrainer", has vertical grooves rather than ribs to control cross-over of lateral roots.

Notwithstanding the design features of these and other containers, all of them still create a vertical root cage. It is this root cage that is of concern with respect to root deformation, particularly in the pines. It is feared that this vertically shaped root system will result in a fulcrum, which will predispose the planted tree to basal sweep, instability, and, under certain climatic and soil conditions, toppling. This concern should not be dismissed lightly. Many examples of plantation failure cited in the literature have been attributed to root deformation.

SUMMARY OF ROOT FORM SYMPOSIUM

To bring you up to date on recent information on the subject, I take this opportunity to provide a summary and my perspective of the recent Symposium on the Root Form of Planted Trees (Van Eerden and Kinghorn 1978). This symposium provided irrefutable evidence that all nursery and planting techniques cause some degree of root deformation to newly planted trees. It was shown that:

1) root deformation occurs with both bare-root and container-grown stock;

2) the potential for deleterious root deformation is strongly species-related, particularly in the pines;

3) root deformation in young plantations does not inevitably lead to total plantation failure;

4) where plantation failures have occurred as a result of root abnormalities the effects of root deformation have frequently been compounded by other factors, such as:

    - unfavorable site conditions (heavy, shallow or poorly drained soil) or poor site preparation;
    - climatic conditions (gales, hurricanes, heavy snow);
    - the growth characteristics of a given species (Pines are generally more subject to instability and basal bowing than most other species because of their characteristically rapid early height growth and relatively slow root growth. They are consequently top-heavy and can become highly unstable under unfavorable site and climatic conditions.);

5) root systems repair themselves with time, and increasingly acquire a "normal" or natural habit;

6) study of root form has generally focused on relatively small trees, so that it remains a matter for conjecture whether or not root deformation represents an economic risk with respect to long-term stand stability and yield;

7) potential solutions to the "problem" of root deformation in container stock particularly will have to originate in the nursery through improved cultural practices and/or changes in container design.

Perhaps inevitably, the symposium provided primarily a diagnosis of the causes and symptoms of root deformation in planted trees, with a promise of remedies for correcting or minimizing the problem. The quantitative relationship between early root form of planted trees and yield at rotation age remains undefined.

HOW DO WE DEAL WITH THE RISK OF ROOT DEFORMATION?

In my view, there are three approaches to dealing with root deformation:

1) cease planting of container-grown stock for species that are particularly susceptible to root deformation;

2) assess the risks associated with root deformation of container stock in economic terms, and then decide whether to accept the risk or not;

3) minimize root deformation through improvements in container design and cultural practice.

Determining the Risk

As a result of their ability to produce adventitious roots, white spruce *(Picea glauca* [Moench] Voss) seedlings can quickly overcome the imprint and effects of the container on the root system. Consequently, the risk of toppling in this species appears to be minimal.

The effects of the container on root form in lodgepole pine *(Pines contorta* Dougl. var. *latifolia* Engelm.) are longer lasting than in spruce. This species does not produce adventitious roots, and the roots have a strong tendency to spiral, creating a convoluted root ball with a profusion of weak lateral roots at the base of the root system. Such a root ball fails to provide firm anchorage and predisposes trees to toppling under adverse soil and climatic conditions. In contrast to the relatively slow initial root growth, juvenile height growth in lodgepole pine is usually rapid, creating a potential imbalance between the crown and root system. However, by the fourth or fifth year after planting, or when the trees reach 2.5 to 3 m in height, the apparent effects of root deformation become less visible. By then, anchoring appears to have improved and basal sweep, if it occurred earlier, becomes less obvious. Excavation of complete root systems shows that healthy and normally oriented tissue has started to surround the original root ball, and that individual roots within that root ball have started to graft at the point of contact. Graham and Bormann (1966) indicate that such grafted roots will eventually establish vascular continuity.

On the basis of my personal observations, I suggest that the risk of significant economic loss due to toppling of container stock of white spruce and lodgepole pine in British Columbia, and probably in the boreal and sub-boreal forests throughout Canada, is small. In fact, the risk of loss due to root deformation in white spruce is minimal and, generally, less than 10% in lodgepole pine. Studies of other west coast conifers indicate that a similar conclusion is justified for other species.

Remedying Root Deformation

Reduction or prevention of the effects of the container imprint on early root system form will require significant efforts in research and development, both in container design and in cultural practice.

The notion that root problems can be averted if seedlings are kept small and are not grown much beyond the germinant stage hardly deserves consideration. Although relatively small lodgepole pine is capable of high survival and rapid early growth, container stock of white spruce needs to be substantially larger if it is to perform well after planting. The era of the "micro-seedling in the mini-container" which was largely responsible for the demise of the Ontario tubeling system, and which has detracted from the potential of container seedling reforestation, should never again be considered as a viable planting stock option.

In the short term, chemical pruning with copper carbonate (Burdett 1982) appears to provide a simple and effective resolution of this difficult problem. In the longer term, suggestions for modification of container design advanced by Kinghorn (1978) and Riedacker (1978) merit serious consideration and further development. The new "skeletal" container design developed by Stora-Kopparberg (Andreason 1982) in Sweden also deserves close attention with regard to performance and costs over the next several years. Regardless of the cultural technique or container design employed, any modification must be integrated with the rest of the container system and must be cost-effective. In other words, if the risk of loss due to root deformation by containers is low and the cost of eliminating or significantly reducing that risk is high, it will be difficult to justify the added expense for modification of existing techniques.

CONCLUSION

Field observations and a review of the literature confirm that containerization, like bare-root practice, does modify the natural root form of planted trees. However, in Canada, the economic risk associated with root deformations imparted by the principal container systems currently in use appears to be low. Also, root abnormalities become less evident with time. Roots of planted trees increasingly resemble those of natural trees with advancing age (Gillgren 1972), and any differences between planted trees and natural trees become negligible 30 to 40 years after planting (Bibelriether 1966). Root deformation is just as common in bare-root stock as it is in container-grown stock and, in the case of the former, is both less consistent and less predictable. It might well be asked why container stock precipitated the current concern over root deformation. Part of the answer to this question may lie in the fact that the advent and expansion of container seedling planting were seen as a challenge and threat to the long-established technique of bare-root planting.

The causes and symptoms of root deformation are well understood and have been adequately described in biological terms, while promising remedies have been proposed and are under development. However, the economic significance of the biological observations and potential remedies remain poorly defined.

In conclusion, I suggest that the view of root deformation expressed by Dr. Olavi Huuri of the Finnish Forest Research Institute (Huuri 1978) provides a most perceptive understanding of early root deformation:

> *"It is possible that Scots pine roots have for decades suffered much more than is commonly known. They have in silence overcome the difficulties caused by the planter. The plantations have developed into great stands and yielded their crop. The roots of the planted trees, those 'forgotten victims of the underground prison', have occasionally been pulled out into the light too early, before they have had time to hide their damage. At this stage they have caused common consternation among tree planters. This has happened at about twenty to thirty year intervals...."*

LITERATURE CITED

Andreason, Ove.
1982. Plant System 80: Background, short description, plans. p 429 *in* J.B. Scarratt, C. Glerum and C.A. Plexman, *Ed.* Proceedings of the Canadian Containerized Tree Seedling Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. 0-P-10.

Bibelriether, H.
1966. Die Bewurzelung einiger Baumarten in Abhangigkeit von Bodeneighenschaften. [The effect of soil properties on the root systems of some tree species.] Allg. Forstzeitschr. 21 (47):808-815.

Burdett, A.N.
1982. Box-pruning the roots of container-grown tree seedlings. p 203-206 *in* J.B. Scarratt, C. Glerum and C.A. Plexman, *Ed.* Proceedings of the Canadian Containerized Tree Seedling Symposium. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont. COJFRC Symp. Proc. 0-P-10.

Gillgren, I.
1972. Om rotsnurr, rotdeformation och rotstrangulering. [On root whorl, root deformation, and root strangulation.] Examensarbete i skogsskotsel utfort hos Svenska Cellulosa AB 1971/72, 53 p. [Environment Canada Translation 00ENV TR-866. 1975. 43 p.]

Graham, B.C., Jr., and Bormann, F.H.
1966. Natural root grafts. Bot. Rev. 32: 255-292.

Huuri, O.
1978. Effect of various treatments at planting and of soft containers on the development of Scots pine *(Pinus sylvestris* L.). p. 101-108 *in* E. Van Eerden and J.M. Kinghorn, *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep.No. 8.

Kinghorn, J.M.
1978. Minimizing potential root problems through container design. p. 311-318 in E. Van Eerden and J.M. Kinghorn, *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8.

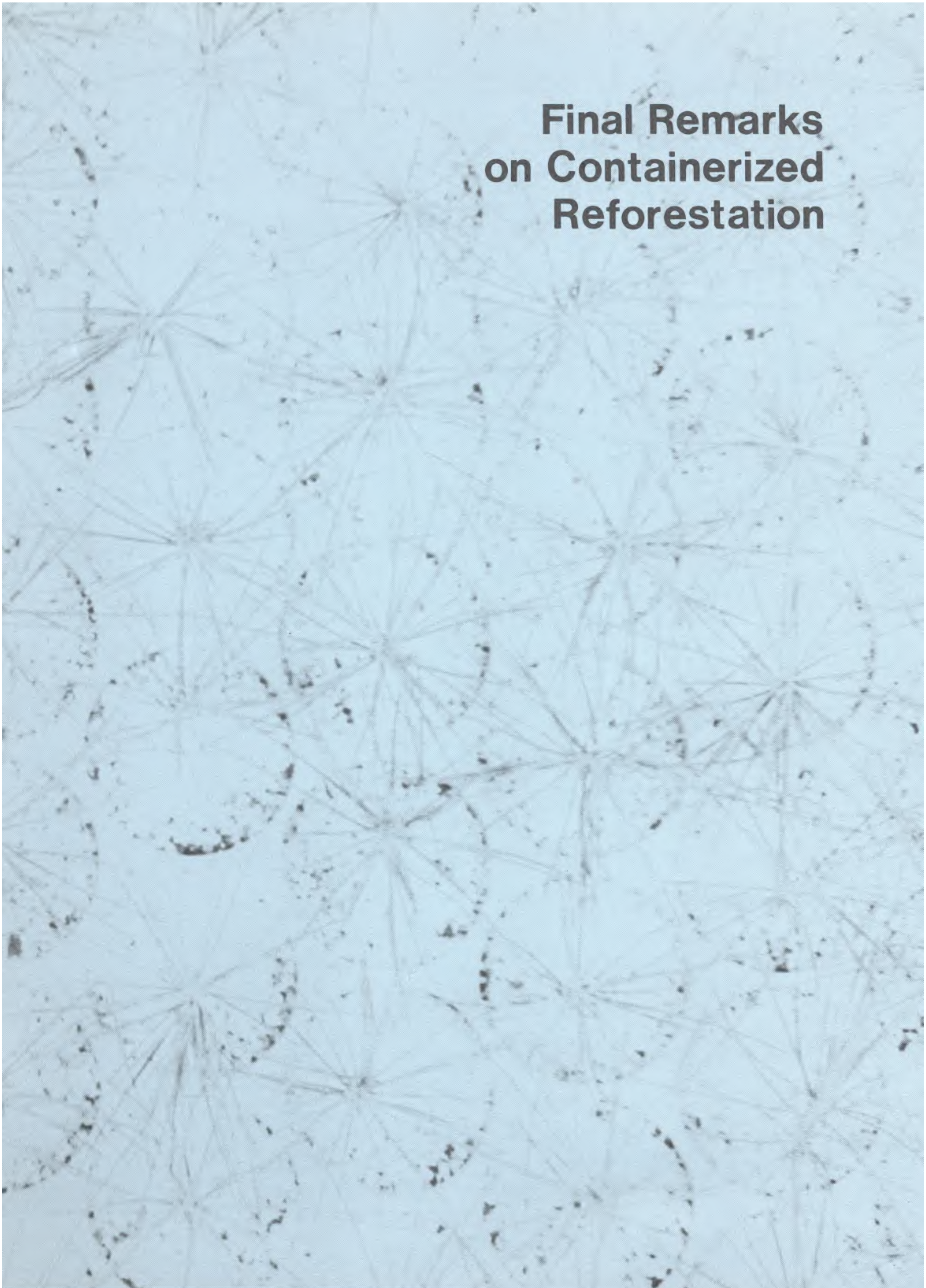
Riedacker, A.
1978. Root deformation and root growth direction. p. 319-321 in E. Van Eerden and J.M. Kinghorn, *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8.

Van Eerden, E.
1978. Roots of planted trees in British Columbia. p 201-208 in E. Van Eerden and J.M. Kinghorn, *Ed.* Proceedings of the Root Form of Planted Trees Symposium. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8.

Van Eerden, E. and Arnott, J.T.
1974. Root growth of container-grown stock after planting. p 393-397 in R.W. Tinus, W.I. Stein and W.E. Balmer, *Ed.* Proceedings of the North American Containerized Forest Tree Seedling Symposium. Great Plains Agric. Counc. Publ. No. 68.

Van Eerden, E. and Kinghorn, J.M. *Ed.*
1978. Proceedings of the Root Form of Planted Trees Symposium. Victoria, B.C. May 16-19, 1978. B.C. Min. For./Can. For. Serv. Joint Rep. No. 8. 357 p.

Final Remarks on Containerized Reforestation



A PROCEDURE FOR COMPARING ALTERNATIVES IN PLANTING TREE SEEDLINGS

Alex Tunner[1]

Abstract.--A simple procedure has been developed for comparing alternatives in the planting of tree seedlings. It uses a specially designed work sheet and takes into account costs, survival and anticipated production of wood. The rationale for the procedure is outlined and some illustrative examples are given.

Résumé.--On a mis au point une méthode simple pour comparer les possibilités dans le plantage de semis d'arbres: sur une feuille de travail spécialement conçue à cette fin, on tient compte des coûts, de la survie et de la production ligneuse prévue. La méthode est expliquée et illustrée d'exemples.

INTRODUCTION

In any planting project, decisions have to be made about the type of nursery stock and planting system to be used. These decisions should take into account costs, silvicultural considerations, and site-related factors including the anticipated production of wood.

Currently there is no generally accepted method for evaluating and comparing the economics of alternatives in planting seedlings. Present cost estimates are frequently based on incomplete data, and they tend to be difficult to compare. Hence, selecting the best planting option is often difficult.

The project described here[2] was undertaken to develop a practical procedure for day-to-day use whereby individuals making reforestation decisions can compare alternatives in a consistent manner and select the most appropriate option.

A simple graphical procedure was developed which involves using a specially designed worksheet. The procedure takes into account performance (survival) variability, which has important economic consequences: variability costs money, and the reduction of variability is as important an objective as average performance improvement.

Variability of performance can be reduced not only by improved control, but also by improved predictability. Both of these require that plantation performance be measured better and monitored more effectively than it generally is now.

FACTORS IN PLANTING DECISIONS

Uncertainty and lack of information

Reforestation through planting, and particularly its economic aspect, is a complex subject involving facts, uncertainties and opinion. Some factors, particularly costs, can be quantified quite readily. For example, the cost of seedlings, containers, special processing, planting (particularly where planting is contracted) and sometimes even site preparation, can be accurately determined. Factors related to sites and seedlings are more difficult to quantify.

---

[1] Head, Operations Management Division, B.C. Research, Vancouver, B.C.

[2] This paper is based on the study "Comparison of Alternatives in Planting Seedlings" which was prepared by B.C. Research for the Silviculture Branch of the B.C. Ministry of Forests in 1979.

While good descriptions of planting sites are generally obtainable, descriptions of planting stock tend to be qualitative rather than quantitative, and this is restrictive from the point of view of analysis. It would be desirable to use quantitative terms such as height, weight, root/shoot ratio, stem diameter and moisture stress (osmotic pressure) in describing the seedlings being planted.

In general, only one-year survival data are currently collected following planting: additional examinations are rare, and the condition of planted trees (height, morphological condition: poor, fair, good) is usually not recorded. Hence, only limited data are available on early survival and growth.

Even more uncertain than survival and early growth is the ultimate productivity of a site, both in terms of the time to harvest (rotation) and the volume of harvestable wood. This must be estimated by foresters using their experience and judgment. From an economic point of view such estimates are essential, since wood production is usually the most important objective of regeneration.

It must be recognized that there will always be considerable variability associated with survival and growth. This uncertainty could be reduced to some extent by measuring variables which are known to affect performance, although this is not always possible in practice. However, there will always be variables at work (e.g., weather, insects, mammals and disease) whose presence and effects may not be known or quantifiable. Variability will, therefore, remain an inevitable fact of life, although it can be reduced with better information, measurement and control.

The approach taken in this study was by no means an attempt to quantify any of the uncertainties. Rather, an attempt was made to identify the key factors to be considered, be they accurately quantifiable or largely judgmental, and to link them through simple relationships to produce some overall performance measure, such as "investment per cubic metre of mean annual increment". Thus, the purpose of the study was to produce a framework whereby key factors could be recognized and combined. The estimate of their actual values in specific situations is the task of the forester.

Foresters differ widely in their viewpoints on preferred stock types, levels of stocking, and planting practices. Advocates of particular planting systems are often able to produce evidence in the form of data (survival, growth rates, etc.) and photographs (seedlings, root structures, etc.) to support their preferred system, and to point out the shortcomings of "competing" systems. This may involve:

- selecting evidence to support a particular argument;
- "comparing apples and oranges" (e.g., different types of stock planted on different sites);
- presenting incomplete data (e.g., not including all cost components);
- producing explanations for poor performance (e.g., poor nursery stock, frosted tops, .. .).

On the other hand, there are often legitimate ambiguities in the results of experiments, even when they are designed to compare alternatives. Also, the results of operational plantings are often markedly different from experimental ones. Hence, it is difficult to draw firm objective conclusions.

While large volumes of data on planting are available, comparatively little conclusive information has been (or can be) obtained from them to assist in making planting decisions. The principal reason for this is the lack of performance criteria and a comprehensive, generally accepted set of measurements in experimental and operational planting projects.

Performance Criteria

There are several criteria which could be used to compare alternative planting options.

Survival

This is a commonly used criterion and obviously a critical one. However, it is incomplete in that it says nothing about costs, the quality of the surviving stock, the volume of wood to be expected from the site and the time taken to produce it. Thus, while survival is certainly a necessary component of measurement, by itself it is not sufficient for comparing planting alternatives.

Cost per hectare

The cost per hectare of establishing a stand is a criterion which includes both costs and survival. Its shortcomings are that it depends on the level of stocking selected (i.e., the greater the level of stocking, the higher the cost) and it does not reflect the volume of wood to be produced from a site or the time taken to produce it. Nevertheless, it is felt that this criterion can be useful provided that it is not used in isolation.

Cost per unit of harvestable lumber

This criterion takes into account survival, costs, and the anticipated production of wood from a site. The only factor missing is the time to produce the wood. Like the foregoing, this criterion could also be of interest.

Cost per unit of mean annual increment

This criterion takes into account survival, costs, volume of wood and rotation. It gives the costs of establishing an average annual rate of wood production. This is considered to be the most useful criterion since the ultimate objective of planting is to ensure that a site produces the largest possible volume of merchantable wood annually as economically as possible (consistent with hydrological, wildlife and other environmental considerations).

One theoretical shortcoming of the criterion is that it does not include any reference to the quality of wood produced (i.e., market value). While this may be desirable, it would be difficult to implement in practice. Not only is the future value of wood unknown, but the relative values of different types of wood can change with respect to each other. Hence, such a criterion would not be constant over time, and could rate alternatives differently depending on market price estimates. Nevertheless, such a criterion may be of interest in certain economic studies.

Common Factors in Reforestation Decisions

Numerous questions have to be answered before reforestation decisions are made. For example:

- Should a site be replanted or should it be allowed to regenerate naturally?
- Should a site be burned over or scarified in order to promote natural regeneration?
- What species and type of stock should be planted on a particular site?
- If the preferred stock is unavailable, is it better to wait perhaps two years until it is available or should some other stock type be used?
- How do the relative costs of understocking (necessitating replanting) and overstocking (necessitating juvenile spacing) affect the number of seedlings to be planted?
- How much improvement in performance (e.g., survival) is required to compensate for the extra cost of some form of site treatment or special type of planting stock?

Although the questions to be answered are many and varied, they involve consideration of only a relatively small number of factors. These can be grouped under five headings, as outlined below.

Planting objectives

The first requirement in making reforestation decisions is to set a clear, quantitative objective of what is to be achieved on a site in terms of established seedlings and, ultimately, the production of wood. Depending on the potential for natural regeneration, targets can be set for what is to be achieved through planting.

Excessive stocking will result in higher planting and future site tending costs, and possibly in a decreased volume of merchantable lumber. On the other hand, insufficient stocking will result in lost production of wood. Therefore, in setting stocking targets, upper and lower limits of stocking must also be set, and these must take into account both silvicultural factors and costs.

Costs

Costs are clearly of major consideration in reforestation decisions. They can be considered in two groups, "variable" costs and "fixed" costs.

The variable cost per seedling (cents per seedling) is the marginal cost of planting an additional seedling and is the sum of costs such as:

- production cost of the seedling in the nursery, including seed, tending, lifting;
- the cost of containers or special treatments such as mud-packing;
- the cost of packaging, storage and transportation;
- the cost of planting.

The fixed cost per site (dollars per hectare) is the "set-up" cost of establishing a plantation on a particular site. It is the sum of costs such as:

- site preparation (burning, scarifying);
- access to the site (plowing roads of snow in the spring, bulldozing washed-out roads, helicopter air-lifting onto the site, etc.);
- the expected cost of corrective action as a result of being outside the specified stocking limits (i.e., cost of fill-in or thinning).

It is not necessary to estimate the future value of wood (a relatively meaningless task, in view of the length of time involved). There is no argument about whether or not to replant--that decision has been made in the affirmative in light of general social, economic and environmental considerations. The problem is to replant in the most cost-effective way possible.

Survival

The percentage of seedlings surviving to become an established stand is the most critical silvicultural variable in planting decisions.

Survival results are almost always reported only as averages. It would also be desirable (and relatively easy) to estimate standard deviations to provide a measure of the range of variability to be expected in seedling survival and the potential cost of this variability as a result of overstocking or understocking.

Furthermore, existing survival data do not explicitly reflect the fact that survival is related to seedling and site parameters. Such information has to be available if meaningful comparisons of alternatives are to be made.

Production

In estimating the volume of wood which can be produced on a particular site, three variables have to be considered:

- Number of crop trees (i.e., the number of mature, merchantable trees to be harvested) should be related to the planted seedlings only, and not reflect any natural regeneration. In situations where both of these factors are at work, they should be considered as two separate components of reforestation.

- Volume of wood per mature tree is obviously a key factor in estimating the yield of wood from a particular site.

- Rotation age is another key factor which determines the yield of wood from a particular site.

Volume and rotation together determine the production potential of a site. These factors may differ according to species and stock type, and the resulting differences in production potential may influence the planting alternative selected.

Variability (uncertainty)

Variability is an important though seldom recognized factor in reforestation decisions, and one which costs money.

Two major factors relating to uncertainty are considered important in this context:

- Dispersion coefficient of survival (ratio of standard deviation to average survival);

- Off-target costs if the initial planting is outside acceptable limits (the cost of fill-in below the lower stocking limit and the cost of extra spacing above the upper stocking limit).

AVAILABLE DATA

Cost Data

Accurate data on costs are generally obtainable from comprehensive cost accounting systems which allocate the costs of labor, materials and overheads to the various phases of seedling production at each nursery. However, careful thought must be given to making the best use of cost information. The problem centres on the fact that the cost of a particular type of planting stock varies from year to year according to the nursery producing it and the volume of stock produced. These differences can be in excess of 100%. There are differences in nursery facilities and growing environments, and they can be affected by weather and other natural conditions in different ways.

Hence, it is not considered appropriate to use stock costs directly from accounting systems for comparing planting alternatives. To do so could result in decisions which might reflect isolated production peculiarities. Consequently, in any given year and for every type of stock, it would be more meaningful to use a weighted average of the costs at a group of nurseries which produce seedlings of comparable quality.

Even this may not be entirely satisfactory if there are large fluctuations in average costs from year to year. In that case, some kind of moving average, possibly over a 3-year period, may be appropriate. While it is certainly necessary to reflect cost differences in comparing alternatives, it is not meaningful to let isolated short-term factors affect long-term decisions. There is no clear-cut solution, and the answer is a matter of judgment.

Silvicultural Data

Good silvicultural data (survival, growth) are much more difficult to obtain than cost data. A great many data are available on survival but they have to be used with great caution to avoid "apples and oranges" comparisons because of differences in species, type and quality of stock, site, local conditions and other factors. While some of these differences can be identified retrospectively, many will remain unknown.

Most operational survival data relate only to first-year survival, and are not associated with any indication of plantation quality. Furthermore, "old" survival data, though providing information on several years' survival, may be limited in their usefulness because of changes in planting stock quality in more recent years. Another complication is that there may be gaps in the production of major stock types, and hence no continuity of data.

To overcome these difficulties, a major long-term program of operational performance measurement should be implemented. It is suggested that about 1% of the annual seedling production be involved.

A central feature of the program would be (as part of some regular planting projects) the planting of seedlings of one or two stock types which are different from the type being planted in the project. This could be done quite easily when the planting program is being set up, and well established statistical techniques on experimental design could be taken into account. In each planting project, seedlings of the different stock types should be as similar as possible with respect to seedlot, tending, lifting, etc. In this way differences in performance due to stock type could be determined with considerable confidence.

The cost of variation

It is rarely recognized that costs are incurred because of variations in performance. If performance is consistent (i.e., predictable), it is much easier (and cheaper) to achieve planned objectives than if it is not.

For example, suppose that two stock types are available, both costing the same and having the same average survival (70%) but different ranges of survival (standard deviations of 5% and 10%, respectively). Suppose further that it is desired to establish 700 seedlings/ha (i.e., plant 1000 per ha), and that the stocking is considered satisfactory if it is between 600 and 800 (i.e., fill-in costs are incurred below 600 and thinning costs above 800). If 1000 seedlings are planted, 700 will survive on average with either type of stock. However, as is illustrated in Figure 1, the performance of the more predictable stock will be outside the specified limits only 4% of the time, while the less predictable stock will be outside those limits 32% of the time.

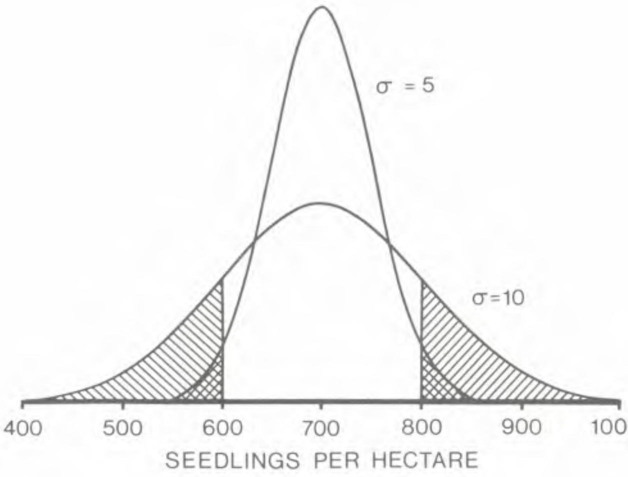


Figure 1. Variability in the number of established seedlings if 1000 are planted per hectare with 70% average survival (normal distribution).

Clearly the less predictable stock is far more costly in practice than the more predictable type, although their costs appear to be identical at the planting stage. In fact, it may be that a lower but more consistent rate of survival is preferable to a higher but more variable one.

Standard deviations in survival are typically in the order of 20%, so that the situation is actually much more extreme than that shown in the example. Thus, it is seen that variation in performance can be very costly, and that it is economically desirable to reduce it as much as possible.

The factors affecting variation in performance can be considered to fall into three groups:

- factors related to the production and planting of stock: these can be minimized by improved nursery and planting practices;
- site-related factors: while these cannot be controlled, the effects of site characteristics can be estimated statistically and hence taken into account in making improved predictions of performance;
- unknown and random factors: these are uncontrollable in principle (e.g., weather, pests) or in practice (e.g., not measurable or not understood at present).

Improvements can be made for the first two:

- by improved production procedures and quality control;
- by improved measurement and statistical (prediction) procedures.

A METHODOLOGY FOR COMPARING ALTERNATIVES

General Form

The central requirement of this project was to develop a method for comparing alternative planting options which takes into account the key factors involved and, at the same time, is practical and easy to use. The need for elaborate computation was to be avoided.

During the developmental stages of this project, several different approaches were explored. These included the use of various formulae and precalculated reference tables. In the end, however, an essentially graphical procedure was judged to be the most practical.

The graphical approach has a number of major advantages over other alternatives:

- it requires only a ruler and pencil (no formulae, tables or calculating devices);
- it provides a visual indication of what is being done, a "feel" for the importance of various factors and the sensitivity of the results to changes in them;
- plotting two or more alternatives on the same page provides an immediate visual comparison;
- because of the simplicity of the approach, numerous alternatives can be explored in a matter of minutes.

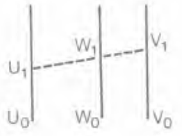
A graphical approach is obviously not as accurate as one based on computation; however, this is not considered to be a disadvantage here. Forestry is by no means an exact science, and a graphical approach certainly allows an acceptable degree of precision.

The method developed consists essentially of a series of nomograms. Nomograms have long been recognized in science and technology for the ease with which they can be used to solve specific mathematical formulas (e.g., Levens 1948). In recent years their popularity, like that of the slide-rule, has declined drastically in favor of computers, electronic calculators and other sophisticated gadgetry.

The nomograms used consist basically of combinations of two types of simple alignment charts:

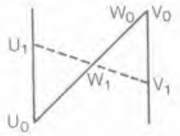
a) The first type consists of three parallel lines and solves equations of the form:

$$f_1(u) + f_2(v) = f_3(w)$$



b) The second type (a Z-chart) solves equations of the form:

$$f_1(u) = f_2(v) \cdot f_3(w)$$



In each case the scales are graduated in such a way that a straight line cutting the scales will determine three points whose values satisfy the given equation.

Procedure and Work Sheet

The procedure for comparing alternatives generally uses five groups of variables as inputs. These are combined to produce several measures of plantation cost whereby the preferred alternative can be selected. An overview of the procedure is shown in Figure 2.

For two of the input groups, better estimating procedures should be developed than are currently available:

- First, there are no guidelines at present for estimating off-target costs. It would be desirable to produce such guidelines, perhaps in the form of a table. Such a table could provide estimates of overstocking and understocking costs for a range of different site types.

- Second, better procedures are required for estimating survival. As has been indicated, relationships should he derived which take into account stock- and site-related variables affecting survival.

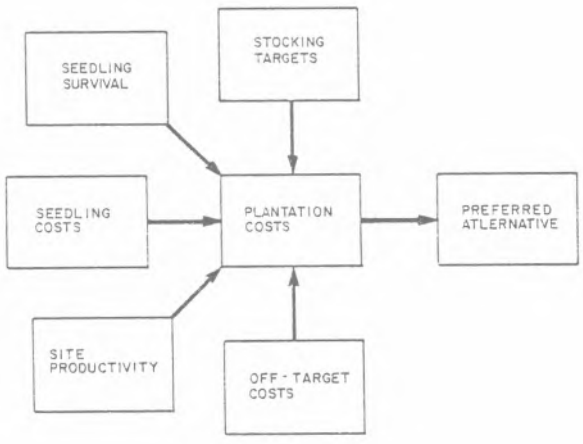


Figure 2. Comparison of alternatives in planting: an overview.

The procedure for comparing planting alternatives is set out on both sides of a single work sheet (Appendices A and B):

- The front contains a table for recording the values of the factors describing each alternative and also the results.

- The reverse contains several groups of alignment charts.

It should be noted that, of the five work sheet figures (alignment charts), two are "complex" in the sense that their function involves more than simple arithmetic: Figure 2 calculates probabilities and Figure 5 is a yield table, based on the formula:

$$V = 4.6 \times 10^{-5} D^{1.8} H^{1.08}$$

where V = volume of the tree in m^3;
D = diameter at breast height in cm;
H = height in m.

This formula produces good volume estimates for most of the major tree species in British Columbia.

The other three figures on the work sheet involve only addition, multiplication and division. It was considered useful to include them in the procedure not so much because they solve complex arithmetical operations, but because of their illustrative function in comparing alternatives.

ILLUSTRATIVE EXAMPLES

As an illustration of the methodology, and to suggest the wide range of questions it can assist in answering, two hypothetical examples are given here.

Selection of Stock

Suppose that a decision has to be made as to which of the following three stock type alternatives should be used to replant a site:

	Survival		Nursery
	S	σ	Cost
1) conventional 2-0 bare-root	70%	20%	10¢
2) conventional container stock	70%	15%	12¢
3) special stock	80%	10%	22¢

The site is expected to produce trees of 30 m high and 50 cm in diameter at a rotation of 60 years using conventional stock (1, 2). The special stock (3) is assumed to be superior, producing trees 10% higher and with 10% greater diameter at the same rotation.

The planting objective is to establish 1000 seedlings per ha so as to end up with 250 crop trees at rotation. If fewer than 800 trees are established, replanting would be required at a cost of $300; if more than 1300 are established, thinning would be required at a cost of $100 per ha in excess of the normal cost of juvenile spacing.

By using the work sheet (Appendix A), one can draw the following conclusions:

- If we consider planting cost P alone, the bare-root stock is cheapest, followed by the conventional container stock, with the special stock being the most expensive.

- If we consider the total planting project cost T, which includes an allowance for off-target costs, the bare-root and conventional container stock cost the same, with the special stock still the most expensive.

- If costs are related to site production by using criteria J and K, the special stock is found to be the most economical in spite of the fact that its cost of production is double that of bare-root.

- Since J and K are considered to be the most appropriate criteria, the special stock should be chosen.

Survival Improvement to Justify Extra Stock Cost

As another variation of the basic example, suppose that there is a choice between planting conventional container stock and special container stock costing 6c more per seedling. What improvement in survival is needed to justify the extra cost?

From the basic example, the cost of the conventional container stock is known to be $834.

In the work sheet in Appendix B, alternatives for the special container stock are evaluated for S = 75%, 80%, 85%.

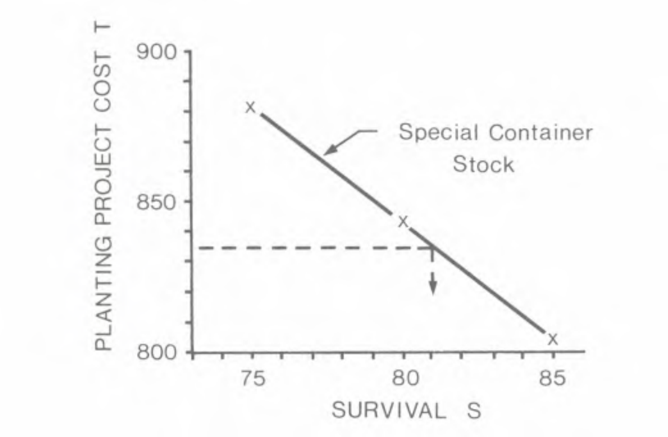


Figure 3. Chart to determine required survival rate for special stock, such that the total planting project cost is the same as that which would be incurred if conventional container stock were used.

By simple graphical interpolation (Fig. 3), it is seen that the planting project cost of the special container stock at 81% survival is the same as that of the conventional container stock. Thus, the extra cost of the special stock requires a survival of 81% (or better) for it to be economically competitive with the conventional stock at 70% survival.

CONCLUDING COMMENTS

It is felt that the methodology developed in this project has the potential to be useful in the field on a day-to-day basis. It is simple yet appears to incorporate all the necessary key variables. The methodology incorporates as a factor the concept of performance variability, which has considerable economic importance.

As has been discussed, major programs of large-scale operational measurement should be implemented to monitor continuously the performance of stock types, planting procedures, etc. It is recognized that extensive operational trials are already carried out, hut these have specific objectives. What is suggested here would be done as a matter of routine for purposes of on-going measurement and control.

It was also pointed out that one of the measurement problems involved in planting is that the seedlings planted are not described in quantitative terms. This would, of course, be necessary as part of an on-going operational monitoring system. The required measures certainly do exist, but they are not widely used. It is felt that a group of experienced foresters could readily select a suitable set of measures. While there would undoubtedly be debate as to what constituted an "ideal" set of measures, it is felt that some practical compromise should be possible. The economic benefits would be considerable.

LITERATURE CITED

Levens, A.S.
1948. Nomography. John Wiley & Sons, New York. viii + 176 p.

APPENDIX A — WORK SHEET

COMPARISON OF ALTERNATIVES IN PLANTING SEEDLINGS

This work-sheet provides a basis for comparing the costs of alternatives in planting seedlings. The variables to be taken into account are shown in the table below and are defined at the bottom of the page. For each alternative, one line in the table is to be completed.

In general, the variables marked by arrows (↓) are the ones required as inputs, and they must be known or estimated. The remaining variables are determined by simple arithmetic as indicated, or by use of the alignment charts on the back of this page.

The alignment charts are designed to satisfy the relationship between groups of three variables as shown in the corresponding 'ovals". For example, Figure 5i relates H, D, V. Thus, given the values of any two variables in a group, the value of the third variable is obtained by using a ruler and pencil to draw a line through the two given values.

In comparing alternatives, the values of the variables for each case are recorded in the table below, and the required lines are drawn on the alignment charts. Thus, the difference between the alternatives will be apparent both numerically and graphically.

ALTERNATIVE #1	ALTERNATIVE #2	ALTERNATIVE #3
Conventional 2-0 bare-root.	Conventional container stock.	Special stock.

PROJECT	
REGION	Vancouver
DISTRICT	Maple Ridge
OPENING	92G82-27
NUMBER	P92G4-27
DATE	10 May 79
NAME	Lost Creek

# ALT	STOCKING TARGETS					SURVIVAL			PLANT
	N_T ↓	N_U ↓	N_L ↓	n_U $100(\frac{N_U}{N_T}-1)$	n_L $100(1-\frac{N_L}{N_T})$	S ↓	σ ↓	d (σ/S)	N_P Fig 1
1	1000	1300	800	30	20	70	20	.29	1430
2	"	"	"	"	"	70	14	.20	1430
3	"	"	"	"	"	80	10	.13	1250

OFF-TARGET COSTS				
A_U Fig 2	A_L Fig 2	B_U ↓	B_L ↓	B $A_UB_U+A_LB_L$
.15	.24	100	300	87
.06	.16	"	"	54
.01	.06	"	"	19

# ALT	PRODUCTION POTENTIAL OF SITE						
	N_C ↓	H ↓	D ↓	V Fig 5 i	W Fig 5 ii	R ↓	M Fig 5 iii
1	250	30	50	2.1	520	60	8.7
2	"	"	"	"	"	"	"
3	250	33	55	2.7	680	60	11.3

SEEDLING COSTS			
c_1 ↓	c_2 ↓	c_3 ↓	C $c_1+c_2+c_3$
.10	.20	-	.30
.12	.20	-	.32
.22	.20	-	.42

PLANTATION COSTS					
P Fig 3 i	F ↓	Q B+F	T Fig 3 ii	J Fig 4 i	K Fig 4 ii
430	320	407	837	1.60	97
460	320	374	834	1.60	97
530	320	339	869	1.28	77

STOCKING TARGETS

N_T – Stocking target (number of successfully established seedlings per hectare).
N_U – Upper limit of stocking.
N_L – Lower limit of stocking.
N_P – Number of seedlings to be planted per hectare.
n_U – Percentage by which upper limit exceeds the desired stocking: $n_U = 100(N_U/N_T - 1)$.
n_L – Percentage by which lower limit falls short of the desired stocking: $n_L = 100(1 - N_U/N_T)$.

SURVIVAL

S – Average percent survival of seedlings.
σ – Standard deviation of survival (%).
d – Dispersion coefficient (d = σ/S).

PRODUCTION POTENTIAL OF SITE

N_C – Number of crop trees to be harvested per hectare.
H – Height of crop trees (metres).
D – Diameter of crop trees (centimetres at breast height).
V – Volume of wood per mature tree (cubic metres, average for all species).
W – Wood production (cubic metres per hectare).
R – Rotation period (years to maturity).
M – Mean annual increment (cubic metres of wood per hectare per year).

OFF-TARGET COSTS

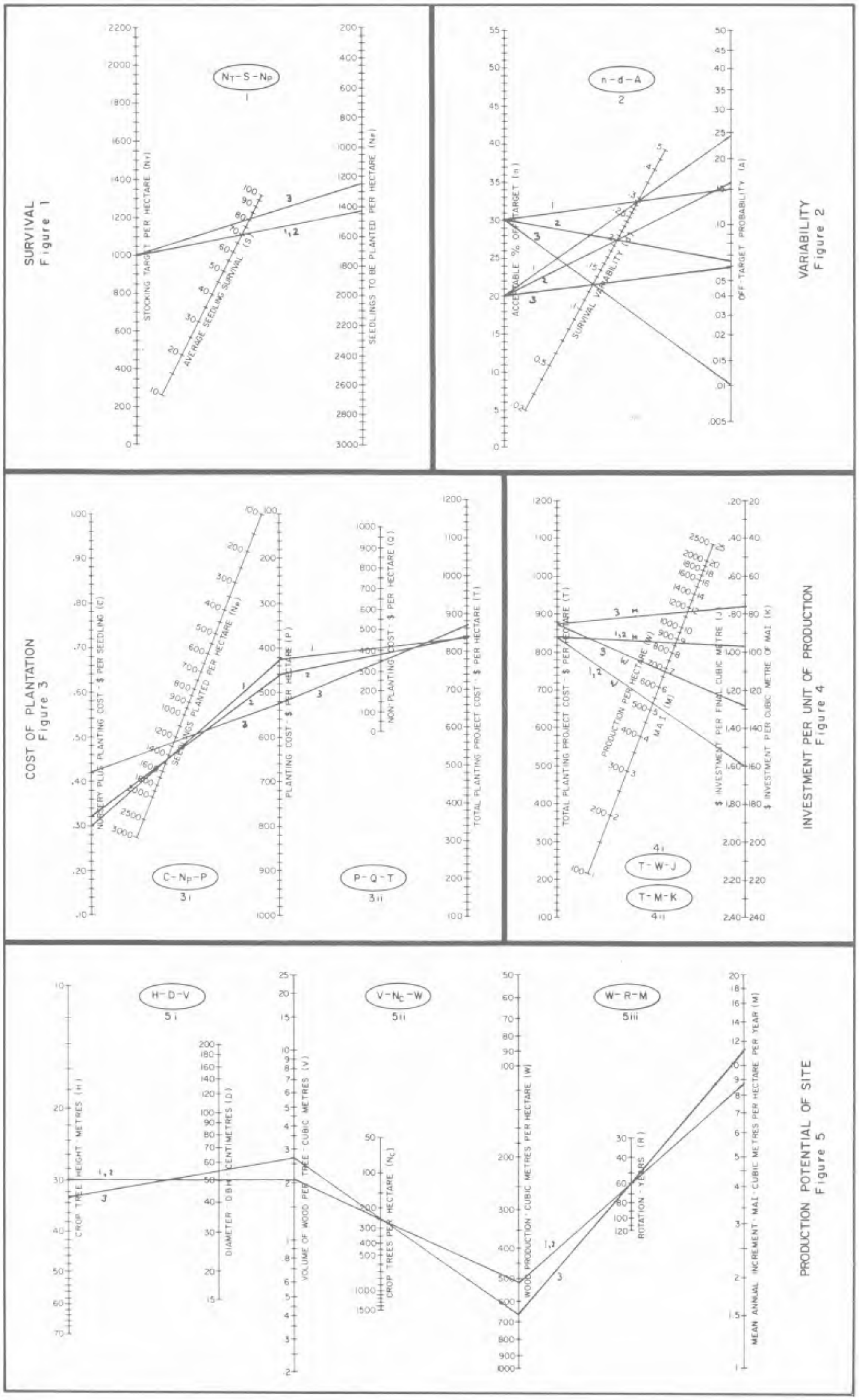
A_U – Probability of exceeding N_U.
A_L – Probability of not meeting N_L.
B_U – Cost incurred if the upper limit of stocking is exceeded (thinning, loss of quality, ...).
B_L – Cost incurred if the lower limit of stocking is not met (replanting, loss of production, ...).
B – Expected cost of being outside the specified stocking limits: $(B = A_UB_U + A_LB_L)$.

SEEDLING & PLANTATION COSTS

c_1 – Nursery cost per seedling including all production costs (seeding, tending, containers, lifting, packaging, land-rent, overhead, ...).
c_2 – Planting cost per seedling including all field-related costs (planting, transportation, ...).
c_3 – Extra cost (eg. special treatment) per seedling.
C – Cost per planted seedling: $(C = c_1 + c_2 + c_3)$.
P – Planting cost per hectare.
F – Site preparation costs per hectare (burning, scarifying, access, establishment period tending, ...).
Q – Non-planting costs per hectare including site preparation and failure to be within specified stocking limits: $(Q = F + B)$.
T – Total planting project cost per hectare.
J – Present investment (cost) required to obtain one cubic metre of wood at rotation.
K – Present investment (cost) required to establish one cubic metre of mean annual increment.

(cont'd)

APPENDIX A (concl.)



APPENDIX B — WORK SHEET

COMPARISON OF ALTERNATIVES IN PLANTING SEEDLINGS

This work-sheet provides a basis for comparing the costs of alternatives in planting seedlings. The variables to be taken into account are shown in the table below and are defined at the bottom of the page. For each alternative, one line in the table is to be completed.

In general, the variables marked by arrows (4) are the ones required as inputs, and they must be known or estimated. The remaining variables are determined by simple arithmetic as indicated, or by use of the alignment charts on the back of this page.

The alignment charts are designed to satisfy the relationship between groups of three variables as shown in the corresponding "ovals". For example, Figure 5i relates H, D, V. Thus, given the values of any two variables in a group, the value of the third variable is obtained by using a ruler and pencil to draw a line through the two given values.

In comparing alternatives, the values of the variables for each case are recorded in the table below, and the required lines are drawn on the alignment charts. Thus, the difference between the alternatives will be apparent both numerically and graphically.

ALTERNATIVE #1	ALTERNATIVE #2	ALTERNATIVE #3
Special Container Stock: S = 75 %	Special Container Stock: S = 80%	Special Container Stock S = 85%

PROJECT	
REGION	Vancouver
DISTRICT	Maple Ridge
OPENING	92 G 82 - 27
NUMBER	P92G4 - 27
DATE	10 May '79
NAME	Lost Creek

ALT #	STOCKING TARGETS					SURVIVAL			PLANT
	N_T ↓	N_U ↓	N_L ↓	n_U $100(\frac{N_U}{N_T}-1)$	n_L $100(1-\frac{N_L}{N_T})$	S ↓	σ ↓	d (σ/S)	N_P Fig 1
1	1000	1300	800	30	20	75	14	.19	1330
2	"	"	"	"	"	80	14	.18	1250
3	"	"	"	"	"	85	14	.16	1180

OFF-TARGET COSTS				
A_U Fig 2	A_L Fig 2	B_U ↓	B_L ↓	B $A_UB_U+A_LB_L$
.06	.15	100	300	51
.05	.13	"	"	44
.03	.10	"	"	33

ALT #	PRODUCTION POTENTIAL OF SITE						
	N_C ↓	H ↓	D ↓	V Fig 5 i	W Fig 5 ii	R ↓	M Fig 5 iii
1							
2							
3							

SEEDLING COSTS			
C_1 ↓	C_2 ↓	C_3 ↓	C $C_1+C_2+C_3$
.12	.20	.06	.38
"	"	"	"
"	"	"	"

PLANTATION COSTS					
P Fig 3 i	F ↓	Q B+F	T Fig 3 ii	J Fig 4 i	K Fig 4 ii
510	320	371	881		
480	"	364	844		
450	"	353	803		

STOCKING TARGETS

N_T - Stocking target (number of successfully established seedlings per hectare).

N_U - Upper limit of stocking.

N_L - Lower limit of stocking.

N_P - Number of seedlings to be planted per hectare.

n_U - Percentage by which upper limit exceeds the desired stocking: $n_U = 100(N_U/N_T - 1)$.

n_L - Percentage by which lower limit falls short of the desired stocking: $n_L = 100(1 - N_U/N_T)$.

SURVIVAL

S - Average percent survival of seedlings.

σ - Standard deviation of survival (%).

d - Dispersion coefficient ($d = σ/S$).

PRODUCTION POTENTIAL OF SITE

N_C - Number of crop trees to be harvested per hectare.

H - Height of crop trees (metres).

D - Diameter of crop trees (centimetres at breast height).

V - Volume of wood per mature tree (cubic metres, average for all species).

W - Wood production (cubic metres per hectare).

R - Rotation period (years to maturity).

M - Mean annual increment (cubic metres of wood per hectare per year).

OFF-TARGET COSTS

A_U - Probability of exceeding N_U.

A_L - Probability of not meeting N_L.

B_U - Cost incurred if the upper limit of stocking is exceeded (thinning, loss of quality, ...).

B_L - Cost incurred if the lower limit of stocking is not met (replanting, loss of production, ..).

B - Expected cost of being outside the specified stocking limits: ($B = A_UB_U + A_LB_L$).

SEEDLING & PLANTATION COSTS

c_1 - Nursery cost per seedling including all production costs (seeding, tending, containers, lifting, packaging, land-rent, overhead, ...).

c_2 - Planting cost per seedling including all field-related costs (planting, transportation, ...).

c_3 - Extra cost (eg. special treatment) per seedling.

C - Cost per planted seedling: ($C = c_1 + c_2 + c_3$).

P - Planting cost per hectare.

F - Site preparation costs per hectare (burning, scarifying, access, establishment period tending, ...).

Q - Non-planting costs per hectare including site preparation and failure to be within specified stocking limits: ($Q = F + B$).

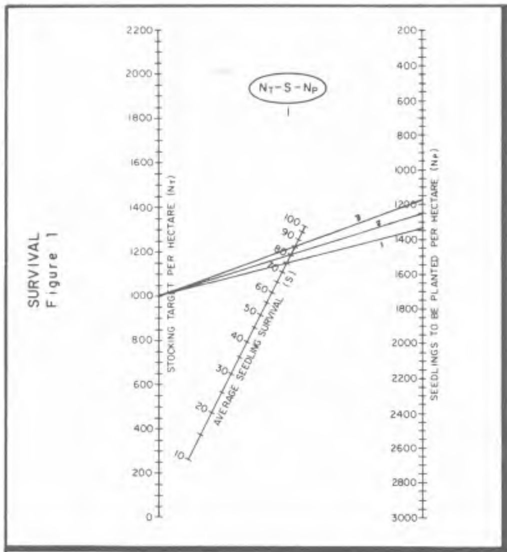
T - Total planting project cost per hectare.

J - Present investment (cost) required to obtain one cubic metre of wood at rotation.

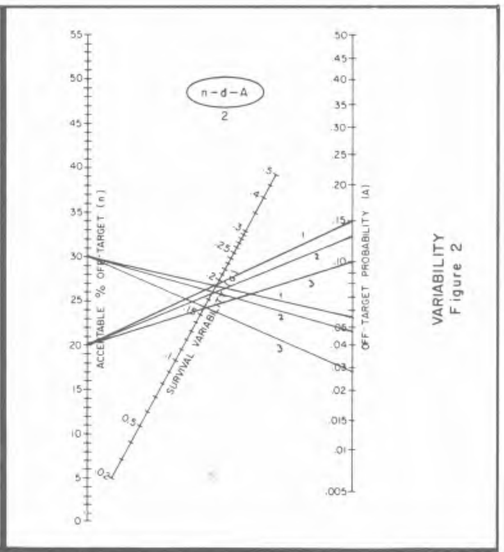
K - Present investment (cost) required to establish one cubic metre of mean annual increment.

(cont'd.)

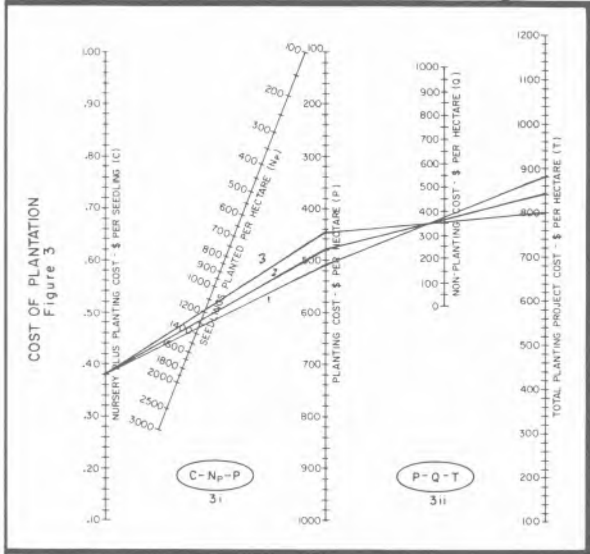
APPENDIX B (concl.)



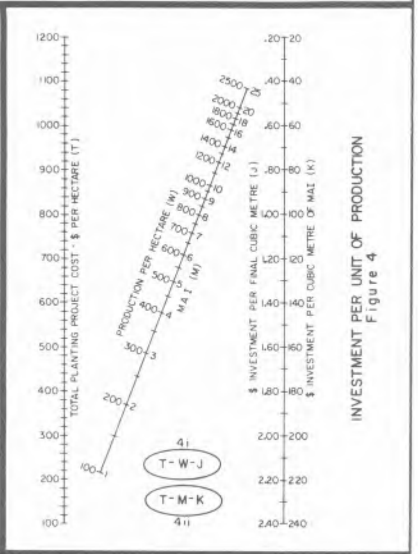
SURVIVAL
Figure 1



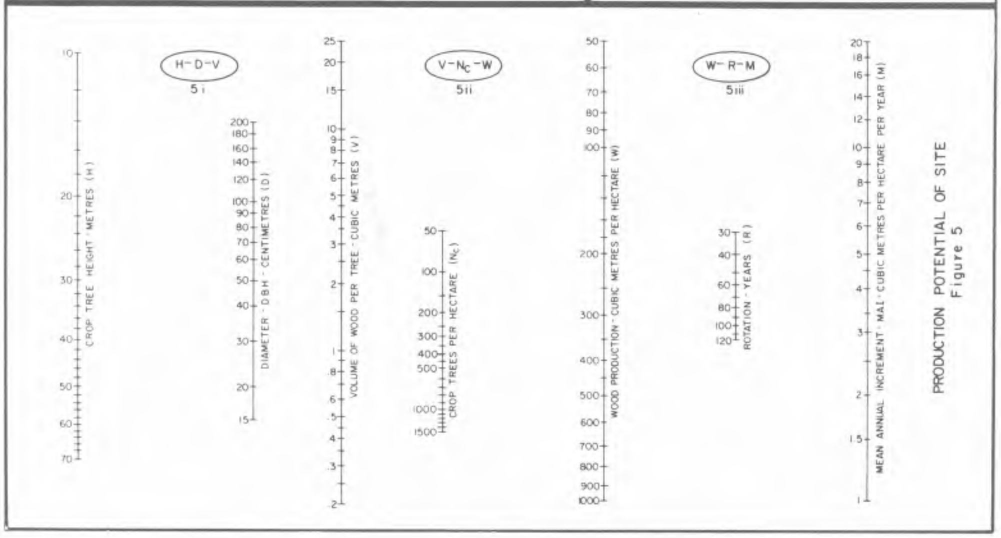
VARIABILITY
Figure 2



COST OF PLANTATION
Figure 3



INVESTMENT PER UNIT OF PRODUCTION
Figure 4



PRODUCTION POTENTIAL OF SITE
Figure 5

OPPORTUNITIES FOR IMPROVEMENT IN CONTAINERIZED REFORESTATION--AN INDEPENDENT VIEW

Henry A. Spencer'

Abstract.--The basic container system is examined with reference to areas relatively untouched by research. Profitable areas for research, where economies and/or productivity improvements could be realized, are suggested.

Résumé.--On examine l'essentiel du système de semis en récipients par rapport à des domaines qui sont demeurés relativement à l'écart d'une recherche approfondie. On propose des domaines fructueux de recherche qui permettraient certaines économies ou une amélioration de la productivité.

INTRODUCTION

Pathways to change are always strewn with obstacles. To establish a container installation quickly one must often push ahead and get the work done, without considering side effects. There is always opportunity for improvement, but at some stage one has to stop improving and start producing. Nevertheless, it is essential to consider the longer term, especially when one is dealing with forests that may not be harvested in one's own lifetime. "Never leave well enough alone" is a motto for the innovator. Perhaps it is time to evaluate our progress and see what opportunities there are for the future.

The main advantages offered by containers include:

- individual control over seedling growth
- possible mechanization of operations
- absence of planting shock
- extended season for outplanting
- greater control in tree improvement programs.

However, there are a number of concerns related to container planting, viz:

- economics of container operations vary with size
- investment in one system discourages change to a better system
- progress in mechanization of container handling has been slow
- not all extended season plantings are successful
- even experts disagree on genetic requirements for "tree improvement".

ECONOMICS

When designing a new containerized seedling production facility, it is important to consider the size of the operation, both now and in the near future. Budgets for staff and greenhouses can vary from $10,000 to $10 million. A surplus of labor in remote areas may eliminate the need for automation. The availability of materials, hardware, machine shops, and innovative or mechanically inclined staff should all be kept in mind.

Some of the main economic considerations for anyone planning a containerized seedling production operation are:

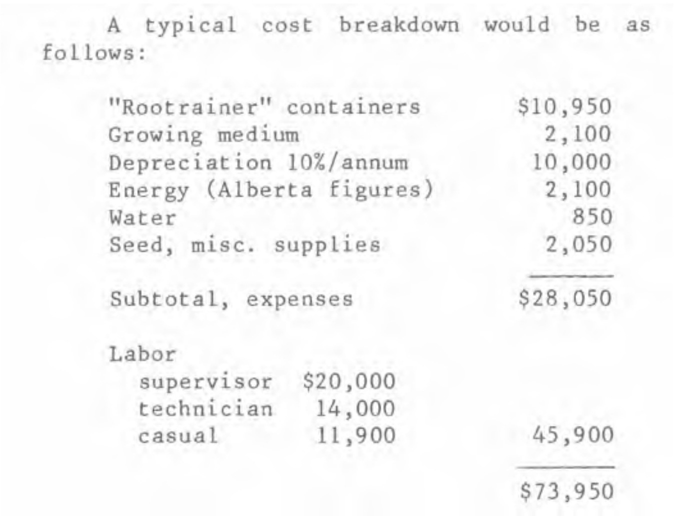
- budget
- target cost per seedling
- greenhouse location

---

[1] President and General Manager, Spencer-Lemaire Industries, Edmonton, Alberta.

- materials--growing media, water, fertilizers, energy sources
- management preferences and standards
- staff--labor, management, technical (and availability of experienced nursery staff in local area).

A typical goal is to grow one million seedlings annually, with a $100,000 budget for a greenhouse, and to produce those seedlings for less than $75.00 per thousand. This gives an operating budget of $75,000.



A typical cost breakdown would be as follows:

"Rootrainer" containers		$10,950
Growing medium		2,100
Depreciation 10%/annum		10,000
Energy (Alberta figures)		2,100
Water		850
Seed, misc. supplies		2,050
Subtotal, expenses		$28,050
Labor		
supervisor	$20,000	
technician	14,000	
casual	11,900	45,900
		$73,950

("Rootrainers" may be used three times; hence, $3,650 annually should be budgeted for container replacement after the first year.)

Economics of scale can apply if two crops a year are grown in the facility. The costs of growing medium, energy, water, seed, and miscellaneous supplies will likely double, but depreciation and possibly labor will remain at the same level. An important thing to note is that labor costs cannot be reduced much below $34,000 (i.e., the salaries of the supervisor and technician). This means that, with an allowance of $75 per thousand seedlings, the break-even point is about 750,000 seedlings in this greenhouse. It should be remembered that a labor cost of $45,900 is unrealistic unless the greenhouse is well automated.

Research is needed to standardize methods of cost analysis so that comparison between greenhouses can be made fairly. This is especially true when Forest Management Agreements are signed and private companies begin to raise their own seedlings. Factors sometimes forgotten are labor benefits and holidays, extra transport, borrowed money, and productivity for species type. Perhaps only 85% of the seedlings sown will be of sufficiently high quality to plant. Effective planning requires such information.

GERMINATION

Perhaps 85% of the seedlings that germinate will be plantable. Such information is essential for effective planning.

A number of nurseries find it most economical to obtain as high a quality of seed as possible and to sow one seed only in each container. Other nurseries sow as many as five seeds in each container, and accept the need for thinning. Although thinning is labor-intensive, it may be that the job can be done by workers who are not fully occupied elsewhere. In some cases, government departments will employ casual labor. Thinning, however, requires care, and it is best, if thinning is planned, to hire skilled people, even if only for a few weeks.

One or two companies have begun selling equipment to pregerminate seeds and then sow them. The advantage of this technique, if it works, is that it eliminates extra seed and/or thinning costs. More research and development are needed to improve the speed and efficiency of this technique.

As noted above, the germination rate has a tremendous influence on the economics of container seedling production. If, through research, we can obtain 98-100% germination while maintaining adequate seedling quality, and can guarantee one seedling per cavity, then thinning, selection, standardization and consolidation will cost a great deal less. In addition, greenhouse utilization will be more efficient, and mechanization will begin to make more sense.

SYSTEM RESEARCH

The container system may be illustrated by means of a flow diagram (Fig. 1). The forester can use this diagram as an aid in analyzing his costs, by adding or subtracting those elements of the system that he will or will not require.

TREE IMPROVEMENT

Tree improvement presents a basic dilemma. The criteria of the past may not apply to the future. Consider structural timber, for example. In recent years, construction grade lumber has contained many knots and checks because trees are being harvested at a younger age than formerly. "Clear fir" is seldom available. Selection of seed from trees that have few branches may mean slow growth, since there will be less photosynthetic activity. The large trees have all been harvested.

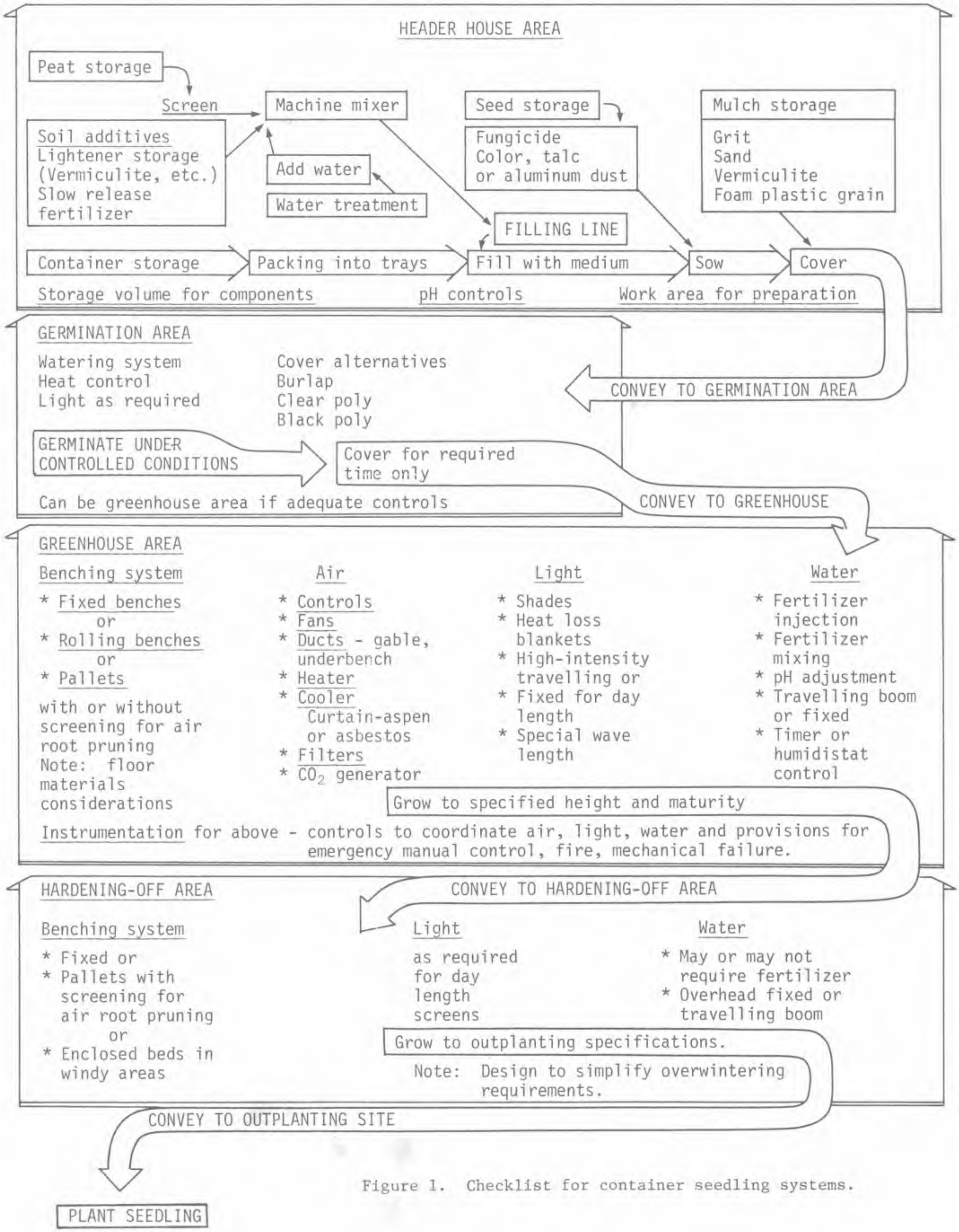


Figure 1. Checklist for container seedling systems.

A researcher may, in the future, find a way of removing the lignin and bonding materials from trees, of separating out long strands of fibre, and of reconstituting the wood into an extruded structural member of standard density and size, with a smooth finish, the way aluminum is extruded or steel is rolled. Harvests might then take place in 20 years instead of 60 or 80 years, and tree spacing in a new forest could be very close.

For now, we need to determine the genetic makeup of trees that provide easy germination, fast growth, strength, suitability for paper fibre, and perhaps in the near future as oil becomes more expensive, good cellulose quality for making cellulosic plastics.

CONTAINER DESIGN

A great deal of work has been done in the container field over the past 10 years or so. Even 20 years ago, the Walters bullet was proven successful. Still earlier, degradable tubes of various kinds made from materials at hand, and compacted plugs made like native bricks, sections of polyethelene pipe, and canvas, jute and perforated plastic bags were developed in tropical countries. The use of such methods recognized the need for individual seedlings to be grown and outplanted safely and reasonably cheaply. How can containers be improved?

(a) Injection planting

In the area of injection planting, research is needed on biodegradeable containers, including the development of a non-wicking growing medium, some means of controlling root direction, and foolproof filling devices.

In handling these single containers there may be some advantages to designing or developing machines for use in the nursery to consolidate and sort seedlings before packing for shipping to the field.

(b) Growing medium

Other types of container would benefit as well from improvements to the growing medium. Peat is an inexpensive but delicate medium, and one which does not always behave suitably. It needs to be studied and experimented with so that its best properties can be used effectively. The Finnish Peat Institute has undertaken such work in the past, but further research could bring better germination, easier wetting, uniform and ideal growing conditions throughout the container, easier handling and consequently less breakup of the medium.

GREENHOUSES

Greenhouses themselves are not immune from critical analysis. In view of the fact that their main function is to provide a suitable environment for germinating seed and growing the seedlings to a plantable stage, some possible improvements come quickly to mind.

Glazing materials offer many options. General Electric has tested various kinds and thicknesses of polycarbonate plastic in Florida over the past five years. Rohm and Haas combined with Cyanamid to produce extruded double-wall acrylic. Monsanto developed a sunlight-resistant polyethylene, and in Canada CIL Plastics have come up with an alternative. Tempered glass seems to find favor with a lot of growers, while PVC (clear vinyl), fibreglass-reinforced polyesters (IBG's Denverlight) and woven polypropylene have all captured part of the market. Why are there so many different types of glazing materials? What advantages are there to any or all of them? A little unbiased research has been done but a lot more is needed.

In Alberta, the ideal greenhouse would allow for fairly high operating temperatures, CO2 enrichment, a broad spectrum of useful light, and temperature reduction by shading. Research on the use of copper salts in solution passed between two sheets of plastic or glass has shown that 50% of the heat can be absorbed while still allowing the passage of useful light, thereby eliminating the need for ventilation and facilitating the maintenance of high CO2 concentrations in sunny conditions. At present there are problems with leakage, maintenance of suitable plumbing, differential expansion and corrosion (Fig. 2), but research in this field holds promise.

Waste heat for greenhouses is being used in many areas where feasible. Light-gauge polyethylene will pass 002 but not NO2, NO3 or N203. Hot flue gas can thus be mixed with outside air to bring its temperature to a suitable working level, and passed between the two sheets of a double-poly greenhouse to keep the poly clear of snow and to raise the 002 level within the house.

GREENHOUSE SYSTEMS

It is important to take a systematic approach when developing a greenhouse operation. Factors such as the height of containers above the ground, type and height of bench, pallet and dolly system, methods for loading and unloading greenhouses, palletization for shade frames, transportation and

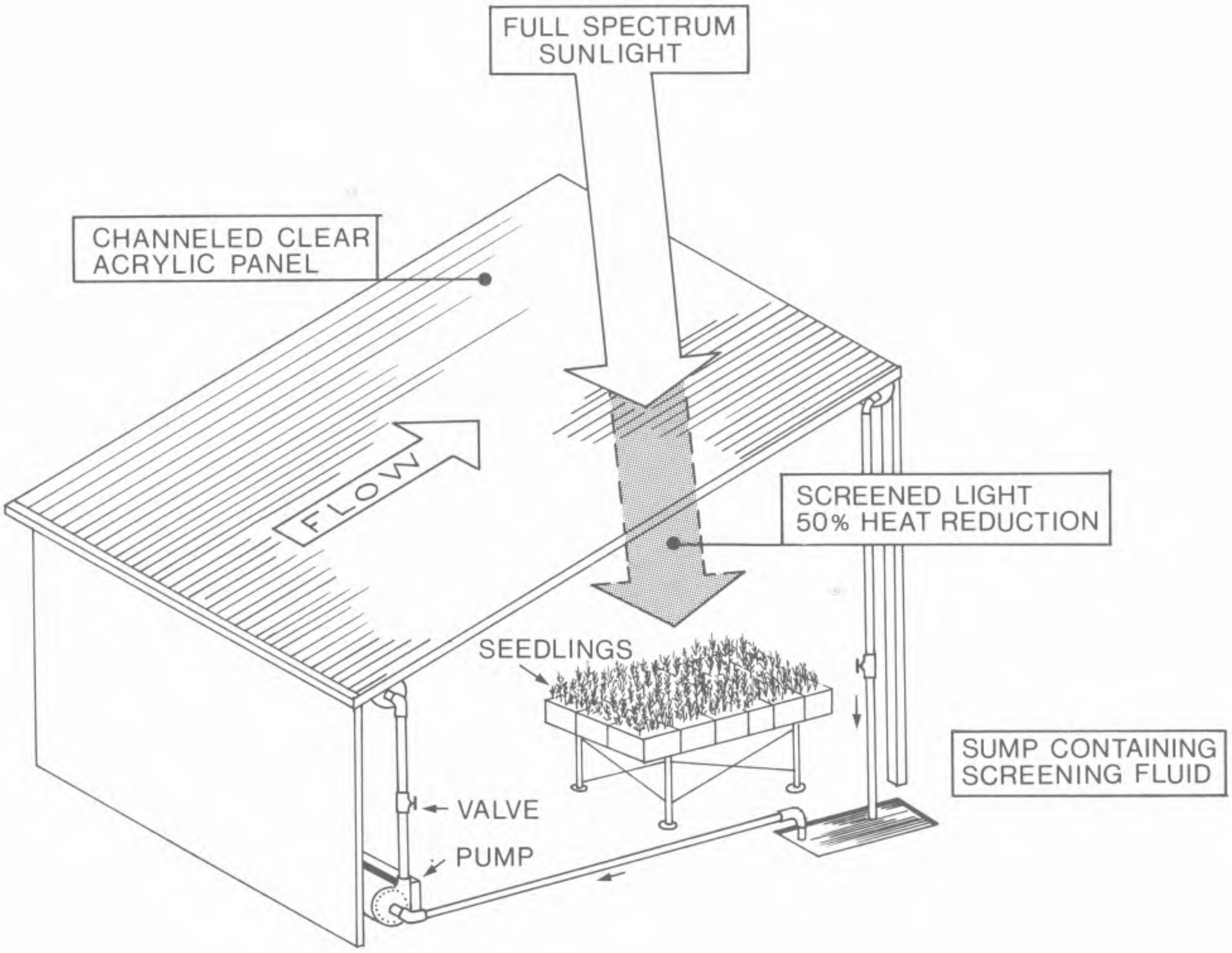


Figure 2. Screened light for greenhouse cooling.

field handling practices all need to be carefully analyzed. In the past many decisions have been made simply by rule of thumb. Some greenhouse operators keep their seedlings 5 to 8 cm above ground, others keep theirs at about 1 m above ground. Various factors affect the height that should be chosen, including the size and height of greenhouse, the style of container tray used, the degree of automation required, and above all, those factors associated with the growing cycle. Germination count will affect thinning, and thinning may require more aisle access than originally planned. Consolidation and grading of seedlings may compensate for heavy competition in the field. Watering may be critical in warm climates and the lighting system chosen and light availability may decide the benching system used. Some computer modelling has been done to study these factors, but a good deal more could be done to provide operational guidelines. Research to determine the most economical alternatives for various situations must be done critically and objectively.

Greenhouse systems are being developed. It is now quite practical to use travelling booms for watering and lighting. These could be improved further by eliminating the hoses, using instead a reservoir tank that travels with the boom, and is refilled at one end of the greenhouse. Greenhouse environment control systems have been developing rapidly, especially in Europe, and research in this field is very active. A visit to the cooperative growers' research establishment at Wageningen in The Netherlands would put the grower in touch with the most modern control systems available.

Practical research in controlled conditions is essential for the development of effective growing regimes. Dr. Richard Tinus of the USDA Forest Service in Bottineau, North Dakota, routinely tests seedlings of different provenance under growth chamber conditions and develops criteria for best growth in a series of isobar-like maps or graphs. Further research of this nature is required.

STORAGE AND CONDITIONING

To date, little research has been done on conditions for outside storage. Many growers have had problems with overwintering (e.g., inadequate snow cover, desiccation of roots, snow mold, etc.). Techniques that could be explored include the use of "Agri-foam", a material developed by the National Research Council of Canada to help save tomatoes from frost, or covering the needles of seedlings with a chemical like Gelgard to retard desiccation without suffocating the plants. More information is needed on factors influencing overwinter survival.

TRANSPORTATION AND PLANTING

A number of papers dealing with the handling and planting of containerized seedlings were presented at the A.S.A.E. Symposium held in North Carolina in 1981. A careful study of the research on which these papers were based reveals that much remains to be done. Scandinavian companies seem to have advanced more quickly than others in the field of mechanized planting, although their techniques are not readily applicable to those parts of British Columbia, Washington, and Oregon where slopes are so steep that men would find it difficult to drive machines. A spiderlike vehicle with a central pod that is always balanced seems worthy of study. Such a vehicle could adapt to steep slopes and still carry a large number of seedlings (Fig. 3).

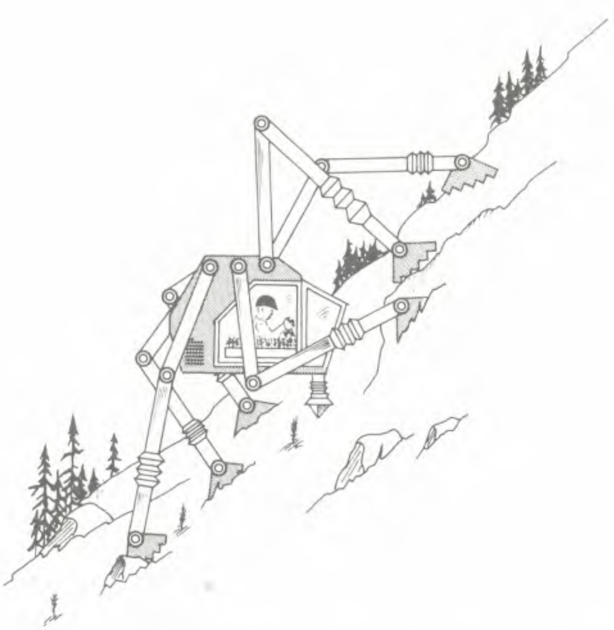


Figure 3. Mechanized planter for steep slopes.

CONTAINER MANUFACTURE

In the past, most Canadian container systems were designed without consideration of the effects of rising petroleum prices and consequently the greater expenses incurred for raw materials. Those of us who manufacture plastic products may have to make containers from better quality materials so that they can be used for a long time and thereby justify the higher cost.

THE CRYSTAL BALL

As automation becomes more precise, we may see, for example, the development of a container with sowing spaces that serves as its own pallet, is easily sterilized and will last for 15 years. Greenhouses will have automated handling systems that fill these containers with a treated homogenous wood waste medium containing slow-release fertilizers. Seeds will be pre-germinated and sown automatically with suitably gentle equipment.

Greenhouses will be designed so that they require no more heat than the sun provides, and watering systems will not need fertilizer controls. High levels of CO2 (and any other gases that benefit photosynthesis) will provide rapid cellulose buildup. Pallets will be handled mechanically at all stages from nursery to field. Automatic, mechanized planting will require only one operator, and machines will pre-scan, spot-scarify, prepare the soil, plant continuously, and be able to travel without compacting the soil. Seedlings grown from hybrid seed will mature in 20 years in Canada and will provide us with all we need in the way of timber, pulp, paper, and chemical products.

With a lot of dedicated and imaginative research, it can happen.

LITERATURE CITED

Anon.
1981. Forest regeneration. Proceedings of the Symposium on Engineering Systems for Forest Regeneration. Am. Soc. Agric. Engin., St. Joseph, Mich. ASAE Publ. 10-81. viii + 376 p.

SUMMATION:

CONTAINERIZATION - BOON OR BOONDOGGLE?

James M. Kinghorn[1]

In several recent provincial and national studies and at various meetings the need for intensifying forest management across Canada has been stressed. Dramatic increases in the rate of forest renewal, particularly by planting, are considered essential if fibre shortages are to be avoided. The use of containerized seedlings may have the potential for expanding planting programs rapidly, but are the cost and field performance of these seedlings as satisfactory as their proponents claim? Do successes exceed failures sufficiently to justify the current upswing in container seedling production, or are we simply riding a wave of enthusiasm that cannot be sustained by operational performance?

The attendance of over 300 people at this symposium indicates that containerized seedlings have at last achieved a degree of popularity, if not respectability. Heretofore, Canadian container enthusiasts often believed that they were in the vanguard of a new technology. Mr. Räsanen reminds us, however, that a form of containerization antedated bare-root practice as the principal means of planting forests in Europe. In reality, therefore, bare-root planting is the new, cheap method of reforestation. We are now rediscovering, with new materials and techniques, a very old reforestation option. Are research and development providing sufficient guidance for us to meet the demands of increased production? The Ontario tubed seedling program of the late 1960s demonstrated the hazard of production outpacing technical development and nursery expertise. Annual production, which rose from zero to 20 million plants in only three years, declined to a token quantity within a decade. The number of seedlings produced is not the best criterion by which to judge the success of a method; successful production will be sustained, but production leading to successive plantation failures will decline and ultimately disappear. Very rapid increases in production may only signify popularity, but sustained production provides a real measure of acceptability.

The excellent review of reforestation in the Scandinavian countries by Räsanen should inspire some confidence in containerized methods. Try to visualize the magnitude of these programs. Container-grown stock in Norway, Sweden and Finland currently accounts for 357 million seedlings per year, a total exceeding all types of planting stock produced in Canada! Notwithstanding some setbacks, high levels of container seedling production have been sustained in Scandinavia for more than a decade.

The status reports given at the beginning of the meeting indicate that Canadian container seedling production now totals about 140 million per year; projections estimate that production could reach 220 million by 1983. In comparison with a production of 17 million and an attendance of only 40 people at the 1972 Kananaskis container workshop, current production and conference attendance show that interest, expertise and production have all increased exponentially over the last 10 years. The status reports also show that container production is concentrated in British Columbia, Alberta, the Atlantic provinces and the Pacific northwest United States. Like the northeastern and north central United States, Ontario and Quebec have not yet increased their container seedling production to any degree. One must assume that in these regions planting stock demands have been relatively static, and that bare-root production is providing sufficient low cost planting stock to meet reforestation goals. It is not surprising that interest in containerization has lagged in the southern pine region of the United States. There, enormous bare-root programs have been satisfying demand for decades with excellent, inexpensive short rotation crops. A radical change in technique cannot be justified unless a reliable improvement over present

---

[1] Fomerly Forester, Pacific Forest Research Centre, Canadian Forestry Service, Victoria, British Columbia (now retired).

practice is clearly demonstrated. If a technique is serving adequately, change should not be sought simply for the sake of change or popularity.

By contrast, there are some good reasons for seeking change in the harsh climates of the northern latitudes. Open field culture is riskier and more uncertain than it is in milder southern climates. Container methods permit compact nurseries in which the growing environment can be controlled economically. Although good bare-root stock can be grown in harsh climates, it is often difficult to maintain a constant and predictable level of production. Where three or four years are needed to grow each crop, erratic production creates havoc with reforestation planning. Often the container option is chosen by default because the short-rotation container crop can quickly fill the short-falls in bare-root production.

At a time when demands for more planting stock are on the increase in many parts of Canada, perhaps the most compelling reason for adopting container systems is that production can be initiated quickly and effectively.

Neither default nor panic is a very good reason for adopting new methods, but both are influences that cannot be ignored. I have heard it said that the rapid expansion of the Swedish planting program could not have been effected without the aid of containerization. Similarly in Canada, the urgency for accelerated planting will result in increased container seedling production, regardless of the readiness of the technology or the availability of expertise capable of translating promises into practice.

The purpose of meetings such as this is to provide guidelines for rational expansion of production so that the potential of containerization can be realized and the risk of repeated boondoggles or failures can be minimized.

Papers, posters and commercial exhibits presented at this Symposium update the state of the art. Although a detailed review of this wealth of material is neither possible nor appropriate at this juncture, I will comment briefly on highlights I consider significant, and draw attention to a few glaring deficiencies.

Both Tinus and Van Eerden provide principles and prescriptions for growing seedlings that merit repeated attention. While Tinus stresses the need to understand the effects of environmental manipulation on seedling physiology, Van Eerden exhorts new growers to heed container growing techniques that have evolved and have proven successful for over 10 years in British Columbia. He draws from a long and intimate association with the largest and most diversified container seedling program in Canada. In our eagerness to innovate, we are often guilty of wasting time and effort by failing to copy exactly, or at least to mimic closely, successful methods demonstrated elsewhere.

The three papers on contrasting approaches to container seedling production provide details of current production methods. It is interesting to note, however, that the various cultural methods now have more in common than they have differences. Perhaps this reflects the maturing of technology and a lessening of extremes in approach.

The four papers on photoperiod and temperature manipulation for preventing premature dormancy and for inducing cold hardiness describe techniques that have now reached the stage when they are practicable for operational use.

Although mycorrhizal manipulation may enhance seedling quality, it is evident that much work is still required before quality gains are realized.

The possibility of root form problems with container-grown stock is a source of continuing debate. Wall ribs, air root pruning, and correct matching of stock to site can reduce the risk of root problems. The two papers on chemical root pruning demonstrate that it is now possible virtually to eliminate the risk of instability due to root form problems. I find it curious, however, that active investigations are still under way in Ontario and Quebec, in an attempt to reinvent forms of the paperpot and the biodegradability of various wood pulp and synthetic fibre combinations. At least three Scandinavian innovations are serious attempts to improve on root form without relying on uncertain rates of biodegradability.

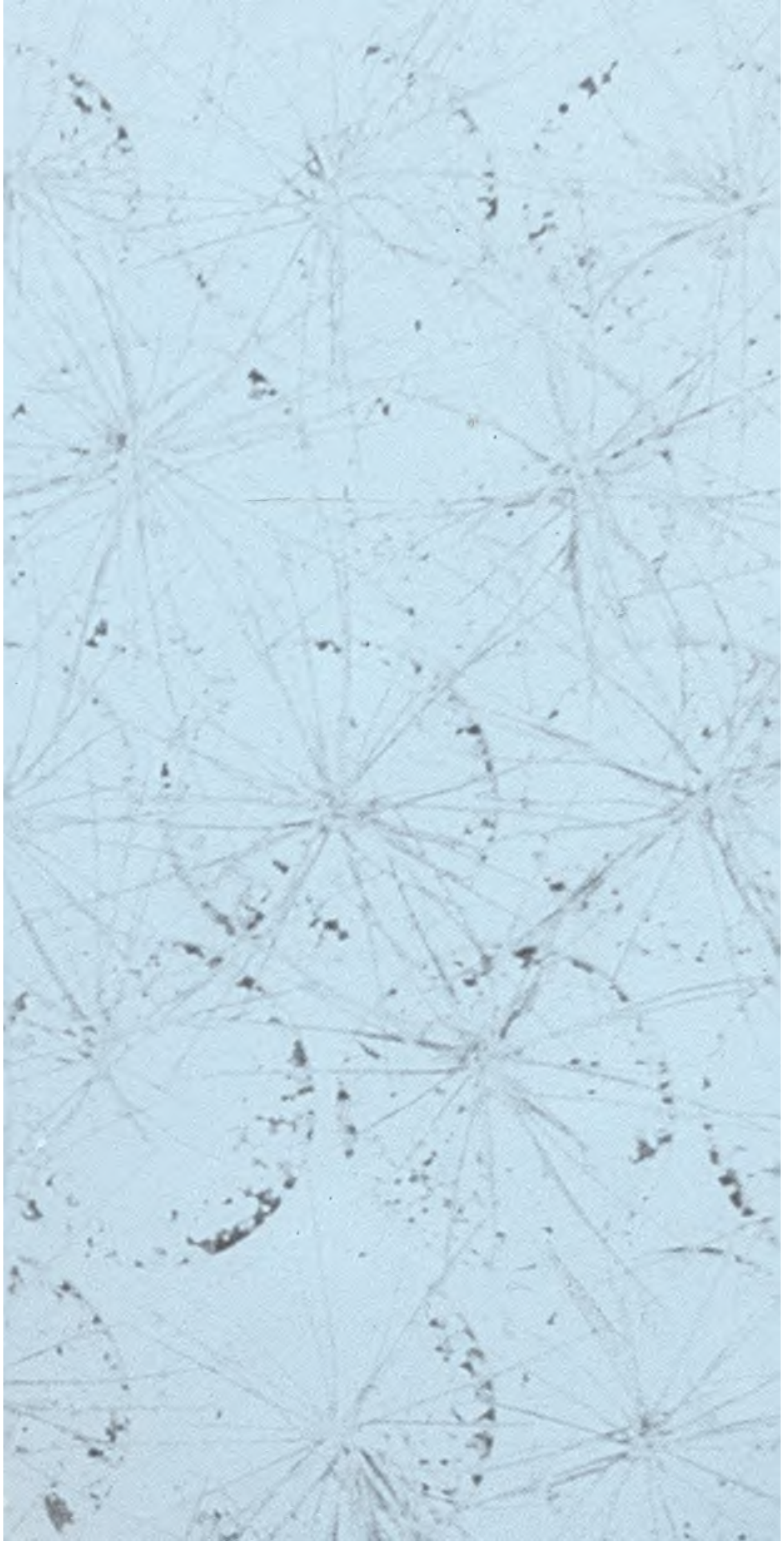
With respect to the technical aspects of rationalizing and planning container operations, Canadians have much to learn from Scandinavia. The papers and exhibits presented by the Scandinavian delegates illustrate the sophistication of attempts to improve all aspects of container processing and handling, including the possibilities of mechanical planting. It is to be hoped that some of these innovations can be demonstrated on a practical scale in Canada. It would be appropriate if the Canadian Forestry Service were to continue its leadership role by encouraging the introduction and demonstration of the more promising new methods. In the meantime, Canadian growers should concentrate on means of maximizing crop quality within the limits of currently available containers.

Field trials provide the basis for judging the merits of various classes of planting stock. Trials have been established long enough now that they have earned a degree of credibility. However, many of the earlier experiments were established with stock that would now be considered completely inadequate in size and quality. In some of the papers presented, investigators are still attempting to compare non-comparable nursery products--a practice akin to comparing apples with oranges. Two new classes of trials and appraisals are now common. First, there are those trials concerned with matching stock quality with site quality and condition, including improved methods of site description. The results of these investigations will represent a step forward in defining future regeneration prescriptions. Second, appraisals are now being undertaken that use as an information base large numbers of operational plantations rather than a few carefully controlled experimental plots. With this type of appraisal, results reflect the full impact of the operational process. Similar appraisals need to be instituted whenever container seedling production is introduced so that any problems can be identified and corrected quickly. Without ongoing operational appraisal, planting practice can atrophy long before a planting system is optimized.

Whereas reports of field performance are plentiful, cost appraisals of various planting systems are notably lacking. Tunner presents a useful methodology for comparing options and presumably his illustrative examples reflect realistic costs in British Columbia. But where are the hard cost data for other Canadian programs? The organizers of this meeting were unable to elicit other specific contributions on capital and operating costs, let alone economic analyses. This is a curious phenomenon. We meet to ascertain the advantages of one planting system over another, and yet half of the effectiveness equation is missing.

Mechanization of the planting process has always been considered the principal potential advantage of containerization. Walters is consistent in reaffirming that planting should be precisely mechanized, and that a rigid-walled container is the best-suited to this purpose. Sutherland and Heikurinen outline some of the problems facing machine design and the practical difficulties of machine planting. But even if progress in mechanical planting is slow, Canadian container programs would not have reached their present stage of operational readiness without Walters' enthusiasm and dedication. It should not be forgotten that several important features of container design and cultural practice were learned from early trials of his rigid bullet container.

As Armson has noted, now that more industrial and private growers are being permitted to participate in planting stock production, the base of nursery expertise is being broadened and diversified. Excellence --and incompetence--should become evident quickly, as the masking influences of a few state enterprises are stripped away. If the expertise base is broadened, more frequent opportunities for technology transfer will be needed. This symposium marks the arrival of containerization at a new plateau of respectability and acceptability. Perhaps this should be the last Canadian meeting devoted exclusively to containerized seedling production. It is time to integrate container seedling production with bare-root production. Although the techniques may differ, the goal of both systems is to produce stock that will yield biologically and economically viable plantations. Container transplants represent a hybrid form of planting stock that is becoming popular and useful in the west. Rather than competing with each other the two systems can reinforce and complement one another. Similarly, bare-root and container nurserymen should complement, rather than compete with each other. More regional integrated stock production meetings will ensure that both systems are a boon to reforestation.



PLANT SYSTEM 80:

BACKGROUND, SHORT DESCRIPTION, PLANS

Ove Andreason[1]

Stora Kopparberg-Bergvik owns 800,000 ha of productive forest land in central Sweden. Over a long period of time new forests have been established through sowing and more recently by planting. Almost 25 million plants are set out each year. In 1970 we changed from bare-root plants to container plants (Japanese paperpots and some multipots). Stora Kopparberg-Bergvik now has more than 10 years' experience in using container-grown plants.

On the basis of this experience we have found that today's container systems have the following drawbacks:

- Roots are guided to the bottom of the container. This is disadvantageous to the establishment of seedlings after planting and is a problem with spruce particularly.

- The systems do not allow an accurate sorting of plants before delivery to the forest.

- The plant packages delivered to the forest are either too large or too heavy and therefore difficult to handle, or call for return transport.

- Because of the heaviness of existing systems plant production costs have soared during the last few years.

Since 1978, when it became clear that we could neither come to terms with these drawbacks nor find a better system on the market, we have concentrated on developing our own system (Fig. 1) which is distinguished by the following :

- Containers allow the roots to grow at all horizontal levels. Most roots are pruned by the air space between the containers. In case of roots bridging the air space, automatic root pruning will be carried out at the nursery. Equipment for root pruning is under development.

- It is possible to sort plants, even as seedlings, thus avoiding too many empty containers during the nursery period. A machine that "senses" seedlings and rejects empty containers has been tested. It must he supplemented by equipment for transplanting seedlings into the empty containers.

- Containers are joined together to form easily handled units for circulation within the nursery only. These units allow automatic filling, sowing, sorting and packing.

  A peat filling machine, a sowing machine and pallets for air pruning and transportation within the nursery have all been used and tested. Automatic systems for predelivery sorting of seedlings and packing into cardboard boxes are also being developed.

- The plant packages are easy to handle for manual planting and can be adapted to automatic planting. For manual planting special cardboard boxes are used.

Present production costs at the nursery are estimated to be the same as for paperpot seedlings, but should drop after a few years. The system is estimated to bring about lower costs for transportation to the forest and for planting.

Figure 1. Pine seedlings grown in Plant System 80 containers.

---

[1] Chief Forester, Stora Kopparberg-Bergvik, Falun, Sweden.

THE NEW GENERATION OF CONTAINERS:

MICRO CONTAINERS

F. Wiesinger[1]

Black spruce *(Picea mariana* [Mill.] B.S.P.) seedlings are raised in micro containers (5 mm x 5 mm x 40 mm - WELLAIR MAGAZINE) filled with special peat. The seedlings survive at densities of up to 25,000/m^2 without significant pest or disease problems, under a specific watering and fertilizing regime. A first tier of roots is evident following airpruning in the magazine when the seedlings are 30 days old.

The seedlings are then transplanted horizontally into larger containers (25 mm x 25 mm x 75 mm - WELLAIR BACKBONE GRID) at age 60-90 days when they are 50 mm tall. The roots are airpruned again in the Grid, and this results in a second root tier. Both Magazine and Backbone enable mechanical side ejection--without dismantling the plug--during transplanting and outplanting, thereby enhancing seedling regeneration potential.

The economic, biological and mechanical advantages of the magazine and backbone grid system are:

1. Space and energy savings: A greenhouse with dimensions of 7.3 x 3.7 m (Wiesinger design) accommodates up to 500,000 magazine seedlings.

2. More crops at less cost: Crop rotation between magazine house and nursery. Plug + 1 can be outplanted into bare-root field or shadehouse shortly after transplanting from magazine to backbone grid.

3. Precision seeding and mechanical transplanting with minimization of transplant shock.

4. Mycorrhizal inoculation during transplanting is unique to this system.

5. Interplanting using magazine seedlings increases production by 30%. Expensive greenhouse space may be fully stocked.

6. Elimination of thinning out--no root spiralling--side ejection of plug.

7. Increased field survival: Transplanting a short airpruned seedling to a deeper container increases the number of upper roots and plug firmness. Root growth after early airpruning produces a well branched root system that forms a knitting network throughout the soil as well as a distinct second root tier. This could result in better field performance.

Figure 1. A green carpet of black spruce seedlings. Each tray contains 11,000 potential seedlings. Easy handling, complete control in compact space. Micro containers meet demands for increased production.

---

[1] President, Wiesinger Systems Ltd., Winnipeg, Manitoba.

CONTAINER SEEDLING PRODUCTION IN BRITISH COLUMBIA

N.E. Sjoberg and R.D. Hagell

The styroblock system was developed cooperatively by the Canadian Forestry Service, British Columbia Ministry of Forests, and the University of British Columbia, after experimentation and testing of other systems. Approximately 185 million container seedlings have been grown in British Columbia since 1970. Plans call for an increase in government container production to 50 million seedlings annually by 1985. Private production will increase from 20 million seedlings in 1981 to 45 million seedlings annually in 1985.

In most British Columbia nurseries the styroblock-2A and -4A are the standard containers. Both have four vertical ribs down the cavity walls to prevent root spiralling. The cavity design directs roots to the bottom drain hole and, with good air circulation, the emerging root tips dry and air prune. This not only discourages root spiralling, but promotes the lateral root growth necessary for developing a firm root plug.

Growing facilities in the coastal and continental regions of the province utilize different levels of environmental control. They range from steel-framed fibreglass greenhouses with automatic heating, ventilation and cooling, to shadeframes, which use woven plastic fabric to provide 20-46% shade.

Most facilities have an asphalt base for ease of cleaning and movement of stock.

A 3:1 (v:v) peat/vermiculite growing medium is used with dolomitic lime added to raise the pH and provide a source of calcium and magnesium. After filling the containers and sowing, the seed is covered with a thin layer of coarse sand with particle sizes ranging from 2-4 mm.

Nutrients are applied by incorporating slow-release fertilizers into the growing medium, by injecting soluble fertilizers into the irrigation water, or by both methods.

Where a slow-release fertilizer is used, Osmocote 18-6-12 is added at the rate of 5.85 kg/m^3 of growing medium. Frit 503 trace elements are also added at the rate of 0.13 kg/m.^{3}.

Soluble fertilizers are injected directly into the irrigation water 3 or 4 times per week. Nutrient schedules are specific to species, growing facility and locality, but generally begin with a high phosphorous fertilizer (10-52-17 at 625 g/kL of irrigation water), followed by a balanced fertilizer containing trace elements (20-20-20 at 625 g/kL). After adequate height growth is achieved 10-52-17 is again used to maintain root growth. Problems with lime-induced chlorosis have been eliminated by bi-weekly applications of ferrous sulphate (heptahydrate at 150 g/kL).

A travelling irrigation boom is used in all greenhouses to achieve precise distribution of water, fertilizers and other chemicals, and to provide a transportation vehicle for the supplementary lights. All are controlled electronically and can be operated at different speeds to satisfy various cultural functions. In shadeframes, water and fertilizers are applied through fixed irrigation systems.

For dormancy prevention, interruption of the dark period is provided by low-intensity light from sodium-vapor lamps mounted on the irrigation booms (2 minutes every half-hour).

Seedlings are extracted manually from the styroblocks and are repackaged for storage or direct shipment to the planting site. A commercial wrapping machine is used to package 25-seedling bundles with plastic film. The bundles are then placed vertically in waxed cardboard shipping cartons.

Extraction and packaging may reach 12,000 seedlings/man/day. After extraction the styroblocks are washed for reuse in a machine with revolving brushes. The blocks are disinfected by dipping them into a potassium coconate soap solution.

'Container Development Officer and Technician, respectively, Silviculture Branch, Ministry of Forests, Victoria, B.C.

SOME ASPECTS OF FERTILIZATION USING CONTAINERIZED WHITE SPRUCE SEEDLINGS

A. Gonzalez[1]

The purpose of this experiment was to establish the nutrient content in the substrate and foliage associated with satisfactory development of containerized white spruce *(Picea glauca* [Moench] Voss) seedlings. Experimental details were: **Seedling quantity**: 924 (540 Quebec tube, 115 cm^3; 384 Rootrainer Hillson, 183 cm^3); **Environment**: plastic greenhouse; **Duration**: 24 wk (sown 12 Feb.; fertilization 17 March to 18 Aug.); **Irrigation/fertilization**: dilutor adapted to automatic boom system; **Fertilization regime**: 7 wk 20-20-20, 7 wk 15-30-15, leached 1 wk, 8 wk 0-10-25; **Growing medium**: sphagnum peat moss; **Measurements and analysis** (weekly: fertilizer:pH, conductivity and volume; seedling/growing medium:N, P, K; plant shoot and root lengths.)

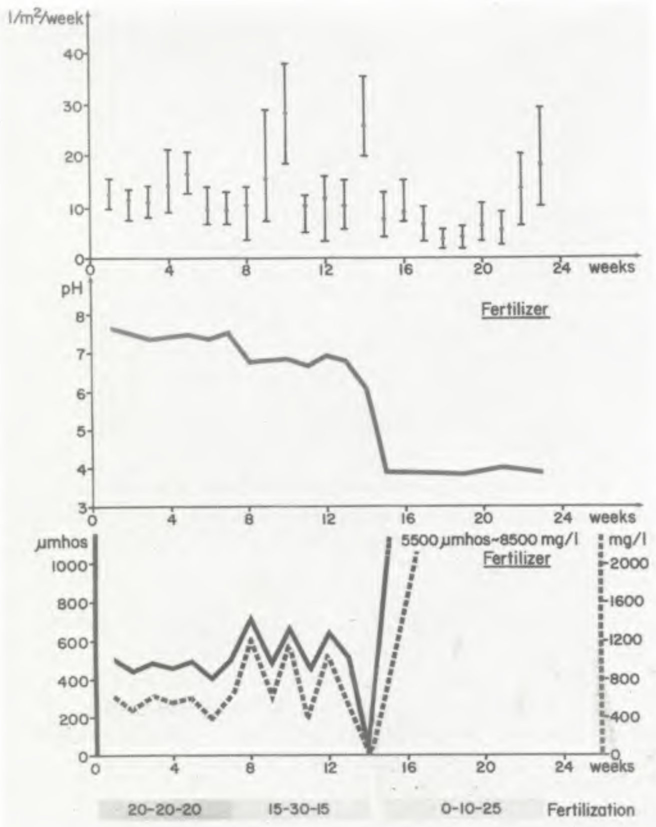


Figure 1. Some characteristics of the fertilization regime.

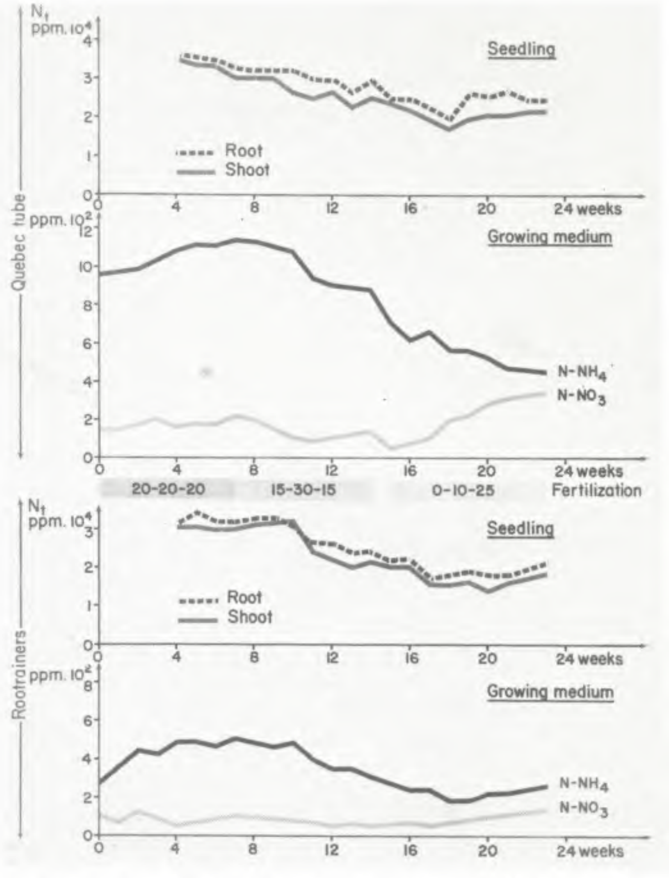


Figure 2. Nitrogen forms in seedlings and growing medium.

Despite fluctuations in fertilization (Fig. 1), which were more perceptible after analysis of the growing medium than of the foliage, the general appearance of the seedlings was very satisfactory. Growth was similar in both containers, although the root system appeared larger in the "Rootrainers". Nitrogen content decreased gradually in the foliage, showing a stabilization trend (2.10^4 ppm) after 16 weeks. Ammonium and nitrate diminished with time in the growing medium (Fig. 2). A gradual accumulation of P (6-8.10^2 ppm) and K (2-3.10^3 ppm) was observed in the peat medium. In view of the quality of seedlings produced it can be concluded that they can tolerate appreciable changes in the nutrient and water regime without normal development being affected.

This experiment was carried out within Dr. A. Corriveau's genetics project.

---

[1] Research Scientist, Laurentian Forest Research Centre, Canadian Forestry Service, Ste-Foy, Quebec.

THE SHOOT GROWTH HABIT PECULIAR TO SECOND-YEAR PINE SEEDLINGS

S.J. Colombo[1]

Shoot elongation in rising two-year-old pine seedlings is accomplished mainly by the extension of stem internodes below the terminal bud, rather than by bud flushing. This unique mode of shoot elongation, described by Thompson (1976), was studied using one-year-old overwintered jack pine *(Pinus banksiana* Lamb.) Japanese paperpot seedlings, placed in a greenhouse (16-hr day, 17 to 26 °C) where shoot elongation was observed daily.

The overwintering shoot of one-year-old jack pine seedlings consisted of a closely spaced cluster of primary needles below the terminal bud, each subtended by an easily seen axillary bud. This cluster of needles is known as the rosette. Axillary buds were also present in the axils of the budscales of the terminal bud. In the fall the appearance of large axillary buds in the rosette was the first visible sign that height growth was slowing down in preparation for overwintering. This was usually followed by the formation of terminal buds with visible brown budscales. However, when buds were not visible, dissection of the shoot tip revealed the presence of succulent green budscales in all instances.

The entire first-year overwintering shoot is analogous in structure to the terminal buds of older trees, with primary needles in the seedlings being equivalent structures to budscales in older trees (compare Fig. 1 in Cannell and Willett, 1975 to Fig. 4 in Thompson, 1976). Axillary buds are initiated in the axils of primary needles of the rosette of first-year seedlings and of budscales in older trees. Terminal budscales are present at the tip of both structures (Fig. 1).

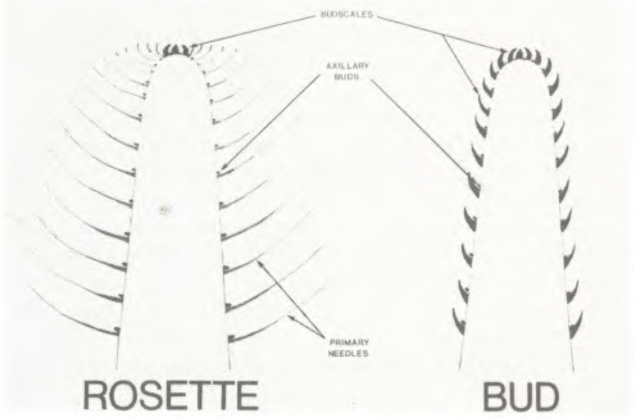


Figure 1. Structure of the rosette in one-year-old seedlings and terminal buds of older trees.

Shoot growth in the rising 2-0 year began with the extension of internodes between primary needles at the base of the rosette. As internode elongation spread from the base to the top of the rosette, buds in the axils of primary needles in the rosette swelled during the first week and flushed in the second week, resulting in the development of fascicle shoots. Activity from the third week on consisted mostly of the elongation of fascicle shoots, to form secondary needles, with negligible increases in height.

During the second and third weeks, terminal buds began to elongate and axillary buds present at the base of budscales flushed and developed into fascicle shoots. The contribution to total height growth by the rosette was approximately nine times greater than the height growth resulting from the extension of the terminal bud.

Cannell, M.G.R. and Willet, S.C.
1975. Rates and times at which needles are initiated in buds on differing provenances of *Pinus contorta* and *Picea sitchensis* in Scotland.Can. J. For. Res. 5:367-380.

Thompson, S.
1976. Some observations on the shoot growth of pine seedlings. Can. *J.* For. Res. 6:341-347.

---

[1] Research Scientist, Ontario Tree Improvement and Forest Biomass Institute, Ministry of Natural Resources, Maple, Ontario.

CONDITIONING, OVERWINTERING AND FROST EFFECT IN MULTI-CROP CONTAINER PRODUCTION

Harry Zalasky[1]

Multi-crop container seedlings of lodgepole pine *(Pinus contorta* Dougl. var. *latifolia* Engelm.) and white spruce *(Picea glauca* [Moench] Voss) that are grown for a relatively short time in the greenhouse, followed by outside rearing, are difficult to winter in prime condition without frost damage and substantial loss. The alternative method would be to rear up to three crops of seedlings in greenhouses for 10 to 14 weeks using fertilizer and irrigation schedules published by Carlson (1979), and then condition them in greenhouses until 20 weeks old by providing automatic blackout screens for 8-hr day length and 10°C constant temperature and by concurrently reducing fertilizer and irrigation requirements. Ample field storage sheds with R40 fiberglass batt insulation should be provided for winter storage to maintain stable inside temperature of 0° to -2°C when outdoor temperatures are 15° to −30°C or lower. The storage space should be cooled by overnight venting during the last week of October or first week of November, then sealed when the hygrothermograph stabilizes at -1°C. Removal from the greenhouse and storage of the conditioned trees should begin about 7 November, and all seedlings should be in place by 7 December. Seedlings of pine and spruce require no light or water for the duration of field storage to maintain the container stock in prime condition till spring planting. Survival in the first season of outplanting should be 95%, with site conditions accounting for not more than 5% subsequent loss.

Soundness (health) of the roots and shoots of planting stock outweigh size as a factor in survival and growth in the Prairie Region. In the short seasons of the northern latitudes the seedlings must respond quickly to establish a normal growth rhythm essential for tree survival. Stock which is frost damaged during outside storage can be expected to suffer relatively high mortality after planting. The survivors are often too weak to withstand cold soils, frost heave, lack of moisture or high temperatures. Survivors also have delayed and irregular patterns of phenology in bud flushing, cambial repair, foliation, and root and shoot development (Fig. 1 and 2). As a result of irregular recovery patterns, damaged stock requires several years to recover and resume a normal phenological rhythm.

Carlson, L.W.
1979. Guidelines for rearing containerized conifer seedlings in the Prairie Provinces. Dep. Environ., Can. For. Serv., Edmonton, Alta. Inf. Rep. NOR-X-214. 62 p.

Figure 1. Outplanted frost-damaged lodgepole pine showing, left to right, unsatisfactory and satisfactory rehabilitation.

Figure 2. Frost-damaged white spruce seedlings showing similar effects on vigor but with greater variation from left to right.

---

[1] Research Scientist, Northern Forest Research Centre, Canadian Forestry Service, Edmonton, Alberta.

CONTAINERS USED FOR TREE GENETICS AND BREEDING

C.W. Yeatman, T.C. Nieman, Z. Zdrazill

ADVANTAGES OF CONTAINERS

The use of containers permits:

- optimal yields from scarce and expensive seed;
- easy, error-free application of statistical designs;
- precise labelling and identification of up to several hundreds of seedlots and many thousands of seedlings from sowing to field planting (Fig. 1);
- provision of uniform and optimal cultural environments for both root and shoot;
- ease of plant replacement, rearrangement or rejection (Fig. 2);
- stock portability with no root disturbance and minimal top damage;
- rapid seedling growth with consequent reduction in time to reach specified size for field planting;
- ease of storage, e.g., in a refrigerated room to maintain dormancy;
- economy, accuracy and effectiveness in field establishment of complex test plantations and seedling seed orchards.

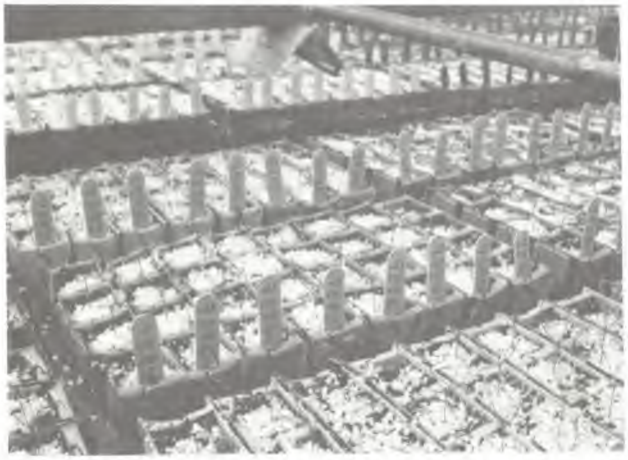


Figure 1. Precise labelling of many seedlots is made easier by the use of containers.

DISADVANTAGES OF CONTAINERS

- root penetration from cell to cell in paperpots and peat pots when grown too long;
- container breakdown, and inflexibility with number and arrangement in paperpots;
- in certain soils paperpots maintain their integrity long after planting, and this may result in root deformation;
- smooth-walled, round plastic containers induce unsatisfactory root systems;
- styrofoam containers permit root penetration and make it difficult to extract the plant from the container;
- precautions must be taken to prevent rodent damage to overwintering stock.

CONTAINER PREFERENCE

The containers routinely used at Petawawa are sharply ridged with good basal drainage that induces good air-pruning of the root ends. They range from sets of five cavities to single 15-cm square plastic pots. The size used depends on the species, the duration of culture in the containers, the required size of plant and the purpose for which it is grown. Spencer-Lemaire "Rootrainers" suit most purposes very well in the raising of stock for progeny tests and for seedling seed orchards. Larger single pots are preferred for growing root stock plants for grafting.

Figure 2. Transferring plugs to ensure complete stocking.

---

[1] Project Leader, Plantation Supervisor and Nursery Supervisor, respectively, Tree Genetics and Breeding Project, Petawawa National Forestry Institute, Canadian Forestry Service, Chalk River, Ontario.

PELLETED SEED: PROS AND CONS

M.J. Adams'

This poster dealt with the influence of various pelleting methods on the germination of black spruce *(Picea mariana [Mill.]* B.S.P.) and jack pine *(Pinus banksiana* Lamb.) seeds, and discussed some of the advantages and disadvantages of pelleted seed.

Germination of various experimental and commercially available pellet types was compared to that of untreated black spruce seed under optimum incubator conditions at 21 °C. The Moran pellet, produced in California, gave the best results and is probably the most readily available commercially produced pellet. All other pellet types had comparable results after 28 days, except for FMC encapsulation which severely reduced germination, viz:

Type of pellet	Mean cumulative germination percent at 7 and 28 days from sowing	
	7 days	28 days
Untreated control	92	99
Moran	23	98
Asgrow	3	96
Cornell	0	97
GLFRC	0	94
FMC	0	52

The main advantage of pelleted seed is in its ease of handling. Its uniform size and shape make it well suited for vacuum seeding of container stock and eliminate the problem of missing or multiple seeds. Because the size of the pellet can be altered to match the calibration required, accuracy in direct seeding can also be greatly increased. The increased weight of the pellet compared to that of naked seed makes aerial seeding under higher wind velocities more feasible with less chance of drift.

Additives to the seed coat are still at the experimental stage. The Asgrow Seed Company is able to incorporate several additives into its coating medium (e.g., fungicides, herbicides, fertilizers and rodenticides) which will protect or enhance germination and development. Experimental work aimed at delaying germination to facilitate later summer seeding is now under way. This involves plasticizing the pellet, thereby making it impermeable to moisture but subject to fission by frost during the winter, allowing germination the following spring. Storage had no toxic effects on Moran coated black spruce seed after a three-year storage period.

However, pelleting does have a significantly adverse effect on the rate of germination at the extreme cardinal temperatures of 10 °C and 32 °C. This may severely hamper its potential for direct seeding since field conditions are rarely optimal, but it should not interfere with greenhouse production where optimum temperatures are maintained.

Another disadvantage is additional cost. The present cost of pelleting one million black spruce seeds with the Moran coat is $150.00.

A major disadvantage of pelleting is its poor germination response with species other than black spruce, e.g., jack pine, red pine *(Pinus resinosa* Ait.) and white spruce *(Picea glauca* [Moench] Voss). These species are not recommended for pelleting unless a watering regime is adopted which will remove the pellet coat soon after sowing and reduce any inhibiting effects on germination.

It is concluded that Moran coat pelleting of black spruce seed is an acceptable practice without any adverse effect on germination where optimum conditions can be maintained. It also warrants serious consideration in direct seeding if the potential advantages outweigh the likelihood of delayed and/or depressed germination and if provision is made to counteract these adverse effects.

---

[1] Silviculture technologist, Great Lakes Forest Research Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario.

DROUGHT TOLERANCE AND PHYSIOLOGICAL MECHANISMS OF DROUGHT RESISTANCE IN THREE NORTHERN CONIFERS

G.F. Buxton,[1] D.R. Cyr,[1] E.B. Dumbroff[1]

In order to maintain a sustained yield of commercially valuable wood from its forest lands, the province of Ontario supports an active program of production and outplanting of forest tree seedlings. Significant numbers of these seedlings are lost each year from various causes including insects, disease, fire, animal damage and drought. Moisture stress (i.e., any intensity of drought) may account for greater losses in growth and survival than all other factors combined. Although cultural prescriptions necessary to reduce these losses are urgently needed, their development has been delayed by a lack of basic information concerning the morphological and, particularly, the physiological characteristics that convey drought tolerance to newly outplanted seedlings. The present investigations have been designed to define, evaluate and compare the physiological mechanisms by which seedlings of black spruce *(Picea mariana [Mill.]* B.S.P.), white spruce *(Picea glauca* [Moench] Voss) and jack pine *(Pinus banksiana* Lamb.) respond to various intensities of moisture stress. Data derived from this work should provide the kind of information necessary to develop practical hardening procedures that will induce the physiological states most conducive to seedling survival following outplanting.

Seedlings are grown in liquid culture and moisture stress is routinely imposed by adjusting the osmotic potential of the nutrient solutions to specific values by additions of various quantities of polyethylene glycol 6000 (PEG 6000) (Michel and Kaufmann 1973). Future tests will compare the PEG method with the use of balanced, high-salt solutions in liquid culture (Cooper and Dumbroff 1973) and exposure of seedlings to alternate cycles of wetting and drying in sand cultures.

Although analyses of samples from our first formal study are still in progress, many preliminary results have been obtained. Shoot growth of the three species was reduced by approximately 70% of that of the controls when root systems were exposed to an osmotic stress of -400 kPa, and growth all but ceased during exposure to osmotic potentials of -1200 kPa. In contrast, root growth was stimulated under conditions of mild stress (-200 to -400 kPa) and this suggests the presence of drought avoidance mechanisms in all three conifers.

Water potentials and osmotic potentials decreased with stress, but pressure potentials (measured with a pressure bomb) showed little change from their initial values by the end of the 7-day stress period.

Transpiration rates in black spruce and white spruce fell during osmotic stress at -400 kPa but recovered quickly following stress relief. A similar response in jack pine did not occur until the seedlings were exposed to osmotic potentials of -800 kPa or less. Transpiration rates failed to recover in any of the species during the 72 hr of stress relief that followed exposure to -1200 kPa of osmotic stress.

Biochemical analyses include measurement of chlorophyll, chlorophyll stability, starch, soluble carbohydrate, total nitrogen, protein, total free amino acids and proline. Although most of this work remains to be done, there are strong indications that starch and proline levels increase in the spruces during stress and that total free amino nitrogen increases in jack pine. Little change was noted in the levels of soluble carbohydrate in any of the species.

Cooper, A.W. and Dumbroff, E.B.
1973. Plant adjustment to osmotic stress in balanced mineral-nutrient media. Can. J. Bot. 51:763-773.

Michel, B.E., and M.R. Kaufmann.
1973. The osmotic potential of polyethylene glycol 6000. Plant Physiol. 51:914-916.

---

[1] Department of Biology, University of Waterloo, Waterloo, Ontario.

PERFORMANCE OF CONTAINER-GROWN AND BARE-ROOT JACK PINE THREE YEARS AFTER OUTPLANTING ON A NORTHERN ONTARIO CUTOVER

C. Glerum and J. Paterson[1]

During the spring of 1979 an outplanting was conducted in Makawa Township (Let. N. 48° 36', Long. 83° 55') to study early growth and establishment of jack pine *(Pines banksiana* Lamb.) bare-root and container-grown nursery stock. The planting site previously supported jack pine and black spruce *(Picea mariana* [Mill.] B.S.P.) and was logged in 1977, prescribed burned and T.T.S. disc trenched during the spring and summer of 1978. The soil is stone-free, fine to medium sand, and shallow to deep over bedrock with a pH of 4.7 to 5.4.

One dry and one fresh site were selected and planted, in late May, with three stock types: 1) 2-0 bare-root, 2) overwintered FH 408 Japanese paperpots (70 cm^3) and 3) Spencer-Lemaire "Rootrainers" (40 cm^3). In addition, three successive plantings were established at 2-week intervals on the dry site with the third and fourth containing one additional stock type, i.e., spring-sown FH 408 Japanese paperpots. Thus the first and second planting contained bare-root and overwintered stock types and the third planting contained all stock types, while the fourth contained only spring-sown stock. The bare-root and overwintered container-grown stock were placed in cool storage (1°C) to prevent bud flush until time of planting whereas the spring-sown stock was stored on site until planted. All plantings conformed to a randomized block design with five replications of 35 trees each in the first planting, and 50 trees each in subsequent plantings.

Although the poster display outlined growth responses in relation to soil moisture, stock types and time of planting in some detail, only third year survival and average height data are summarized here.

The data demonstrate that: 1) survival of bare-root stock is significantly less than that of container stock on both sites; 2) initial height differences between bare-root and container-grown stock at time of planting remained significant on the dry site but were nonsignificant after the third growing season on the fresh site; 3) site differences have a significant effect on total height of container stock but this difference became noticeable only during the third growing season.

	Dry site		Fresh site	
Stock type	Survival %	Height cm	Survival %	Height cm
Bare-root	81a[a]	67.3a	73a	66.8
Overwintered paperpots	98b	59.0b*	99b	63.7*
Overwintered "Rootrainers"	98b	58.0b*	97b	66.4*

[a] Figures in columns not followed by the same letter and figures in rows marked with an asterisk differ significantly at the 99% level.

Another observation was that planting delays did not have a significant effect on survival. However, total height and height increment for all stock types showed a significant reduction between the plantings of 31 May and 27 June. Furthermore, survival differences between overwintered and spring-sown stock were not significant. The spring-sown stock did not increase significantly in height during its first year after outplanting. Its height increment in the second and third year after outplanting was similar to the first and second year height increment of the overwintered stock. Therefore, plantations established with spring-sown stock can be expected to have a one-year lag in growth in comparison with overwintered stock planted in the same year.

---

[1] Research Scientist and Forest Technician, respectively, Ontario Tree Improvement and Forest Biomass Institute, Ontario Ministry of Natural Resources, Maple, Ontario.

COMPARISONS OF CONTAINER SEEDLING PLANTING WITH OTHER METHODS OF REFORESTATION IN NEWFOUNDLAND USING BLACK SPRUCE

J. Richardson[1]

A major reforestation program focusing on black spruce *(Picea mariana [Mill.]* B.S.P.) is beginning to gain momentum in Newfoundland. It is planned to increase production from the 500,000 seedlings planted in 1979 to 19 million seedlings by 1985. To date the program has involved the use of several types of containerized seedling as well as different types of bare-root stock and direct seeding.

To determine which reforestation method will give the best survival and performance under the varied site conditions encountered in Newfoundland, a series of comparative trials is being established. These all employ the same Latin Square design. They have the immediate objective of comparing the performance of container seedling stock, bare-root planting stock and direct seeding on a variety of reforestation sites using black spruce. Three trials have been established by the Newfoundland Department of Forest Resources and Lands and one by Abitibi-Price, Grand Falls. All four are on burned cutover sites of either wildfire or prescribed burn origin; three are in central Newfoundland and one is in western Newfoundland. Design, analysis, reporting and overall coordination are carried out by the Newfoundland Forest Research Centre. Plot layout, establishment and measurements are undertaken by the cooperators on their respective trials.

Each trial has five treatments, replicated five times, as follows:

A. Department of Forest Resources and Lands trials:
   1. Spencer-Lemaire overwintered stock - 55 cm^3 containers
   2. 2-1 bare-root stock
   3. 2-2 bare-root stock
   4. Direct seeding funnels - 3 seeds/funnel
   5. Direct seeding cones - 5 seeds/cone

B. Abitibi-Price trial:
   1. Spencer-Lemaire overwintered stock - 55 cm^3 containers
   2. 2-1 bare-root stock
   3. 2-2 bare-root stock
   4. Multipot seedlings - 55 cm^3 containers
   5. Paperpot seedlings - FH 408 containers

There are 25 seedlings (or seeded spots) per plot, at approximately 2 m spacing. Each trial occupies 0.25 ha. Seedlings of each type were selected carefully as being 'aver-. age' for the production run, but were also rigorously culled for uniformity. They were handled and planted with care by standard techniques--Wistfa hoes or planting spades for bare-root, Pottiputkis for containers. Planting was carried out in June 1981, and seeding treatments will be applied in fall 1981.

Average dimensions, at time of planting, of the stock included in the Abitibi-Price trial were as follows:

Seedling type	Shoot height (cm)	Root collar diam. (mm)	Shoot:root ratio (dry wt)
Spencer-Lemaire	11.4	1.5	3.1:1
2-1 bare-root	22.7	4.3	2.1:1
2-2 bare-root	26.7	4.9	1.5:1
Multipot	11.3	1.5	2.0:1
Paperpot	8.5	1.7	0.8:1

Survival, height and condition of all seedlings will be recorded in the fall of each year for at least five years. One seedling per plot will be removed at each remeasurement to determine root growth, dry weight, etc. Direct seeding treatments will be evaluated on the basis of stocked spots (one stocked spot is considered equivalent to one planted seedling) and growth.

---

[1] Research Scientist, Newfoundland Forest Research Centre, Canadian Forestry Service, St. John's, Nfld.

FIELD EVALUATION OF CONTAINER-GROWN NORTHERN RED OAK

P.E. Pope[1]

Planting seedlings as a method of artificial regeneration has been largely unsuccessful with red oak *(Quercus rubra* L.) because of poor survival and early growth. Seedlings grown in individual containers and inoculated with specific mycorrhizal fungi are believed to experience less planting shock and to have a competitive growth advantage over bare-root seedlings produced in the conventional fashion. The objectives of this study were to determine the effect of containerization and inoculation with a specific mycorrhizal fungus on the survival and early growth of red oak seedlings.

Northern red oak seedlings were grown in a fumigated soil-peat-vermiculite rooting medium in 8 x 8 x 26 cm plastic-coated paper containers for 16 weeks in a glasshouse under 16-hr photoperiod and day-night temperatures ranging from 30 to 20 °C. Seedlings were hardened off in February-March and planted when still dormant. Conventionally grown nursery seedlings were sown in 1978 and lifted in March 1979, four weeks prior to planting. For each method of production, the soil medium was inoculated (control not inoculated) with the equivalent of 200 ml of vegetative mycorrhizal inoculum of *Pisolithus tinctorius* at the time of seeding. Container-grown seedlings were fertilized every 14 days with 0.5 strength Hoaglands No. 2 solution; nursery-grown seedlings were fertilized according to standard nursery guidelines.

The planting site was an abandoned old field of 5-8% slope, S-E aspect and supporting old field grasses and scrub hardwood vegetation. The soil type is an eroded phase of a Zanesville silt loam (Typic Fragiudalfs) with a fragipan within 36 cm of the surface. Four 25-tree plots of each of the four treatments were planted at random. Weeds were controlled in a 0.5 m radius around each seedling with annual applications of the chemical herbicide Roundup at a rate of 3 kg ai/ha.

Survival and annual height growth were significantly influenced by the method of seedling production and mycorrhizal fungal inoculation (Table 1).

Table 1. Influence of containerization and mycorrhizal inoculation on survival and first and second year height growth increment of red oak seedlings.

	Containerized, inoculated	Containerized, not inoculated	Bare-root, inoculated	Bare-root, not inoculated
Survival (%)	100	96	96	88
Seedling height (cm)				
Initial	62.3	64.3	78.7	73.4
1st year increment	17.3a[a]	11.2b	10.5b	6.0b
2nd year increment	37.8a	16.3c	23.6b	10.1c
Total height	117.4	91.8	112.8	89.5

[a] Row values not followed by the same letter are significantly different ($\alpha = 0.05$) (Duncan's New Multiple Range test).

---

[1] Assistant Professor, Department of Forestry and Natural Resources, Purdue University, West Lafayette, Indiana.

BLACK WALNUT GROWN IN TARPAPER CONTAINERS

F.W. von Althen[1] and F.A. Prince[2]

In the autumn of 1978 black walnut *(Juglans nigra* L.) seeds were collected in Indiana, Michigan and Manitoba. Following hulling all nuts were stratified in moist sand at 0.5°C. In April, 1979 half of the nuts were sown in a nursery while the other half were sown into tarpaper containers, one nut per container, and grown in a greenhouse. The containers consisted of open-ended, tarpaper tubes 6.5 cm in diameter and 20 cm high. The growing medium was 75% peat and 25% loam without amendments. The containers were stored in Coca Cola boxes with walls 10 cm high, 28 containers per box. The seedlings were grown under an extended photoperiod of 16 hours and a temperature of approximately 18°C (night) and 28°C (day). After 6 weeks the seedlings were transferred to outdoor shadeframes for 2 weeks of conditioning. In mid-June the containerized seedlings were planted by spade into a well drained loam in a fully cultivated field near Parkhill, Ontario. At the time of outplanting the seedlings were 20 cm high and actively growing.

In April of the following year the seedlings grown in the nursery from the same seed sources as the containerized seedlings were planted by spade in alternate rows between the rows of containerized seedlings. Weed control was maintained by annual spring applications of 5.0 kg/ha of simazine and spot treatments of 2.0 kg/ha of glyphosate.

At the end of the first growing season from germination the average height of the 1-0 nursery-grown and containerized seedlings was 36 and 27 cm, respectively (Table 1). However, in the second year outplanting shock restricted the average height increment of the 1-0 seedlings to 13 cm while the containerized seedlings grew 51 cm. In the third year the 1-0 seedlings grew 63 cm while the containerized seedlings grew 83 cm.

Although the cost of production, transport and planting of containerized seedlings will probably always be greater than that of 1-0 nursery-grown seedlings, containerized seedlings might have a place in the establishment of seed orchards, progeny from plus trees or other high-value plantations.

Table 1. Height of two black walnut stock types by years from germination.

Seed source	Stock[a] type	Total height(cm) 1st year	2nd year	3rd year
Indiana	N	41	56	134
36C	C	29	87	189
Indiana	N	33	53	122
41C	C	24	84	165
Indiana	N	35	49	112
44C	C	29	86	171
Indiana	N	37	53	130
55C	C	27	89	176
Indiana	N	36	52	132
95C	C	28	84	176
Indiana	N	39	52	116
118C	C	31	90	191
Indiana	N	37	51	122
122p	C	29	77	165
Michigan	N	43	52	99
Jackson Co.	C	22	72	162
Manitoba	N	20	26	43
Morden	C	23	33	54
Mean	N	36	49	112
	C	27	78	161

[a]N = nuts seeded in a nursery bed and outplanted as 1-0 seedlings.
C = nuts seeded in containers and outplanted in containers 8 weeks after seeding.

---

[1] Research Scientist, Great Lakes Forest Research Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario.

[2] Woodland owner and inventor of container, Mt. Clemens, Michigan.

JACK PINE SEEDLINGS GROWN IN QUEBEC TUBES AND OTHER CONTAINERS

Ronald M. Girouard[1]

A preliminary study of container-grown jack pine *(Pinus banksiana* Lamb.) seedlings showed that root spiralling was a problem in Quebec tubes (Fig. 1A). Seedling quality was highest in styroblock-8 and lower, but similar, in tubes and Rootrainer "Hillsons" at 4, 6 and 10 months (Fig. 1B).

In a second study, jack pine seedlings grown 4-6 months in several modifications of the Quebec tube were compared with those grown in regular tubes and styroblock-8s. Two or four cords, 1.6 mm and 4.8 mm thick, reduced but did not eliminate root spiralling when fixed to the inner surface of the tubes with smooth transparent tape (Fig. 2). Although root spiralling was least in tubes with four 4.8 mm cords, differences in thickness and two versus four cords were not always statistically significant. No significant differences in quality were found between seedlings in modified or regular tubes (Fig. 3). Plant quality of all tubed seedlings was significantly less than that of plants grown in styroblock-8s.

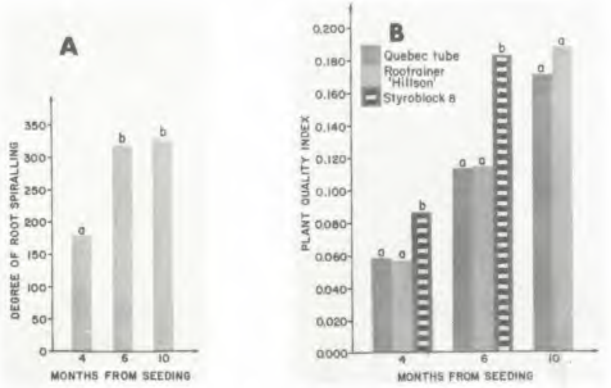


Figure 1. After 4, 6 and 10 months, (A) degree of root spiralling of seedlings grown in Quebec tubes, and (B) plant quality of seedlings grown in three container types. Mean separation by Duncan's multiple range test, 5% level.

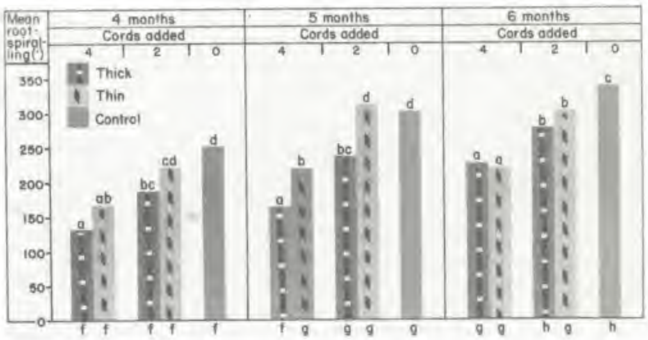


Figure 2. Degree of root spiralling of seedlings grown in modified and regular Quebec tubes. Mean separation within an age group by Duncan's multiple range test, 5% level, letters abcd; between age groups of a treatment, letters fgh.

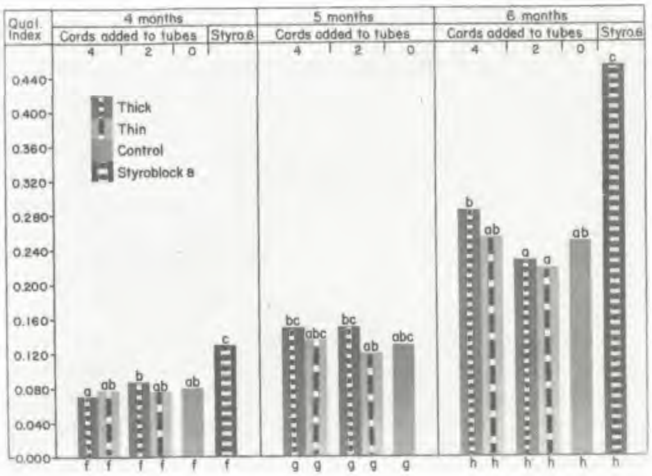


Figure 3. Plant quality of seedlings grown in modified and regular Quebec tubes and in Styroblock 8s. Mean separation within an age group by Duncan's multiple range test, 5% level, letters abc; between age groups of a treatment, letters fgh.

---

[1] Research Scientist, Laurentian Forest Research Centre, Canadian Foresty Service, Ste-Foy, Quebec.

THE ROOT STUDY BOX:

A DEVICE FOR THE EVALUATION OF ROOT DEVELOPMENT

Anders Lindström[1] and J.B. Scarratt[2]

In the evolution of container planting systems, concern has frequently been expressed that containerization might lead to potentially adverse effects upon seedling root development and the vigor and stability of the subsequent stand. Experience has shown that certain containers are more likely to induce root deformations than others. Consequently, with the continuing proliferation of container types, there are obvious benefits to be derived from any method which, in a relatively short time, can provide an indication of a seedling's probable rooting habit after planting.

To facilitate rapid evaluation and documentation of root system development, the Root Study Box was developed at the Swedish University of Agricultural Sciences, Garpenberg, based on the pinboard method for studying root habit. The version demonstrated (Fig. 1) was constructed at the Great Lakes Forest Research Centre from 6 mm acrylic plastic sheet. It consists of a 17.5 x 17.5 x 22.0 cm box, open at both ends, with holes bored in each face at 2 cm vertical and 2.5 cm horizontal spacing. Nylon fishing line (20 lb test) was threaded horizontally through the holes to produce a multi-layered network of crossed strands, which serve to support the root system *in situ* when the growing medium is washed away. A loose-fitting plywood or plastic base, with drainage holes, facilitates filling and handling of the boxes, and may be left in place during the growing period.

The Root Study Box offers the following advantages:

- it may be constructed to accommodate any size of tree or length of growing period;
- it may be used in growth chamber or greenhouse, thereby accelerating root development and avoiding the delays inherent in the conduct of rooting studies under field conditions;
- the root system, undamaged and with the original root orientation intact, is preserved in *situ;*
- it provides an early warning of the potential for root deformation, and can be used to simulate and evaluate many planting problems;
- the clear plastic walls permit a three-dimensional view of rooting habit, and provide suitable conditions for photographic documentation;
- the integral network of nylon strands facilitates quantitative assessment of rooting habit;
- seedling root systems may be preserved for future demonstration (those displayed were stabilized by soaking in ethylene glycol).

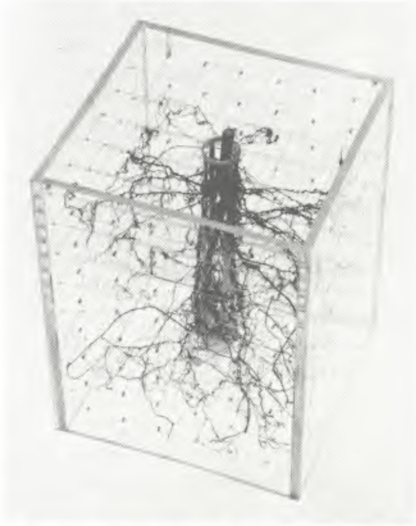


Figure 1. The Root Study Box

---

[1] Research Forester, Faculty of Forestry, Swedish University of Agricultural Sciences, Garpenberg, Sweden.

[2] Research Scientist, Great Lakes Forest Research Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario.

ROOT FORM OF JACK PINE PAPERPOT SEEDLINGS EIGHT YEARS AFTER OUTPLANTING

J.K.K. Heikurinen[1] and J.B. Scarratt[2]

More than 50 eight-year-old jack pine *(Pinus banksiana* Lamb.) trees, originally grown in FH 308 Japanese paperpots and planted near Thessalon in the Algoma District of Ontario, were excavated to investigate the effects of root deformation on seedling performance after outplanting.

The trees had been planted as part of a time study of an operational container planting operation (Scarratt and Ketcheson 1974). The planting site was characterized by weakly broken topography with deep, deltaic deposits of stone-free, medium sands, and offered easy planting conditions. Average seedling dimensions at time of planting were: shoot height - 11.8 cm; oven-dry weight - 520 mg; root: shoot ratio - 2:1. By present standards, the 16-week-old seedlings had been held too long in the FH 308 paperpots before planting, and difficulties were experienced in separating individual seedlings at the planting site because of heavy root intergrowth between the pots. Although the most severely damaged seedlings were culled before planting, all seedlings planted undoubtedly suffered some degree of root breakage during separation. Furthermore, because of the excessive root development, many of the longer seedling roots were bent or otherwise deformed during the planting operation, especially during heeling-in. Similar planting quality would not be acceptable today. The relatively severe root deformities observed were considered to be a direct result of the planting problems described.

Eight years after planting, of the 51 tree roots excavated, 88% had good vertical root development, and 67% of these also had a well developed tap root. In the horizontal plane, 14% of the trees had a multi-tiered lateral root system, whereas 53% had only a single tier of lateral roots. In both cases, roots radiated outwards from the main axis in all directions. However, the lateral roots of the remaining 33% of planted trees grew out from the main axis in a single direction only or, at best, into a narrow segment of the available rooting space as viewed from above. All seven natural trees of similar size sampled on the same site had well developed tap roots with well distributed horizontal roots.

Cross sections of the roots revealed that most of the roots originally within the confines of the paperpot had fused together, with the cambial sheath completely enveloping the formerly deformed roots. Bark and soil inclusions were present in the root ball of most trees.

There were no significant differences in height growth between the natural (225.3 cm) and containerized trees (220.5 cm) at time of sampling. Furthermore, there were no correlations between root distribution indices or root deformation indices and tree growth.

No recent mortality from any cause was evident in the plantation. Data on past mortality are lacking, and we cannot discount the possibility that seedlings with severely deformed root systems may have died in the interim as an indirect result of such deformities. However, the absence of reduced height growth or evident pathological condition in those trees sampled which exhibited root deformities leads us to conclude that the root deformations imposed during planting have had no significant effect on the growth of surviving paperpot seedlings eight years after planting.

Scarratt, J.B. and Ketcheson, D.E.
1974. Japanese paperpots for containerized planting of tree seedlings. II. Preliminary evaluation of planting tools. Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. 0-X-204. 13 p.

---

[1] Forestry Specialist, Northeastern Region, Ministry of Natural Resources, Sudbury, Ontario.

[2] Research Scientist, Great Lakes Forest Research Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario.

ROOT SYSTEM DEVELOPMENT AFTER PLANTING OF VARIOUS SCOTS PINE NURSERY STOCK TYPES

Jari Parviainen[1]

The height growth and root development of several different types of Scots pine *(Pinus sylvestris* L.) nursery stock and direct-sown seedlings were compared 7-9 years after planting or sowing in the field. The types of nursery stock compared were bare-root transplants, peat-pot seedlings (pot sizes FP-615 and FP-620), peat-pot transplants (pot size FP-522 B), paperpot seedlings (FH 408) and plastic roll seedlings (Nisula roll). At the time of planting containerized seedlings were one year old and the bare-root transplants two years old. In the case of the containerized seedlings grown in FP-615, FP-620 and FH 408 pots, any roots penetrating the container wall were pruned immediately prior to planting.

The experiment was conducted on three typical sites used for operational forestry in southern Finland, located at Varkhaus, Heinola and Vilppula. The sites were prepared by plowing, and the nursery stock was planted on the shoulders of the plow furrow. A fourth experiment was established in the nursery of the Suonenjoki Research Station, where root system development could be studied in a favorable growth environment. In all, 9600 plants were included in the study.

Survival and height growth after outplanting in the field were best for the bare-root stock. In the nursery the direct sown seedlings had the highest relative height growth. Pruning of the roots of containerized seedlings prior to outplanting did not reduce height growth in comparison with that of unpruned seedlings.

In comparison with other stock types, the bare-root stock had the highest number of plants with taproots classified as deformed. Among the containerized stock types no differences wee found in incidence of deformed root systems or in numbers of lateral roots (Parviainen 1976). No relationships were found between parameters of root development and height growth after planting. The pruning of long roots penetrating the container wall prior to outplanting was judged to be beneficial since these stock types had less deformed root systems, larger total root areas and better stability than unpruned containerized stock.

Parviainen, J.
1976. Initial development of root systems of various types of nursery stock for Scots pine. Folia For. 268:1-21.

---

[1] Head, Joensuu Research Station, Finnish Forest Research Institute, Joensuu, Finland.

APPENDIX I

REGISTRATION LIST

Alm, Prof. A.A.
University of Minnesota
Cloquet Forestry Center
175 University Road
CLOQUET, Minnesota 55720

Almy, Wm.
Western Maine Forest Nursery
36 Elm St.
FRYBURG, Maine 04037

Altmann, B.F.
Ministry of Natural Resources
P.O. Box 5080
KENORA, Ontario P9N 3X9

Andreason, Ove
Stora Kopparberg-Bergvik
Div. Skog
S-791 80 FALUN
Sweden

Armson, K.A.
Ministry of Natural Resources
Forest Resources Group
Queen's Park
TORONTO, Ontario M7A 1W3

Arnott, J.T.
Canadian Forestry Service
Pacific Forest Research Centre
506 West Burnside Road
VICTORIA, B.C. V8Z 1M5

Atherton, J.A.
E.B. Eddy Forest Products Ltd.,
ESPANOLA, Ontario POP 1C0

Attema, Al
Beaver Plastics Ltd.
12806 - 63rd Street
EDMONTON, Alberta T5A 0W2

Au, P.N.
Northwood Pulp and Timber Ltd.
P.O. Box 9000
PRINCE GEORGE, B.C.

Bailey, R.E.
Reforestation and Silviculture Branch
Department of Lands and Forests
P.O. Box 68
TRURO, Nova Scotia B2N 5B8

Ball, W.J.
Canadian Forestry Service
Northern Forest Research Centre
5320 - 122 Street
EDMONTON, Alberta T6H 3S5

Barbulescu, A.
C.R.I.Q.
333, rue Franquet
STE-FOY, P.Q. G1V 4C7

Barkhout, Peter
Canadian Greenhouses Ltd.
P.O. Box 5000
GRIMSBY, Ontario L3M 4N6

Baron, Wm. A.
Dept. of Forests & Parks
111 West St.
ESSEX JCT., Vermont 05452

Barron, D.
Canadian Pulp & Paper Association
2300 Sun Life Building
MONTREAL, P.Q. H3B 2X9

Barteaux, M.K.
Forest Management Branch
Department of Natural Resources
P.O. Box 6000
FREDERICTON, N.B. E3B 5H1

Bell, G.W.
Spruce Falls Power & Paper Co. Ltd.
P.O. Box 100
KAPUSKASING, Ontario P5N 2Y2

Bell, Scott
Great Lakes Forest Products
P.O. Box 430
THUNDER BAY, Ontario P7C 4W3

Bergstrom, Ms. L.
Lulea Smidesverkstad
Handelsvagen 9
S-951 59 LULEA
Sweden

Blood, Leon
Great Northern Paper Co.
77 Water St.
MILLINOCKET, Maine 04462

Bolduc, A.
Ministry of Natural Resources
P.O. Box 310
THESSALON, Ontario POR 1L0

Boreald, W.
True Foam Ltd.
Vanier Hwy & Doak Rd.
FREDERICTON, N.B.

Boufford, J.
Ministry of Natural Resources
Ontario Forest Research Centre
MAPLE, Ontario LOJ 1E0

Bourque, P.
Scott Paper International, Inc.
P.O. Box 549
NEW GLASGOW, Nova Scotia B2H 5E8

Bradt, L.
Ministry of Natural Resources
Dryden Tree Nursery
P.O. Box 90
WABIGOON, Ontario POV 2W0

Brodrick, M.C.A.
Ministry of Natural Resources
Thunder Bay Forest Station
R.R. #1
THUNDER BAY, Ontario P7C 4T9

Brophy, J.D.
The Ontario Paper Co. Ltd.
Allanburg Road
THOROLD, Ontario L2V 3Z5

Brown, G.
Ministry of Natural Resources
Forest Resources Group
Queen's Park
TORONTO, Ontario M7A 1W3

Brown, R.G.
B.C. Ministry of Forests
Silviculture Branch
1450 Government Street
VICTORIA, B.C. V8W 3E7

Brown, W.A.
Bowater Newfoundland Ltd.
CORNER BROOK, Newfoundland A2H 6J4

Buck, M.
Ministry of Natural Resources
6 Government Road
KAPUSKASING, Ontario P5N 2W5

Burdett, Dr. A.N.
B.C. Ministry of Forests
Research Branch
1450 Government Street
VICTORIA, B.C. V8W 3E7

Burger, D.
Ministry of Natural Resources
Ontario Forest Research Centre
MAPLE, Ontario LOJ 1E0

Burns, Ms. R.E.
Ministry of Natural Resources
Dryden Tree Nursery
P.O. Box 90
WABIGOON, Ontario POV 2W0

Burns, T.W.
Canadian Forestry Service
Maritimes Forest Research Centre
P.O. Box 4000
FREDERICTON, N.B. E3B 5P7

Butler, J.M.
Canadian Forestry Service
Newfoundland Forest Research Centre
P.O. Box 6028
ST. JOHN's, Newfoundland A1C 5X8

Calvert, Ron
Ministry of Natural Resources
60 Wilson Avenue
TIMMINS, Ontario P4N 2S7

Cameron, R.G.
Ministry of Natural Resources
P.O. Box 129
SWASTIKA, Ontario P0K 1TO

Cameron, Dr. S.I.
Canadian Forestry Service
Maritimes Forest Research Centre
P.O. Box 4000
FREDERICTON, N.B. E3B 5P7

Campbell, A.J.
Ministry of Natural Resources
Kemptville Nursery
R.R. #4
KEMPTVILLE, Ontario KOG 1JO

Canning, B.R.
Canadian Forestry Service
Great Lakes Forest Research Centre
P.O. Box 490
SAULT STE. MARIE, Ontario P6A 5M7

Carlson, Dr. L.W.
Canadian Forestry Service
Place Vincent Massey, 19th Floor
OTTAWA, Ontario K1A 1G5

Carlson, Dr. W.C.
Weyerhaeuser Company
P.O. Box 1060
HOT SPRINGS, Arkansas 71901

Carrier, V.A.
Department of Natural Resources
P.O. Box 170
BATHURST, N.B. E2A 3Z2

Cassidy, B.A.
Ministry of Natural Resources
P.O. Box 129
GOGAMA, Ontario POM IWO

Castonguay, G.
Balco Industries Ltd.
Heffley Division
R.R. #3
KAMLOOPS, B.C. V2C 5K1

Chong, B.C.
Boise Cascade Canada Ltd.
Woodlands Division
P.O. Box 5000
KENORA, Ontario

Christian, J.F.
Ministry of Natural Resources
P.O. Box 1340
ESPANOLA, Ontario POP 1C0

Clarke, Prof. R.
Faculty of Forestry
Lakehead University
THUNDER BAY, Ontario P7B 5E1

Cobb, Ms. Cheryl A.
Crown Zellerbach Forestry Research
P.O. Box 368
WILSONVILLE, Oregon 97070

Coffin, S.C.
Moosinee Paper Corporation
Pulp and Paper Division
P.O. Box 238
SOLON SPRINGS, Wisconsin 54873

Colgan, Ms. Andrea
Scott Paper Co.
Northeast Operations
WINSLOW, Maine 04902

Colombo, S.J.
Ministry of Natural Resources
Ontario Forest Research Centre
MAPLE, Ontario LOJ 1E0

Conway, J.M.
Consolidated Bathurst Inc.,
255 — 1st Street
GRAND'MERE, P.Q. G9T 5L2

Corbin, D.C.
Fraser Inc.
27 Rice St.
EDMUNSTON, N.B. E3V 1S9

Corlett, A.S.
Ministry of Natural Resources
34 Birch St.
CHAPLEAU, Ontario POM 1K0

Curtis, F.W.
Canadian Forestry Service
Great Lakes Forest Research Centre
P.O. Box 490
SAULT STE. MARIE, Ontario P6A 5M7

Czobor, C.E.
C.R.I.Q.
245 Hymus Street
POINTE—CLAIRE, P.Q. H9R 1G6

D'Aoust, Dr. A.L.
Canadian Forestry Service
Laurentian Forest Research Centre
P.O. Box 3800
STE—FOY, P.Q. G1V 4C7

Daigle, G.A.
Ministry of Natural Resources
P.O. Box 670
HEARST, Ontario POL 1NO

Dancause, A.
Min. de l'Energie et des Ressources
Service de la Restauration
200—B, Chemin Ste—Foy
QUEBEC, P.Q. G1R 3X7

Dekker, George
Canadian Greenhouses Ltd.
P.O. Box 5000
GRIMSBY, Ontario L3M 4N6

Deschenes, E.
Fraser Inc.
27 Rice St.
EDMUNSTON, N.B. E3V 1S9

de Vries, H.H.
Ministry of Natural Resources
Provincial Government Building
South Boundary Rd.
KEMPTVILLE, Ontario KOG 1J0

de Witt, J.L.
Ministry of Natural Resources
Orono Nursery
P.O. Box 119
ORONO, Ontario LOB IMO

Dionne, Maurice
J.D. Irving Ltd.
Juniper Tree Nursery
P.O. Box 150
JUNIPER, N.B. EOJ 1PO

Donaldson, J.D.
Ministry of Natural Resources
1 Richmond Blvd.
NAPANEE, Ontario K7R 3S3

Donnelly, F.P.
Industrial Forestry Service Ltd.
#101, 1595 Fifth Ave.
PRINCE GEORGE, B.C. V2L 3L9

Dupilka, A.
West Fraser Mills
P.O. Box 6000
QUESNEL, B.C. V2J 3J5

Duquette, M.R.
The James Mclaren Company Limited
BUCKINGHAM, P.Q. J8L 2X3

Duryea, Ms. M.L.
Department of Forest Science
Oregon State University
CORVALLIS, Oregon 97331

Eastman, C.
Western Maine Forest Nursery
36 Elm St.
FRYBURG, Maine 04037

Edwards, Dr. I.K.
Canadian Forestry Service
Northern Forest Research Centre
5320 — 122 Street
EDMONTON, Alberta T6H 3S5

Etheridge, Peter G.
J.D. Irving Ltd.
Sussex Tree Nursery
R.R. #4
SUSSEX, N.B. EOE 1PO

Faltonson, R.R.
Department of Forestry
Iowa State University
AMES, Iowa 50011

Fayle, Dr. D.C.F.
Ministry of Natural Resources
Ontario Forest Research Centre
MAPLE, Ontario LOJ 1E0

Fenwick, M.
World Silviculture Ltd.
R.R. #1
OLIVER, B.C. VOH 1TO

Ferguson, B.A.
Ministry of Natural Resources
P.O. Box 448
IGNACE, Ontario POT 1TO

Ford, R.D.
67 Valentine Drive
DON MILLS, Ontario M3A 3J7

Fortin, A.
Domtar Inc.
2950 Boul. Laurier
STE-FOY, P.Q. G1V 2M4

Foster, L.
Reid, Collins Inc.
12650 Northup Way
BELLEVUE, Washington 98005

Froning, K.
Canadian Forestry Service
800 - 275 Portage Ave.
WINNIPEG, Manitoba R3B 2B3

Fry, D.
Abitibi Price Inc.
P.O. Box 250
WHITE RIVER, Ontario POM 3G0

Fung, M.
Syncrude Canada Ltd.
10030 - 107 St.
EDMONTON, Alberta T5J 3E5

Gale, R.L.
Can-Am Containers Ltd.
P.O. Box 340
SPRINGHILL, Nova Scotia BOM 1X0

Genovese, G.A.
Syncrude Canada ltd.
Mail Drop 0078
P.O. Box 4009
FORT McMURRAY, Alberta T9H 3L1

Gerber, Karl
Ministry of Natural Resources
P.O. Box 129
SWASTIKA, Ontario P0K INTO

Gingrich, D.J.
Plant Products Co. Ltd.
314 Orenda Rd.
BRAMALEA, Ontario L6T 1G1

Girouard, Dr. R.M.
Canadian Forestry Service
Laurentian Forest Research Centre
P.O. Box 3800
STE-FOY, P.Q. G1V 4C7

Glen, L.M.
Reid, Collins Nurseries
P.O. Box 430
ALDERGROVE, B.C. VOX 1A0

Glerum, Dr. C.
Ontario Forest Research Centre
Ministry of Natural Resources
MAPLE, Ontario LOJ 1E0

Gonzalez, Dr. A.
Canadian Forestry Service
Laurentian Forest Research Centre
P.O. Box 3800
STE-FOY, P.Q. G1V 4C7

Graham, H.D.
College of Applied Arts & Technology
P.O. Box 60
SAULT STE. MARIE, Ontario P6A 5L3

Grant, E.
Department of Lands & Forests
P.O. Box 489
INVERNESS, Nova Scotia BOE 1NO

Greenwood, R.B.
Ministry of Natural Resources
P.O. Box 1160
WAWA, Ontario POS 1K0

Groves, C.R.
Ministry of Natural Resources
Midhurst Forest Tree Nursery
MIDHURST, Ontario LOL 1X0

Hagner, Dr. S.O.A.
Svenska Cellulose AB
S-851 88 SUNDSVALL
Sweden

Haig, R.A.
Canadian Forestry Service
Great Lakes Forest Research Centre
P.O. Box 490
SAULT STE. MARIE, Ontario P6A 5M7

Hakala, R.O.
Hakmet Ltd.
P.O. Box 248
DORION, P.Q. J7V 735

Haldane, D.J.
Ministry of Natural Resources
R.R. #1
MOONBEAM, Ontario POL 1VO

Hallett, R.D.
Canadian Forestry Service
Maritimes Forest Research Centre
P.O. Box 4000
FREDERICTON, N.B. E38 5P7

Hatcher, Robert J.
Canadian Forestry Service
Laurentian Forest Research Centre
C.P. 3800
STE-FOY, P.Q. G1V 4C7

Heeney, C.J.
Ministry of Natural Resources
Forest Resources Group
Queen's Park
TORONTO, Ontario M7A 1W3

Heikurinen, J.K.
Ministry of Natural Resources
199 Larch Street
SUDBURY, Ontario P3E 5P9

Helium, Dr. A.K.
Dept. of Forest Science
The University of Alberta
EDMONTON, Alberta T6G 206

Hood, J.V.
Ministry of Natural Resources
Ontario Forest Research Centre
MAPLE, Ontario LOJ 1E0

Hosick, P.L.
Ministry of Natural Resources
P.O. Box 276
ATIKOKAN, Ontario POT 1C0

Huard, P.
Domtar Forest Products
2950 Blvd. Laurier
STE-FOY, P.Q. G1V 2M4

Huber, R.F.
Northern Forest Research Centre
Canadian Forestry Service
5320 - 122 Street
EDMONTON, Alberta T6H 3S5

Hulten, Dr. Hakan
University of Agricultural Sciences
Department of Forest Yield Research
S-770 73 GARPENBERG
Sweden

Hunt, D.J.
Manitoba Forestry Resources Ltd.
P.O. Box 1590
The Pas, Manitoba

Hunter, D.D.
Ministry of Natural Resources
P.O. Box 1160
WAWA, Ontario POS IKO

Husk, C.F.
Ministry of Natural Resources
P.O. Box 190
BLIND RIVER, Ontario POR 1BO

Innes, M.R.
Abitibi-Price Inc.
P.O. Box 21
Toronto-Dominion Centre
TORONTO, Ontario M5K 1B3

Isherwood, T.
Ministry of Natural Resources
60 Wilson Avenue
TIMMINS, Ontario P4N 2S7

Johnson, C.M.
Director, Silviculture Branch
B.C. Ministry of Forests
1450 Government Street
VICTORIA, B.C. V8W 3E7

Johnsson, D.
Swedish Trade Office
1155 Dorchester Boulevard West
Suite 1020
MONTREAL, P.Q. H3B 2J7

Jonsson, Gerth
AB Celloplast
Box 297
S-601 04 NORRKOPING
Sweden

Jovic, D.
Ministry of Natural Resources
P.O. Box 640
GERALDTON, Ontario POT IMO

Kean, M.
Millson Forestry Service
Northglen Park
R.R. #1
TIMMINS, Ontario

Keith, Dick
Swastika Nursery
P.O. Box 129
SWASTIKA, Ontario POK 1TO

Kekanovich, J.
Ministry of Natural Resources
60 Wilson Avenue
TIMMINS, Ontario P4N 2S7

Kelly, G.
Forestry Branch
Dept. of Agriculture and Forestry
P.O. Box 2000
CHARLOTTETOWN, P.E.I. CIA 7N8

Kennedy, Frank
Ministry of Natural Resoures
P.O. Box 3000
DRYDEN, Ontario P8N 3B3

Kilgour, M.
Ministry of Natural Resources
896 Riverside Drive
TIMMINS, Ontario P4N 3W2

Kim, Y.T.
Ministry of Natural Resources
Ontario Forest Research Centre
MAPLE, Ontario LOJ 1E0

Kimmett, C.R.
Sir Sandford Fleming College
P.O. Box 8000
LINDSAY, Ontario

Kinghorn, J.M.
Canadian Forestry Service
Pacific Forest Research Centre
506 West Burnside Road
VICTORIA, B.C. V8Z 1M5

Klages, Wm.
Great Lakes Forest Products
P.O. Box 430
THUNDER BAY, Ontario P7C 4W3

Klapprat, A.A.
Ministry of Natural Resources
Kemptville Nursery
R.R. #4
KEMPTVILLE, Ontario KOG

Knight, J.
Westbrook Greenhouse Systems
330 Main St. W.
GRIMSBY, Ontario L3M 1S7

Kohonen, M.
G.A. Serlachius Oy
Planting Technics
SF-35800 MANTTA
Finland

Kokocinski, G.
Ministry of Natural Resources
P.O. Box 5000
THUNDER BAY, Ontario P7C 5G6

Kooistra, C.
Red Rock Nursery
R.R. #7, 15 Mile Road
PRINCE GEORGE, B.C. V2N 2J5

Krause, Dr. H.H.
Department of Forest Resources
University of New Brunswick
Bag 44555
FREDERICTON, N.B. E3B 6C2

Kreiberg, N.H.
Department of Natural Resources
Provincial Forest Nursery
R.R. #6
FREDERICTON, N.B. E3B 4X7

Lake, Donna B.
International Paper Co.
Northern Forest Research Center
39 Florida Ave.
BANGOR, Maine 04401

Lambie, J.
Ministry of Natural Resources
611 Ninth Avenue East
OWEN SOUND, Ontario N4K 3E4

Landis, T.D.
USDA Forest Service
P.O. Box 25127
DENVER, Colorado 80225

Langlois, C.G.
Min, de l'Energie et des Ressources
Service de la Restauration
200-B, Chemin Ste-Foy,
QUEBEC, P.Q. G1R 4X7

Lansisyrja, E.K.
Lannert Tehtaat Oy
SF-27820 ISO-VIMMA (Sakyla)
Finland

Laporte, M.F.
Canadian Forestry Service
Great Lakes Forest Research Centre
P.O. Box 490
SAULT STE. MARIE, Ontario P6A 5M7

Leale, C.J.P.
Ministry of Natural Resources
199 Larch St.
SUDBURY, Ontario P3E 5P9

Leclaire, K.
Ministry of Natural Resources
P.O. Box 730
COCHRANE, Ontario POL 1C0

Lee, S.
55 Wembley Drive
SUDBURY, Ontario

Lee, Soo-Wook
Department of Forestry
College of Agriculture
Chungnam National University
DAEJEON, Korea, 300-01

Leech, R.H.
Ministry of Natural Resources
Ontario Forest Research Centre
MAPLE, Ontario LOJ 1E0

Lester, Ms. Mary
West Fraser Mills Limited
P.O. Box 6000
QUESNEL, B.C. V2J 3J5

[illegible]
University of Agricultural Sciences
Faculty of Forestry
S-770 73 GARPENBERG
Sweden

Linden, S.
AB Celloplast
Box 297
S-601 04 NORRKOPING
Sweden

Lucas, S.J.
Ministry of Natural Resources
P.O. Box 239
LANARK, Ontario

Luchkow, S.A.
Alberta Forest Service
Whitecourt Forest
Postal Bag 30
WHITECOURT, Alberta TOE 2L0

Ludlow, M.S.
W.R. Grace & Co. of Canada Ltd.
294 Clements Rd. W.
AJAX, Ontario L1S 3C6

Lyon, N.F.
Northern Forest Research Unit
Ministry of Natural Resources
P.O. Box 2960
THUNDER BAY, Ontario P7B 5G5

MacAlpine, D.
Ministry of Natural Resources
P.O. Box 970
NIPIGON, Ontario POT 2J0

MacDonell, M.B.
Boise Cascade Canada Ltd.
1455 Idylwild Dr.
FORT FRANCES, Ontario P9A 3M3

MacDuff, Wm. D.
Ministry of Natural Resources
RAMSAYVILLE, Ontario KOA 2Y0

MacGillivray, G.R.
American Can Canada Inc.
Dorm 7
MARATHON, Ontario POT 2E0

MacNaughtan, D.J.
Ministry of Natural Resources
R.R. #4
KEMPTVILLE, Ontario KOG IJO

Madlung, D.
West Fraser Mills
P.O. Box 6000
QUESNEL, B.C. V2J 3J5

Mahon, D.D.
Ministry of Natural Resources
101 Water St. W.
BROCKVILLE, Ontario K6V 5Y8

Maier, G.B.
Dept. of Indian & Northern Affairs
Forest Resources
P.O. Box 7
FORT SMITH, N.W.T. XOE OPO

Malmberg, C.E.
National Board for Tech. Development
Box 3200
S-100 72 STOCKHOLM
Sweden

Manic, Dr. A.
Institute of Forestry & Wood Industry
Kneza Vigeslava hr. 3
BELGRADE, Yugoslavia

Marsh, C.R.
Ministry of Natural Resources
P.O. Box 5080
KENORA, Ontario

Mason, C.L.
Ministry of Natural Resources
P.O. Box 129
GOGAMA, Ontario POM 'WO

Mathews, A.G.
Ministry of Natural Resources
MINDEN, Ontario KOM 2K0

Matiece, A.P.
Ministry of Natural Resources
922 Scott St.
FORT FRANCES, Ontario P9A 1J4

Mattice, C.R.
Apartment 206
334-A Dacey Road
SAULT STE. MARIE, Ontario P6A 5J7

Mattsson, A.
University of Agriculture Sciences
Faculty of Forestry
S-770 73 GARPENBERG
Sweden

McClain, K.M.
Northern Forest Research Unit
Ministry of Natural Resources
P.O. Box 2960
THUNDER BAY, Ontario P7B 5G5

McCormick, D.
New Brunswick Forest Service
8 No. 1 Highway
ST. STEPHEN, N.B. E3L 2Y7

McDonald, S.E.
U.S.D.A. Forest Service
State and Private Forestry
P.O. Box 2417
WASHINGTON, D.C. 20017

McDonough, Thom
Wooddale Provincial Nursery
Dept. Forest Resources and Lands
P.O. Box 616
GRAND FALLS, Newfoundland A2A 2K2

McGrath, G.A.
Ministry of Natural Resources
P.O. Box 310
THESSALON, Ontario POR 1L0

McIntyre, J.M.
Ministry of Natural Resources
P.O. Box 309
SIOUX LOOKOUT, Ontario POV 2TO

McLeod, G.R.
Ministry of Natural Resources
Orono Nursery,
P.O. Box 119
ORONO, Ontario LOB IMO

McLeod, J.F.
Great Northern Paper Co.
P.O. Box 493
MILLINOCKET, Maine 04462

McMahon, J.M.
Kimberley-Clark of Canada Ltd.
Woodlands Department
LONGLAC, Ontario POT 2A0

McMinn, Dr. R.G.
Canadian Forestry Service
Pacific Forest Research Centre
506 West Burnside Road
VICTORIA, B.C. V8Z 1M5

McNeish, S.
Woodlands (Forestry Department)
N.B. International Paper Co.
DALHOUSIE, N.B.

Mears, R.J.
Ministry of Natural Resources
P.O. Box 1340
ESPANOLA, Ontario POP 1C0

Metcalfe, R.W.
Can-Am Containers Ltd.
P.O. Box 340
SPRINGHILL, Nova Scotia BOM 1X0

Mieske, Roht. E.
W.R. Grace & Co.
14810 3rd Ave.
EDMONTON, Alberta T5L 2Y5

Mikkelesen, A.
Ministry of Natural Resources
Metcalfe St.
TWEED, Ontario KOK 3J0

Miller, B.C.
Can-Am Containers Ltd.
3500 Ridgewood, Suite 502
MONTREAL, P.Q. H3V 1C2

Miller, J.S.
Ministry of Natural Resources
P.O. Box 3070
NORTH BAY, Ontario P1B 8K7

Millson, D.
Millson Forestry Service
Northglen Park
R.R. #1
TIMMINS, Ontario

Millson, S.
Millson Forestry Service
Northglen Park
R.R. #1
TIMMINS, Ontario

Moores, L.
Dept. of Forests, Resources & lands
Bldg. 810, Pleasantville
ST. JOHN's, Newfoundland A1C 5X8

Morley, P.M.
778 Avenue Road
TORONTO, Ontario M5P 2K3

Morse, C.B.
Division of Forestry
Department of Natural Resources
P.O. Box 44, Centennial Office Bldg.
ST. PAUL, Minnesota 55155

Mortensen, B.
Colo-Hydro Inc.
5555 Ute Hwy.
LONGMONT, Colorado 80501

Munro, D.
Ministry of Natural Resources
P.O. Box 3000
DRYDEN, Ontario P8N 3B3

Munroe, J.E.
Ministry of Natural Resources
P.O. Box 130
SAULT STE. MARIE, Ontario P6A 5L5

Murray, Kathleen
Raymur Equipment Ltd.
Highway 59 South
NORWICH, Ontario NOJ 1P0

Murray, Patrick J.
Raymur Equipment Ltd.
Highway 59 South
NORWICH, Ontario NOJ 1P0

Murray, T.S.
Canadian Forestry Service
Maritime Forest Research Centre
P.O. Box 4000
FREDERICTON, N.B. E3B 5P7

Myland, T.R.
Ministry of Natural Resources
P.O. Box 90
WABIGOON, Ontario POV 2W0

Naysmith, D.
Abitibi-Price Inc.
P.O. Box 21
Toronto Dominion Centre
TORONTO, Ontario M5K 1B3

Nieman, T.
Canadian Forestry Service
Petawawa National Forest Institute
CHALK RIVER, Ontario KOJ 1J0

Nilsson, Bo
Swedish Forest Service
Domanverket
Box 397
S-581 04 LINKOPING
Sweden

Numminen, J.
Trade Commission of Finland
2221 Yonge Street, Suite 602
TORONTO, Ontario M4S 2B4

Oley, D.F.
Ministry of Natural Resources
P.O. Box 38
TEMAGAMI, Ontario POH 2H0

Olsen, D.T.
Chippewa Farms
Rte. #1, Box 246
BRANDON, Minnesota 56315

Olsen, M.H.
Chippewa Farms
Rte. #1, Box 246
BRANDON, Minnesota 56315

Omelchuk, H.
Abitibi-Price Inc.
Lakehead Woodlands Division
P.O. Box 2510
THUNDER BAY, Ontario P7B 5E9

Opper, M.A.
McChesney Lumber
TIMMINS, Ontario

Orynik, R.J.
Woodlands Enterprises Ltd.
P.O. Box 1720
PRINCE ALBERT, Saskatchewan S6V 5T3

Paladino, A.
Timberland Equipment Ltd.
P.O. Box 490
WOODSTOCK, Ontario N4S 7Z2

Parker, D.R.
Ministry of Natural Resources
P.O. Box 5000
THUNDER BAY, Ontario P7C 5G6

Parviainen, Dr. J.
Metsantutkimuslaitos
Joensuun tutkimusasema
PL 68
SF-80101 JOENSUU 10
Finland

Patterson, J.
Ministry of Natural Resources
Ontario Forest Research Centre
MAPLE, Ontario LOJ 1E0

Patterson, W.H.
Department of Natural Resources
Forest Management Branch
P.O. Box 6000
FREDERICTON, N.B. E3B 5111

Peacock, A.H.
Ministry of Natural Resources
Forest Resources Group
Queen's Park
TORONTO, Ontario M7A 1W3

Peacock, T.H.
Abitibi—Price Inc.
P.O. Box 10
PINE FALLS, Manitoba ROE IMO

Peters, Robert
Peters Fertilizer Products
W.R. Grace and Co.
570 Grant Way
FOGELSVILLE, Pennsylvania 18051

Peterson, L.C.
Blandin Paper Company
Lands and Forestry Division
P.O. Box 407
GRAND RAPIDS, Minnesota 55744

Phillion, B.J.
Ministry of Natural Resources
Orono Tree Nursery
P.O. Box 119
ORONO, Ontario LOB IMO

Pickard, W.J.
Ministry of Natural Resources
P.O. Box 38
TEMAGAMI, Ontario POH 2110

Pinto, F.N.
Ministry of Natural Resources
P.O. Box 670
HEARST, Ontario POL 1NO

Piotto, Dr. Beti
Centro Di Sperimentazione Agricola
E Forestale
C.P. 9079
300 Aurelio, ROMA
Italy

Polhill, B.E.
Ministry of Natural Resources
Thunder Bay Forest Station
R.R. #1
THUNDER BAY, Ontario P7C 4T9

Potvin, D.R.
Ministry of Natural Resources
P.O. Box 3500, Station A
SUDBURY, Ontario P3A 4S2

Prentice, R.A.
Forestry Department
Michigan State University
E. LANSING, Michigan 48824

Price, Steve A.
Dept. Tourism and Renewable Resources
Room 300, 49 — 12th Street East
PRINCE ALBERT, Saskatchewan S6V 185

Prince, F.A.
37069 Charter Oaks Blvd.
MT. CLEMENS, Michigan 48043

Provencher, G.G.P.
Canadian International Paper Co.
1053 Blvd. Ducharme
LA TOQUE, P.Q. G9X 3P9

Radford, M.J.
Ministry of Natural Resources
P.O. Box 841
CHAPLEAU, Ontario POM 1K0

Rahkonen, J.V.
Lannen Tehtaat Oy
SF-27820 ISO—VIMMA (Säkyla)
Finland

Raitanen, Ms. E.M.
Ministry of Natural Resources
Midhurst Nursery
MIDHURST, Ontario LOL 1XO

Rasanen, Dr. P.K.
National Board of Forestry
Metsahallitus, PL 233
SF-00121 HELSINKI 12
Finland

Reese, K.H.
Ministry of Natural Resources
Forest Resources Group
Queen's Park
TORONTO, Ontario M7A 1W3

Reffle, R.J.
Ministry of Natural Resources
P.O. Box 129
SWASTIKA, Ontario POK 1TO

Reid, S.R.
Ministry of Natural Resources
P.O. Box 1749
CORNWALL, Ontario K6H 5V7

Reynen, Ms. G.E.
Ministry of Natural Resources
199 Larch Street
SUDBURY, Ontario P3E 5P9

Reynolds, E.T.
Ministry of Natural Resources
101 Water Street West
BROCKVILLE, Ontario K6V 5Y8

Richard, M.
Canadian International Paper Co.
Harrington Nature Centre
R.R. #2 Calumet Co.
ARGENTEUIL, P.Q. VOV 180

Richardson, J.
Canadian Forestry Service
Newfoundland Forest Research Centre
P.O. Box 6028
Bldg. 304, Pleasantville
ST. JOHN's, Newfoundland A1C 5X8

Richardson, W.
W. Richardson Farms Ltd.
PONTYPOOL, Ontario LOA 1K0

Riley, L.F.
Canadian Forestry Service
Great Lakes Forest Research Centre
P.O. Box 490
SAULT STE. MARIE, Ontario P6A 5M7

Robertson, D.J.
Ministry of Natural Resources
Provincial Forest Station
R.R. #1
ST. WILLIAMS, Ontario NOE 1P0

Romeril, Ms. S.M.
1390 Magnolia Blvd.
SUDBURY, Ontario P3A 4V2

Ross, H.F.
Nova Scotia Forest Industries
P.O. Box 59
PORT HAWKESBURY, Nova Scotia BOE 2V0

Rosvall—Ahnebrink, Mrs. Gunnel
University of Agricultural Sciences
Division of Reforestation
S-901 83 UMEA
Sweden

Ryans, M.
FERIC
143 Place Frontenac
POINTE CLAIRE, P.O. H9R 4Z7

Sadreika, V.
Ministry of Natural Resources
Forest Resources Group
Queen's Park
TORONTO, Ontario M7A 1W3

Salonius, P.O.
Canadian Forestry Service
Maritimes Forest Research Centre
P.O. Box 4000
FREDERICTON, N.B. E3B 5P7

Saltarelli, N.
Abitibi—Price Inc.
Iroquois Falls Woodlands
IROQUOIS FALLS, Ontario POK 1E0

Sauze, Michael
Canadian Forestry Equipment Ltd.
170 Boulevard Industrial
ST. EUSTACHE, P.Q. J7R 4K3

Scarratt, Dr. J.B.
Canadian Forestry Service
Great Lakes Forest Research Centre
P.O. Box 490
SAULT STE. MARIE, Ontario P6A 5M7

Schaerer, Ms. C.
Ministry of Natural Resources
P.O. Box 323
RED LAKE, Ontario POV 2M0

Schafer, D.W.
Ministry of Natural Resources
60 Wilson Ave.
TIMMINS, Ontario P4N 2S7

Seabrook, R.
Great Lakes Forest Products
P.O. Box 430
THUNDER BAY, Ontario P7C 4W3

Shikaze, G.
Vancouver Bio-Machine Systems
107-13375 - 76th Ave.
SURREY, B.C. V3W 6J3

Shopik, T.D.
Suncor
P.O. Box 4001
FORT McMURRAY, Alberta

Siemens, John
Chemacryl Plastics Ltd.
73 Richmond St. West
TORONTO, Ontario M5H 2A2

Simmonds, Ms. F.
Ministry of Natural Resources
199 Larch Street
SUDBURY, Ontario P3E 5P9

Skeates, D.A.
Ontario Forest Research Centre
Ministry of Natural Resources
MAPLE, Ontario LOJ 1E0

Skinkle, L.E.
Ministry of Natural Resources
P.O. Box 309
MANITOUWADGE, Ontario POT 2C0

Smith, W.A.
Ministry of Natural Resources
P.O. Box 129
SWASTIKA, Ontario P0K 1TO

Smyth, J.H.
Canadian Forestry Service
Great Lakes Forest Research Centre
P.O. Box 490
SAULT STE. MARIE, Ontario P6A 5M7

Speer, R.J.
Department of Natural Resources
Forest Management Branch
P.O. Box 6000
FREDERICTON, N.B. E3B 51I1

Spencer, H.A.
Spencer-Lemaire Industries Limited
11413 - 120 Street
EDMONTON, Alberta T5G 2Y3

Squires, M.F.
Abitibi-Price Inc.
Lakehead Woodlands Div.
P.O. Box 2510
THUNDER BAY, Ontario P7B 5E9

Staley, R.N.
Ministry of Natural Resources
10670 Yonge St.
RICHMOND HILL, Ontario L4C 3C9

Starr, J.
Ministry of Natural Resources
P.O. Box 730
COCHRANE, Ontario POL 1C0

Stehlik, J.
Alaska State Forest Nursery
Star Route B
Box 7441
PALMER, Alaska 99645

Stewart, M.F
Ministry of Natural Resources
P.O. Box 239
LANARK, Ontario KOG 1KO

Sugden, E.A.N.
Ontario Research Foundation
Sheridan Park Research Community
MISSISSAUGA, Ontario L5K 1B3

Sutherland, B.J.
Canadian Forestry Service
Great Lakes Forest Research Centre
P.O. Box 490
SAULT STE. MARIE, Ontario P6A 5M7

Sutherland, Dr. J.R.
Canadian Forestry Service
Pacific Forest Research Centre
506 West Burnside Road
VICTORIA, B.C. V8Z 1M5

Synkiw, E.
Solicitor General of Canada
460 O'Connor Street
OTTAWA, Ontario K1A OP9

Sziklai, P.
P.O. Box 1095
ELKO, B.C. VOB 1J0

Tenaglia, S.L.
Ministry of Natural Resources
P.O. Box 640
GERALDTON, Ontario POT IMO

Ternent, L.K.
Ministry of Natural Resources
P.O. Box 129
SWASTIKA, Ontario POK ITO

Thayer, R.
Ministry of Natural Resources
St. Williams Nursery
R.R. #1
ST. WILLIAMS, Ontario NOE 1PO

Thompson, B.
Ministry of Natural Resources
P.O. Box 129
KIRKLAND LAKE, Ontario P0K ITO

Thompson, Dr. S.
Department of Forestry
University of Aberdeen
St. Machar Drive
ABERDEEN, Scotland

Thor, A.H.
Nova Scotia Forest Industries
P.O. Box 59
PORT HAWKESBURY,
Nova Scotia BOE 2V0

Tiemann, H.
Ministry of Natural Resources
Forest Resources Group
Queen's Park
TORONTO, Ontario M7A 1W3

Till, D.L.
Ministry of Natural Resources
896 Riverside Drive
TIMMINS, Ontario P4N 3W2

Timmermans, Frank
Ickes-Braun Glasshouses (Canada) Ltd.
P.O. Box 2000
BEAMSVILLE, Ontario LOR lEO

Tinus, Dr. R.W.
USDA Forest Service
Rocky Mountain Forest and Range
Experiment Station
BOTTINEAU, North Dakota 58318

Tirschmann, H.C.
Department of Natural Resources
Pineland Nursery
HADASHVILLE, Manitoba ROE OX0

Tomlin, D.G.
The James Maclaren Company Ltd.
BUCKINGHAM, P.Q. J8L 2X3

Tornblom, S.R.
St. Regis (Alta.) Ltd.
129 Reimer Drive
HINTON, Alberta TOE IRO

Tower, T.L.
U.S. Department of the Interior
Bureau of Indian Affairs
Red Lake Agency
RED LAKE, Minnesota 56671

Treitz, M.E.
Ministry of Natural Resources
P.O. Box 323
RED LAKE, Ontario POV 2M0

Tremblay, J.F.
The Ontario Paper Company Ltd.
25 Cedar St. North
TIMMINS, Ontario P4N 6H8

Trevisanutto, D.H.
Creekside Nursery
693 Woodcrest Rd.
R.R. #11
THUNDER BAY, Ontario

Tunner, Dr. A.
British Columbia Research Foundation
3650 Westbrook Mall
VANCOUVER, B.C. V6S 2L2

Twetman, J.
Hilleshog AB
Box 302
S-261 23 LANDSKRONA
Sweden

VanDusen, G.P.
Bowater Newfoundland Limited
CORNER BROOK, Newfoundland A2H 6J4

Van Duyn, H.
Hill's Greenhouse's Ltd.
R.R. #1
MURILLO, Ontario POT 2G0

Van Eerden, E.
B.C. Ministry of Forests
Silviculture Branch
1450 Government Street
VICTORIA, B.C. V8W 3E7

Vermeersch, B.E.
Ministry of Natural Resources
P.O. Box 448
IGNACE, Ontario POT 1TO

Vilim, R.K.
Northern College Waste Heat Greenhouses
82 Lebel Ave.
KIRKLAND LAKE, Ontario P2N 2Z8

Vining, J.F.
Ministry of Natural Resources
Box 3500, Station 'A'
SUDBURY, Ontario P3A 4S1

Von Althen, F.W.
Canadian Forestry Service
Great Lakes Forest Research Centre
P.O. Box 490
SAULT STE. MARIE, Ontario P6A 5M7

Vyse, A.
Ministry of Forests
Cariboo Region
540 Borland St.
WILLIAMS LAKE, B.C. V2G 1R8

Waddell, J.W.
E.B. Eddy Forest Products Ltd.
Station Road
ESPANOLA, Ontario POP 1C0

Waito, R.O.
Ministry of Natural Resources
P.O. Box 309
MANITOUWADGE, Ontario POT 2C0

Waldram, J.M.
Ministry of Natural Resources
P.O. Box 309
SIOUX LOOKOUT, Ontario POV 2TO

Walker, R.W.
Department of Natural Resources
80 Pleasant St.
NEWCASTLE, N.B. E1V 1X7

Wallach, B.P.
Alberta Forest Service
P.O. Box 1420
EDSON, Alberta TOE OPO

Walters, Prof. J.
University of British Columbia
U.B.C. Research Forest
R.R. #2
MAPLE RIDGE, B.C. U2X 7E7

Warner, C.A.
Aidie Creek Gardens
R.R. #3
ENGLEHART, Ontario POJ 1H0

Warwick, B.W.
Ministry of Natural Resources
P.O. Box 1749
CORNWALL, Ontario K6H 5V7

White, B.
Department of Lands & Forests
P.O. Box 489
INVERNESS, Nova Scotia ROE 1NO

Whitefeather, Ms. Gloria
U.S. Department of the Interior
Bureau of Indian Affairs
Red Lake Agency
RED LAKE, Minnesota 56671

Wickstrom, A.E.
Ministry of Natural Resources
922 Scott St.
FORT FRANCES, Ontario P9A 1J4

Wiegand, M.
Department of Natural Resources
Division of Forestry
Box 44, Centennial Office Building
ST. PAUL, Minnesota 55155

Wilson, J.P.
Ministry of Natural Resources
P.O. Box 820
PEMBROKE, Ontario

Winkler, J.A.
Price (Nfld.) Pulp & Paper Ltd.
P.O. Box 500
GRAND FALLS, Newfoundland A2A 2K1

Winn, R.H.
Alberta Forest Service
P.O. Box 750
SMOKY LAKE, Alberta TOA 3C0

Wood, J.E.
Canadian Forestry Service
Great Lakes Forest Research Centre
P.O. Box 490
SAULT STE. MARIE, Ontario P6A 5M7

Yarn, Lloyd
Department of Natural Resources
Forestry Branch
300 - 520 Kenaston Blvd.
WINNIPEG, Manitoba

Young, W.D.
Domtar Forest Products
P.O. Box 480
RED ROCK, Ontario POT 2P0

Zak, B.
British Columbia Forest Products Ltd.
Bag Service 1000
FOX CREEK, Alberta TOH 1P0

Zalasky, H.
Canadian Forestry Service
Northern Forest Research Centre
5320 - 122 St.
EDMONTON, Alberta T6H 3S5

Zdrazil, Z.
Canadian Forestry Service
Petawawa National Forestry Institute
CHALK RIVER, Ontario KOJ

Zelinka, E.
Forjay Inc.
7204 Lake Drive
CIRCLE PINES, Minnesota 55014

NOTE: As of October 1, 1981, the Ontario Forest Research Centre was incorporated into the Ontario Tree Improvement and Forest Biomass Institute. The address remains the same.

APPENDIX II

LIST OF EXHIBITORS

Beaver Plastics Ltd.
12806 - 63rd Street
EDMONTON, Alberta T5A OW2

Canadian Forestry Equipment Ltd.
170 Boulevard Industriel
ST. EUSTACHE, Quebec J7R 4K3

Canadian Greenhouses
P.O. Box 5000
317 South Service Road West
GRIMSBY, Ontario L3M 4N6

Can-Am Containers Ltd.
P.O. Box 340
SPRINGHILL, Nova Scotia BOM 1X0

W.R. Grace and Co. of Canada Ltd.
294 Clements Road West
AJAX, Ontario L1S 3C6

Hakmet Ltd.
881 Harwood Blvd.
P.O. Box 248
DORION, Quebec J7V 7J5

with

Lannen Tehtaat Oy
SF-27829 ISO-VIMMA (Sakyla)
Finland

Ickes-Braun Glasshouses (Canada) Ltd.
P.O. Box 2000
BEAMSVILLE, Ontario LOR 1B0

Plant Products Co. Ltd.
314 Orenda Road
BRAMALEA, Ontario L6T 1G1

Raymur Inc.
Highway 59 South
NORWICH, Ontario NOJ 1P0

Reid, Collins Nurseries Ltd.
2396 - 272nd Street
P.O. Box 430
ALDERGROVE, B.C. VOX 1A0

Spencer-Lemaire Industries Ltd.
11413 - 120 Street
EDMONTON, Alberta T5G 2Y3

Swedish Trade Office
Suite 1020
1155 Dorchester Blvd. West
MONTREAL, Quebec H3B 2J7

representing

AB Celloplast
Box 297
S-601 04 NORRKOPING
Sweden

Hilleshog AB
Box 302
S-261 23 LANDSKRONA
Sweden

Lulea Smidesverkstad
Handelsvagen 9
S-951 59 LULEA
Sweden

National Board for Technical
Development (STU)
Box 3200
S-100 72 STOCKHOLM
Sweden

Stora Koppaberg-Bergvik
Div. Skog
S-791 80 FALUN
Sweden

Svenska Cellulosa AB
S-851 88 SUNDSVALL
Sweden

APPENDIX III

LIST OF CONTRIBUTORS

AUTHOR AND SUBJECT INDEX